Universitat Autònoma de Barcelona

The pattern of Socio-Ecological Systems.
A focus on Energy, Human Activity, Value Added and Material Products

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PhD Thesis
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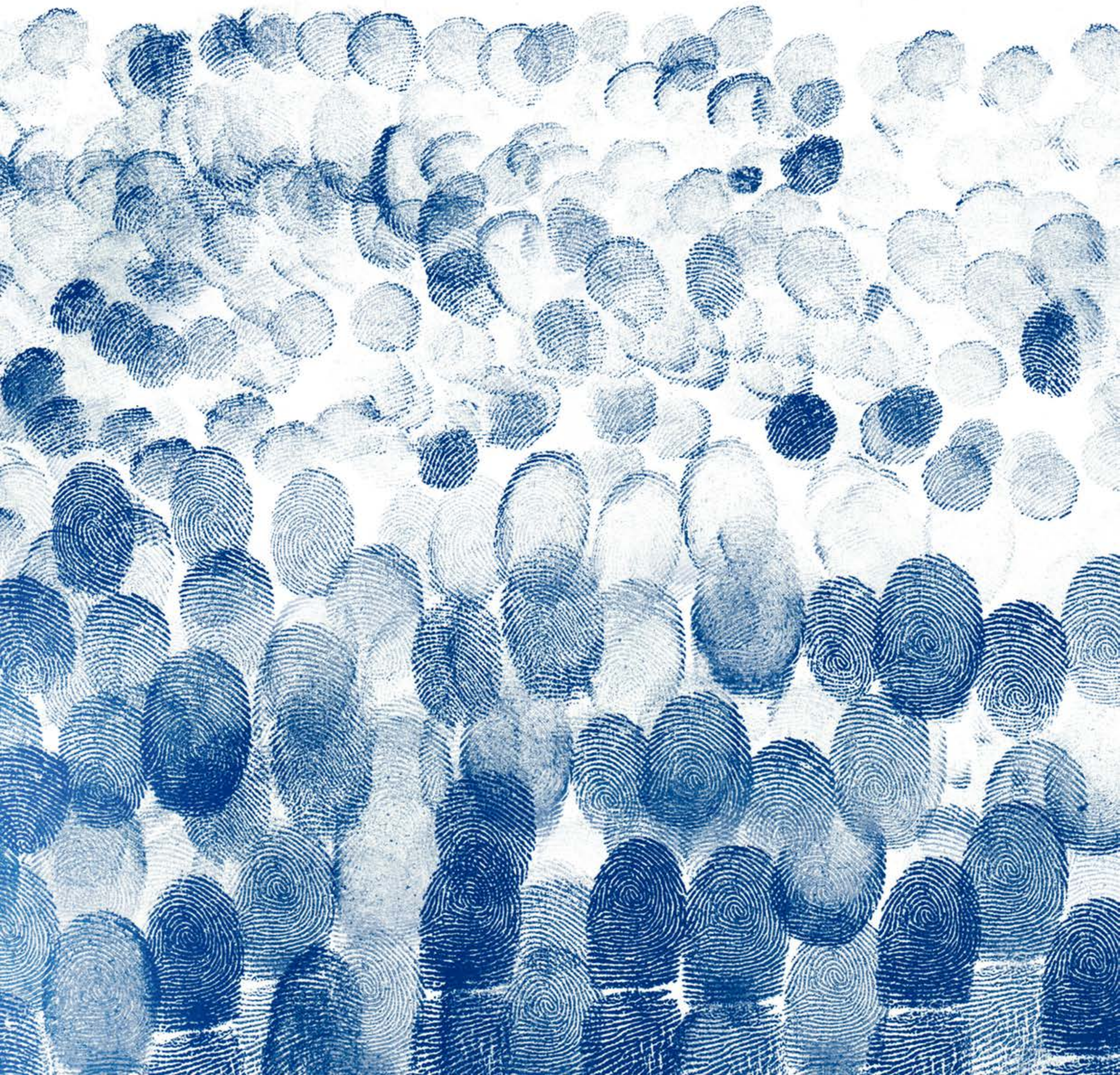
Institut de Ciència i Tecnologia Ambientals · UAB



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Doctoral dissertation
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A Maite,
por todo tu amor y paciencia

A mi madre María,
por darme la vida y enseñarme a ser buena persona

A mi padre Cirilo,
por todo lo que me enseñaste y que sigue en mi memoria.

A mis sobrinos Hèctor, Rus e Iris,
por toda la felicidad que traéis con vuestra simple presencia.

Abstract

This thesis is about the development of analytical tools within an innovative theoretical framework, with the goal of generating more useful quantitative data in relation to the analysis of sustainability. In particular, the methodological approach explored here wants to integrate quantitative information referring to different dimensions of analysis (economic, demographic, social, biophysical and environmental), different scales (macro-regional, regional and national) and different levels of analysis (whole economy, economic sectors and subsectors).

As discussed in detail in Chapter 3, it is becoming more and more evident that biophysical analysis has to become more holistic. It has to be capable of contextualizing and giving meaning to the individual quantitative assessments it produces. Aggregate indicators referring to the whole economy or to specific technical coefficients describing individual processes are not coherent with each other and when used in isolation do not provide reliable information about the performance of the economy.

The innovative theoretical framework I used for my exploration is the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), which allows developing a quantitative relational analysis capable of dealing with multiple scales and dimensions, as required for dealing with sustainability issues. The goal of the method (and of my explorations) has been the identification of the relevant factors that have to be considered in order to study the performance of the metabolic pattern of modern societies.

My research started – Chapter 2 - with a basic application of MuSIASEM's methods to compare the changes in the performance of the economies of China and India in the period between 1971 and 2010. Adopting the established accounting procedure, this analysis was based on data referring to energy (measured in gross energy requirement), value added and human activity at three levels of analysis: (i) average society; (ii) paid work vs. households, and (iii) the set of economic sectors made up of agriculture, industry and services. This analysis identified relevant factors affecting the metabolic patterns of these two big countries: their demographic structure, the level of capitalization of their different sectors or the

different effects that this capitalization generated on the material standard of living in the household sector.

Afterwards, I developed a new protocol of analysis able to keep the accounting of energy forms of different qualities separate. This was required by the unsatisfactory situation with existing biophysical indicators of performance (Chapter 3). The accounting of "energy" was no longer done in Joules of gross energy requirement, but using different categories of "Joules" referring to different energy carriers (electricity, fuels and process heat).

In order to apply the new protocol across different scales, it was applied to a large case study, by considering the metabolic pattern of European countries (EU27 + Norway). Moreover, this analysis was carried out across many levels, arriving to distinguish up to 13 subsectors inside the Manufacturing and Construction sector (Chapter 4).

Finally, the last exploration of the potentialities of the approach was related to an attempt to include material flow accounting, starting with the analysis of the products produced and the level of imports and exports of a subsector of the industrial sector (Chapter 5). The analysis shows that the approach can be effectively used to: (i) identify relevant categories of production processes taking place at lower levels than subsectors, and (ii) characterize the level of openness of the subsectors (the degree of externalization to other socio-ecological systems). This last analysis was carried out for EU22 countries.

Keywords: Bioeconomics, Biophysical Economics, Energetic Metabolism, Energy Accounting, Energy Quality, Energy Uses, Flow-Fund model, Industrial Metabolism, Multi-scale Analysis, MuSIASEM, Socio-Ecological Systems, Societal Metabolism, Transdisciplinarity.

Resumen

Esta tesis trata del desarrollo de herramientas analíticas dentro de un innovador marco teórico con el objetivo de generar datos cuantitativos más útiles en relación al análisis de la sostenibilidad. En particular, el enfoque metodológico explorado quiere integrar la información cuantitativa referente a diferentes dimensiones de análisis (económico, demográfico, social, biofísico y ambiental), así como diferentes escalas (macro-regional, regional y nacional) y diferentes niveles (el total de la economía, sus sectores y subsectores).

Como se analiza en detalle en el capítulo 3, cada vez es más evidente que el análisis biofísico ha de ser más holístico. Asimismo, tiene que ser capaz de contextualizar y dar sentido a las evaluaciones cuantitativas concretas que produce. Los indicadores agregados que se refieren a toda la economía o los coeficientes técnicos específicos que describen procesos individuales, no son coherentes entre sí, y cuando se usan aisladamente no proporcionan información confiable sobre el funcionamiento de la economía.

El innovador marco teórico utilizado para esta investigación es el Análisis Integrado Multiescalar del Metabolismo Societal y Ecosistémico (MuSIASEM de sus siglas en inglés), el cual permite desarrollar un análisis cuantitativo relacional capaz de manejar múltiples escalas y dimensiones, tal como se requiere para abordar temas de sostenibilidad. El objetivo de este método (y el de mis exploraciones) ha sido la identificación de los factores más relevantes que deben considerarse para estudiar el comportamiento del patrón metabólico de las sociedades modernas.

Mi investigación se inicia con una aplicación básica de los métodos de MuSIASEM, comparando los cambios de las economías de China e India durante el período entre 1971 y 2010 (Capítulo 2). Adoptando un procedimiento ya establecido, este análisis se basa en datos referentes a la energía (medida en equivalente de energía bruta requerida), el valor añadido y la actividad humana en tres niveles de análisis: (i) la sociedad en conjunto; (ii) el sector del trabajo remunerado frente al de los hogares, y (iii) el conjunto de sectores económicos compuestos por la agricultura, la industria y los servicios. Este análisis sirvió para identificar relevantes factores que afectaron los patrones metabólicos de estos dos

grandes países: su estructura demográfica, el nivel de capitalización de sus diferentes sectores o los distintos efectos que estas capitalizaciones generaron sobre el nivel de vida material en los hogares.

Posteriormente, se desarrolla un nuevo protocolo de análisis capaz de contabilizar diferentes tipos de energía según sus distintas cualidades. Esto fue requerido dada la insatisfactoria contabilidad de los indicadores biofísicos existentes (Capítulo 3). La contabilidad de "energía" ya no se realiza en Julios de energía bruta, sino utilizando diferentes categorías de "Julios" que se refieren a distintos vectores energéticos (electricidad, combustibles y calor de proceso).

Con el fin de aplicar el nuevo protocolo, se realiza un gran estudio de caso considerando el patrón metabólico de los países europeos (UE27 + Noruega). Asimismo, este análisis se lleva a cabo a través de diferentes escalas, llegando a distinguir hasta 13 subsectores dentro del sector de la Manufactura y la Construcción (Capítulo 4).

Finalmente, la última exploración de las potencialidades del enfoque está relacionada con un intento de incluir la contabilidad de flujos de materiales, empezando por el análisis de los productos producidos y el nivel de importaciones y exportaciones de un subsector del sector industrial (Capítulo 5). El análisis demuestra que este enfoque puede utilizarse eficazmente para: (i) identificar categorías relevantes de los procesos de producción que tienen lugar a niveles inferiores del de subsector, y (ii) caracterizar el nivel de apertura de los subsectores (el grado de externalización a otros sistemas socio-ecológicos). Este último análisis se realiza para 22 países de la UE.

Palabras clave: Bioeconomía, Economía Biofísica, Metabolismo Energético, Contabilidad Energética, Calidad Energética, Usos Energéticos, Modelo Fondo-Flujo, Metabolismo Industrial, Análisis Multi-Escalar, MuSIASEM, Sistemas Socio-Ecológicos, Metabolismo Societal, Transdisciplinariedad.

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Andaluces de Jaén,
aceituneros altivos,
decidme en el alma: ¿quién,
quién levantó los olivos?

No los levantó la nada,
ni el dinero, ni el señor,
sino la tierra callada,
el trabajo y el sudor.

Unidos al agua pura
y a los planetas unidos,
los tres dieron la hermosura
de los troncos retorcidos.

Levántate, olivo cano,
dijeron al pie del viento.
Y el olivo alzó una mano
poderosa de cimiento.

Miguel Hernández.

Contents

List of Figures

List of Tables

Acronyms

General

MuSIASEM	Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism
IEA	International Energy Agency
ILO	International Labor Organization
OECD	Organization for Economic Cooperation and Development

Compartments of the Socio-Ecological system

AS	Average Society
PW	Paid Work sector
HH	Household sector
EM	Energy and Mining
ES	Energy Sector
MQ	Mining and Quarrying
AG	Agricultural Sector (chapter 2)
AF	Agriculture, Fishing and Forestry
AFO	Agriculture and Forestry
FI	Fishing
BM	Building and Manufacturing (chapter 2)
MC	Manufacturing and Construction
IS	Iron and Steel
NF	Non-Ferrous Metals
CP	Chemical and Petrochemical
NM	Non-Metallic Minerals

FT	Food and Tobacco
TL	Textile and Leather
PPP	Paper, Pulp and Print
TE	Transport Equipment
Ma	Machinery
WWP	Wood and Wood Products
Co	Construction
NS	Non-Specified Industry
SG	Service and Government.
SG_nTS	Service & Government without Transport
TS	Transport Service

Fund elements

THA	Total Human Activity
HAi	Human Activity in the sector i
PC	Power Capacity

Flow elements

PES	Primary Energy Sources
GDP	Gross Domestic Product
GVA	Gross Value Added
VA	Value Added
TET	Total Energy Throughput
ET*ij*	Energy Throughput in the sector *i* for the energy carrier *j*
PO*i*	Product Output for the product *i*

Flow/Fund ratios

EMR*ij* — Energy Metabolic Rate in the sector *i* for the energy carrier *j*

ELP — Economic Labor Productivity (chapter 2)

EJP — Economic Job Productivity

PPR — Product Production Rate

Other

BEP — Bio-Economic Pressure

SHE — Strength of the hypercycle

GER — Gross Energy Requirement

EC — Energy Carrier

EU — Energy End Use

EEI — Economic Energy Intensity

MI — Material Intensity

EU22 — The member countries of the European Union, apart from Cyprus, Denmark, Estonia, France, Luxembourg, Malta.

EU27+N — Norway plus EU27 Member States: Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the United Kingdom.

Units of Energy

Value	Symbol	Name
103 J	kJ	kilojoule
106 J	MJ	megajoule
109 J	GJ	gigajoule
1012 J	TJ	terajoule
1015 J	PJ	petajoule
1018 J	EJ	exajoule

Chapter I

"Standing on the shoulders of giants"

Bernard of Chartres

Introduction

The definition of a problem is intrinsically dependent on the context of the person formulating it. My perception of the context now is that human beings have achieved the greatest power control over processes taking place in the planet ever seen. This exceptional capability of controlling natural resources justifies the name proposed for this period: the Anthropocene. This extraordinary event in the history of humankind began only two centuries ago with an intensive transition from hand production methods to machines: The Industrial Revolution. As explained by Karl Marx, this important change in the mode of production is not just a technological issue (Marx, 1993), but also an institutional one. In fact, dramatic social institutional changes - as the French Revolution (1789) or the Russian Revolution (1917) – clearly illustrate how deeply productive forces (means of production and human labor power) and relations of production are entangled.

However, if I had to choose a material factor responsible for boosting the changes in the modes of production, this would be undoubtedly fossil energy. Since their introduction for fueling the industrial revolution, the consumption of fossil energy has not stopped growing. Coal, oil and gas consumption have been progressively augmenting with the introduction of new technologies and the discovery of new end uses. As result, overall material standards of living have improved (not without experiencing inequalities in their distribution) enabling greater life expectancy, lower infant mortality and a reduction of the time and work load. Additionally, all these changes have also led to an unprecedented increase in the planet's population from less than 1 billion people in 1800 to more than 7 billion in 2011, following an exponential trend (the last billion people increased in the last decade). On the other hand, not all societies and communities on the planet have followed this development path or reaped its benefits. On the contrary, the massive use of fossil fuels has created a huge quantity of problems in the form of war for its geopolitical control or the destruction of important ecosystem goods due to their extraction, process and diversity of uses. From this perspective, it is not difficult to see the tremendous challenge that is faced when confronting the current development trend to the peak of fossil fuel resources (Heinberg, 2007). Moreover, one can see how different and broad issues are affected by the energy system on which a society is based on.

From the early times, many voices have claimed that technological improvements would reduce resource consumption. Also early was the observation of William Stanley Jevons in *The Coal Question* (1865), that coal consumption would increase (rather than decreased) after the introduction of the improved Watt steam engine, was farsighted. This accurate observation by Jevons is a clear example of why an analysis of energy issues requires a multiscale approach. Additionally, when looking at the historic changes in institutions, demography, environmental conditions and material standard of living, one can see that energy issues go far beyond technical questions. Any serious debate dealing with peak oil challenges and with the pace of the transition to renewable energies needs to be framed from a transdisciplinary perspective.

1 The problem definition and research objective

Sustainability issues have emerged as an important social problem in the last decades. I can trace its origin from two different types of concerns: (i) the uncertainty generated by the possibility of future fossil fuel shortages threatening the stability of the *status quo*; and (ii) the environmental awareness of the risks created by the impacts of the fossil fuel era. The first concern became very relevant during the first oil crisis in 1973, the second was flagged for the first time by Rachel Carson's famous book *Silent Spring,* published in 1962 (Carson, 1962). Both issues became a warning that the fossil fuel societies have two points of fragility: (i) they depend on the availability of a large amount of resources; and (ii) they are threatened by unpredicted (and undesired) negative consequences of this massive use of resources. All these concerns were effectively reflected by the massive impact of the Meadows' report *The*

Limits to Growth that linked directly the population issue to these two concerns (Meadows *et al.*, 1972).

The institutional answers to these challenges can be identified in the Brundtland Report named *Our Common Future* (Brundtland, 1987), that in 1987 introduced the famous definition of sustainable development as the "*development that meets the needs of the present without compromising the ability of future generations to meet their own needs*". It was successful in reformulating sustainability concerns by introducing politically acceptable nuances for everyone: satisfying the essential need of everybody (including the poor) and guaranteeing a proper future. Unfortunately, thirty years later we are still far from fulfilling the goal proposed there.

In this thesis, I am not looking to provide a final answer to the sustainability problem or magical solutions. On the contrary, framing the issue from a post-normal science perspective (Funtowicz and Ravetz, 1993), I will propose innovative analytical tools that can be used to check the robustness of some of the present narratives proposed to fix our sustainability problems: dematerialization, de-carbonization, boosting efficiency, zero-emissions or decoupling statements. To do this check I will propose the use of alternative indicators and theoretical frameworks. My modest goal is to explore the possibility of using innovative analytical tools and theoretical frameworks capable of handling relevant economic, social and environmental issues in quantitative terms. In this way, more effective information can be used to inform public debates, where different options and different values can be confronted adequately.

For doing so, I will build on the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) framework (Giampietro and Mayumi, 2000a). This approach provides a powerful analytical framework capable of handling information across different scales and across non-equivalent descriptive domains. Using concepts taken from complex system and hierarchical theory, MuSIASEM makes it possible to build semantically relevant protocols for categorizing data and individuating typologies. In this way, it becomes possible to develop a quantitative relational analysis capable of dealing with multiple scales and dimensions as required for dealing with sustainability issues.

The goal is to problematize present narratives in relation to energy and resource issues and to propose alternative quantitative methods for dealing with them.

In short, the main research objective of this thesis is to develop new methodological tools capable of generating fresh insights into the complex set of relations that characterize the societal metabolism of modern societies. Proposing and testing analytical tools requires developing empirical applications. At times, this requires struggling against the lack of coherence of different databases that have to be combined to obtain all the required inputs of information. In this case, one has also to check whether the information based on the new accounting method and the combination of heterogeneous databases still provide comparability in the results.

In the analysis of the metabolic pattern of modern society, I will consider energy as the key stone of the investigation. But then, I will extend the analysis also to the material flows associated with the production of industrial products, the human time allocation and the value-added generation. In that sense, four broad questions relating energy from an economic and social point of view will be: *Energy for what? Energy for whom?* and in relation to the environment *How much energy? Which type of energy?*

2 Research questions

After having generated a very broad problem definition and very general research objectives, my research questions are much more specific and concrete. As already mentioned, I believe that there is a lack of effective tools to carry out quantitative analysis in sustainability science (especially in energy analysis). The problem is particularly severe when dealing with the necessity of integrating quantitative data across scales. In relation to this point, my research has been guided by the following three questions:

* How to identify the most relevant factors determining the performance of the metabolic pattern of modern societies?
* Is it possible to develop a protocol of accounting based on the MuSIASEM approach that can be used to integrate quantitative data from non-equivalent descriptive domains (across scales and dimensions)?

* What are the potentialities and limitations of such a protocol if one wants to carry out a multiscale integrated assessment of the metabolic pattern of modern economies using current national databases?

These basic questions can be re-stated in four more specific questions:

* How valuable is the quantitative information generated by the proposed protocol for improving our understanding of the functioning of the metabolism of societal systems?
* Can we describe how the characteristics of the different compartments of society (described at different levels) are affecting each other?
* What are the different factors determining the energy performance of a societal system?
* How can we identify and assess trade-offs among these different factors?

3 Evolution of the thesis

I arrived to MuSIASEM and to the tutoring of Mario Giampietro and Jesus Ramos Martin looking for a place with people asking similar questions as me. My endless curiosity made me study Sociology after finishing Industrial Engineering and few people considered it as a coherent combination rather than a contradiction. However, in spite of my interdisciplinary background, understanding MuSIASEM was a real challenge due to its deep roots in complex systems theory and theoretical ecology.

I started my thesis in March 2013 with the basic goal of getting a better understanding of sustainability science using MuSIASEM in relation to energy issues. For this purpose, I started with a basic application of the MuSIASEM method to the cases of China and India (Chapter 2). From this first application, I became familiar with a new way of using semantics and indicators in quantitative analysis. Moreover, I learned that when going beyond established methods and exploring new direction, one often has to deal with lack of data or has to work with different databases reflecting the definition of non-equivalent descriptive domains (= non-compatible data).

After finishing the first paper I worked on different attempts aimed at developing a new grammar to study the service sectors, but then I moved to the analysis of the industrial one. From a long process of learning by doing, I developed a new protocol improving the existing MuSIASEM analysis and introduced new methods like the chromatic identification of patterns, the extended end-use matrix and the metabolic structural tables (Chapter 3). In this period, I started to collaborate in the activities of the EUFORIE project, which helped me by giving me more specific goals and questions to solve in my research (until that moment the work on grammar was basically driven by my curiosity!). In EUFORIE I applied my protocol to the analysis of the energy end-uses of European countries (Chapter 4). Moreover, since the data produced in EUFORIE were used to discuss of the concept of efficiency, I understood the extreme relevance of the multiscale analysis to properly address energy and sustainability issues. Thanks to this new awareness, I was able to propose my new advances and results to a public discussion on "efficiency", showing the existence of serious flaws in the current debate (over economic energy intensity, dematerialization, efficiency, decoupling).

At that moment, my supervisors told me that the material prepared for the thesis was enough, and that it was time to interpret, organize and present the results contained in the accumulated material. However, I did not manage to follow this advice. In fact, after crunching so many numbers I was attracted by two new subjects that, in my view, would have dramatically improved my analysis: (i) the accounting of material flows (inputs) and products (output) in the end-use matrix; and (ii) the analysis of the relevance of the utilization factor of power capacity (sharing technological devices) and possible role of institutions in determining their value. Obviously, the supervisors were right. I did not have time to work on these additional lines and by trying to do this I did not use all the potential of the material presented in Chapter 3 and Chapter 4. Of the two additional subjects I could only address the first one – an exploration of the possibility of introducing material flow accounting in the end use matrix of MuSIASEM. Even though the time was short and the difficulties (in relation to availability of data) where important, I managed to introduce in this thesis a few very interesting results, by carrying out the analysis just on one subsector (presented in Chapter 5). When facing the huge number of products to be considered even when dealing with a small subsector, I solved the problem by introducing semantically relevant categories capable of defining classes of industrial compartments based on their pattern of use of material flows. The method certainly needs further development but it undoubtedly represents a new line of application of MuSIASEM, that has tremendous potentialities in improving the characterization of metabolic patterns of modern societies in a globalization context. Unfortunately, I ran out of time (against the submission deadline) before managing to develop my second research line that put in relation institutional analysis with the characteristics of biophysical metabolic patterns. Some of the original ideas and preliminary work are listed in the Future research section.

4 Structure of the thesis

The thesis is organized in the following chapters:

Chapter 1 refers to the introductory section that you are already reading.

Chapter 2 presents a comparison of the changes in the energetic metabolic pattern of China and India, the two most populated countries in the world, with two economies undergoing an important economic transition. The comparison of the changes in the energetic metabolic pattern has the scope to characterize and explain a bifurcation in their evolutionary path in recent years. The analysis shows an impressive transformation of China's energy metabolism determined by the joining of the WTO in 2001. Since then, China became the largest factory of the world with a generalized technical capitalization of all sectors, especially the industrial sector, boosting economic labor productivity as well as total energy consumption. India, on the contrary, lags behind when considering these factors. Looking at changes in the household sector (energy metabolism associated with final consumption) in the case of China, the energetic metabolic rate (EMR) soared in the last decade, also thanks to a reduced growth of population, whereas in India it remained stagnant for the last 40 years. This analysis indicates a big challenge for India for the next decade. In the light of the data analyzed, both countries will continue to require strong injections of technical capital depending on a continuous increase in their total energy consumption. When considering the size of these economies it is easy to guess that this may induce a dramatic increase in the price of energy, an event that at the moment will penalize much more the chance of a quick economic development of India.

Chapter 3 provides new advances in the MuSIASEM methods improving the original protocols used in the study presented in chapter 2. Therefore in this chapter I introduce a new protocol to differentiate and aggregate types of energy carriers and the concept of extended end-uses data array, a biophysical version of the production function in economics useful to evaluate the bioeconomic performance of the economy at different levels and scales. In order to illustrate the protocol, I present a pilot analysis of the bioeconomic performance of the metabolic patterns of Bulgaria, Finland and Spain at different scales. Moreover, I spell out the relational data analysis between energy, labor, population and value-added databases required to handle a multiscale integrated analysis of this type. These new tools will help me to show the problems I found in the current indicators based on the correlation of CO2 emissions and the GDP generated in the economic process. In that sense, the discussion illustrates the limitation to the use of energy intensity as an indicator for bioeconomic performance. Alternatively, I represent modern society as a social-ecological system. In my representation, I single out the energy sector and group the other sectors including agriculture, industry, service & government, transportation, and residential. Advancing from previous MuSIASEM analyses, I open the black box of the industrial sector to look at 13 subsectors. This allows us to identify the specific metabolic patterns observed at this level of analysis and get valuable information explaining the dynamics happening at different levels.

Chapter 4 illustrates an extended application of the protocol presented in chapter 3 for the analysis of 27 countries - the European Union - plus Norway. In this chapter, I (i) characterize the pattern of consumption of energy carriers in Europe at different hierarchical levels of analysis, keeping the distinction between different types of energy carriers; (ii) establish a bridge between quantitative assessments of energy consumption, monetary flows, employment and the biophysical process of production; and (iii) compare the energetic performance of different economies observed at different levels of analysis. The different levels of analysis studied cover the characterization of the metabolic pattern across (i) level n+1 EU averages; (ii) level n Average society; (iii) level n-1 Paid work vs Households; (iv) level n-2 with the main economic sectors: Energy & Mining; Agriculture, Fishing & Forestry; Manufacturing & Construction; Services & Government; and (v) the subsectors defined at the level n-3: Agriculture & Forestry; Fishing; Transport Service; Service & Government without Transport; Energy Sector; Mining & Quarrying; Iron & Steel; Non-Ferrous Metals; Chemical & Petrochemical; Non-Metallic Minerals; Food & Tobacco; Textile & Leather; Paper, Pulp & Print; Transport Equipment; Machinery; Wood & Wood Products; Non-Specified Industry; and Construction. The end-use matrix will be presented for all these compartments comparing countries and for the average Europe. Moreover, I will identify the metabolic pattern distinctions between these economic compartments for the average of Europe. Additionally, I will map metabolic patterns and define functional benchmarks by using boxplots. Finally, I will summarize many of the complex relation by introducing the innovative Metabolic Structural tables.

Chapter *5* explores the possibility of adopting a protocol capable of including the accounting of material flows in the end-use matrix within MuSIASEM. In order to illustrate the basic ideas of this new protocol, the chapter uses the Paper, Pulp and Print subsector (already examined in Chapter 4) as a case study. New indicators are added to the end-uses data array - Product Output (PO) and Product Production Rate (PPR) – making it possible to measure in biophysical units the amounts and types of products produced in a subsector (PO is measured in kg/year), and their rate of production per hour of labor (PPR is measured in kg/hour of labor averaged over the year). As a result of this addition of indicators, the new extended end-use matrix establishes a relation between energy carriers, human activity, value added and material products. The analysis of material flows has to also include information referring to the different sectors' trade balances. This requires using data on imports and exports of material products. These new indicators characterizing the metabolic characteristics of material flows can be used to identify relevant categories of production processes inside the subsectors and the different roles played in the market by the economic sectors of different countries. In this way, it becomes possible to identify the factors explaining the differences in the values of benchmarks describing the energetic metabolic patterns found in the previous chapters. Last but not least, adding to the analysis information referring to the material metabolism makes it possible to clarify again the existence of two interpretations of the concept of efficiency in energetics: (i) efficiency viewed as the maximum ratio between output and input; and (ii) efficiency viewed as the maximum power output (per unit of time). The differences of these two interpretations can be illustrated using our biophysical indicators. Finally, the Paper, Pulp and Print case study is used to illustrate a common criticism to the use of the two indicators of Economic Energy Intensity and Economic Material Intensity, meant to be proxies of efficiency.

Chapter 6 is the conclusion chapter and starts by answering the research questions. Moreover, it wraps up the most important conclusions from the methodological advances presented in this thesis and some of the most relevant results from the case studies. Additionally, it presents an outlook for future research.

Appendix I presents the result tables from chapter 2.

Appendix II presents extra tables from the analysis provided in chapter 4.

Appendix III provides my Curriculum Vitae.

5 Related publications

Articles

Velasco-Fernández R., Ramos-Martín J., Giampietro M. The energy metabolism of China and India between 1971 and 2010: Studying the bifurcation. *Renewable and Sustainable Energy Reviews*. 2015, vol. 41, num. 1, p. 1052-1066

Velasco-Fernández R, Giampietro M. and Bukkens, G. F. Sandra. (under revision). A novel approach to the analysis of the energy efficiency of the industrial sector. *Energy*.

Project Reports

Giampietro M., Sorman A.H. and Velasco-Fernández R. Characterizing Energy Efficiency from the Matrix of Production of Energy Carriers at the National Level. September 2016 EUFORIE project. Available online:

http://www.utu.fi/en/units/euforie/Research/deliverables/Documents/01_D9%20Euforie-ICTAUAB.pdf

Giampietro M., Velasco-Fernández R. and Ripa M. Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers. March 2017 EUFORIE project. Available online:

http://www.utu.fi/en/units/euforie/Research/deliverables/Documents/EUFORIE-Deliverable-4.2.pdf

Conferences Presentations

Metabolic patterns of the industrial sector across Europe: studying the forgotten maker or Service Cities. BIWAES 2015, Biennial International Workshop Advances in Energy Studies 2015. Energy and Urban Systems. Stockholm, Sweden, 4–7 May 2015.

Comparing changes in the pattern of Industrial-Energy Metabolism of South East European Countries between 2008 and 2013. 2nd SEE Sustainable Development of Energy Water and Environment Systems (SDEWES) conference. Piran, Slovenia, 15–18 June 2016.

Social organization strategies for a reduction of energy consumption: Looking for institutions increasing the utilization factor. 5th Degrowth Conference, Walking the meaningful great transformations? Budapest, Hungary, 30 Aug - 3 Sep 2016.

Chapter II

"Earth provides enough to satisfy every man's need,
but not every man's greed"

Mahatma Gandhi

The energy metabolism of China and India between 1971-2010: studying the bifurcation[1]

1 Introduction

"Peak oil" defined as the peak of conventional oil extraction is determining the beginning of the end of cheap fossil energy and therefore it should be considered as a turning point in recent economic history. Associations such as ASPO have been warning about the problem for a long time, and recently even the International Energy Agency (IEA) admitted in its World Energy Outlook 2011 that the peak of 70 million barrels of daily crude oil production was reached in 2008 and has not been regained again (IEA, 2011). The current optimism shown by IEA (2013) with new shale oil and gas discoveries is contested in the academia and investment worlds for not being so financially attractive as claimed by speculators (Rogers, 2013). This, along with the tar sands troubles (Homer-Dixon, 2013) leaves the importance of conventional oil untouched. The overwhelming dependence on cheap fossil fuels of the current economic model will certainly generate stress on the pattern of economic growth in coming decades when these fossil fuels will be no longer

[1] This chapter builds on the published paper: *Velasco-Fernández R., Ramos-Martín J., Giampietro M. "The energy metabolism of China and India between 1971 and 2010: Studying the bifurcation". Renewable and Sustainable Energy Reviews. 2015, vol. 41, num. 1, p. 1052-1066*

cheap. The transition to a global economy free of fossil fuels is certainly desirable to reduce socio-environmental impact –especially in extraction areas- but the complexity of the global economy is locked-in on existing technical and political institutions that make such a transition very difficult in the short run. The relentless growth of oil demand, coupled with the stagnation of conventional oil extraction, it is expected to trigger important increases in oil prices, which in turn may deepen the economic crisis in the U.S., Japan and Europe. Although the economic stagnation in these countries has slowed its energy consumption, global demand has continued to increase due to the strong growth in emerging countries like China, India, Brazil and Russia (BP, 2012). This is the reason why, the study of these fast transition countries and, in particular, of those with a very significant population size, is extremely important.

This chapter presents a biophysical analysis of changes in the energy metabolic pattern of China and India for the period 1970-2010 by using the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) accounting method. These two countries are extremely interesting since they are the most populated countries in the world –together around 2,6 billion inhabitants in 2011, 37% of the world's population– and they are undergoing an important metabolic transition (Ma, Oxley and Gibson, 2009). As result of this fact, China was the largest world energy consumer and India the fourth in 2011 (BP, 2012). This chapter studies the biophysical roots of economic growth analyzing changes in the energetic metabolic pattern associated with the analogous changes in the characteristics of the structures of consumption and production within the economy. In this way, it becomes possible to individuate and explain those relevant characteristics determining differences in the energetic metabolic pattern of China and India, possible future trends and potential environmental consequences. There are several studies about China and India energy economy — e.g. literature review of China's one in (Ma, Oxley and Gibson, 2010). Nonetheless, the quantitative analysis found in available literature does not take into account the crucial difference between flows, funds and stocks (Georgescu-Roegen, 1971). For example, if we want to study changes in the relation between GDP (a monetary flow) and energy consumption (an energy flow), the standard approach is to look at changes in a flow-flow ratio (GDP/total energy throughput) as it happens with Economic Energy Intensity (EEI). This procedure can lead to serious troubles as shown by Fiorito (2013).

This problem is solved by adopting the MuSIASEM method of accounting based on the integration of flow-fund ratios (Giampietro, Mayumi and Sorman, 2012). In this method, the EEI is defined as a ratio over two flow-fund ratios — energy metabolic rate (total energy throughput/total human activity = Energy Metabolic Rate – MJ/hour of human activity, average over 1 year) divided by economic labor productivity (GDP/total human activity = ELP – US$/hour of human activity, average over 1 year). By generating a ratio over two flow-fund ratios we can address the issue of scale, considering heterogeneity in the structural components of the economy when comparing different countries in term of energy use efficiency and labor productivity (Giampietro and Mayumi, 2000b). In this sense, studies of energy efficiency based on energy intensity (see table 4 of (Ma, Oxley and Gibson, 2010)) carried put at the level of the whole country misses the existence of important differences at the level of specific economic compartments. On the contrary, a multi-scale analysis based on flow-fund ratios can identify the role of each economic sector in determining both the economic labor productivity and the energy consumption of the country, when considered as a whole. Therefore, this method makes it possible to identify and compare the characteristics of "apples" and "oranges" and generate more robust forecasts of possible future scenarios.

The rest of the chapter is organized as follows: section 2 briefly introduces the methodology; Section 3 presents the results and interprets them; and finally, Section 4 lists the most important conclusions that have been reached. Appendix A presents the tables with the main data analyzed.

2 Methodology

The concept of societal metabolism refers to the set of transformation processes of energy and materials taking place in a given society which are necessary for reproducing the society over time. This study must be organized bridging two non-equivalent narratives: (i) in relation to internal constraints – focusing on the set of transformations under human control (the interaction of the parts inside the black-box); (ii) in relation to external constraints – focusing on the existence of favorable conditions determined by processes outside human control (the interaction of the black-box with its context). Societal metabolism studies had a boom in the 70's due to the oil crisis, which highlighted the need to better understand human dependence on natural resources, especially energy-related ones. As indicated by Ramos-Martin et al. (2007), these studies focused on the analysis of the interaction of socioeconomic systems with their environment. Many of them were widely used to study farming systems and human communities (Odum, 1983; Rappaport, 1971; Georgescu-Roegen, 1971; Odum, 1971; Leach, 1975; Slesser, 1978; Gilliland, 1978; Pimentel and Pimentel, 1979; Morowitz, 1979; Costanza, 1980; Herendeen, 1981; Hall, Cleveland and Kaufmann, 1986; Smil, 1987; Ayres and Simonis, 1994; Fisher-Kowalski, 1998).

The research methodology used here is based on the approach of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). This analysis framework was introduced by Giampietro and Mayumi (1997a, 2000b); see also (Giampietro, 2003; Giampietro, Mayumi and Sorman, 2012). This approach is an application of Georgescu-Roegen's flow-fund scheme (Georgescu-Roegen, 1971, 1977) and seeks to provide a socioeconomic and biophysical analysis from complex autopoietic system theory inspired by Maturana and Varela (Maturana and Varela, 1980, 1992).

As pointed out by Giampietro et al. (2012), when studying metabolic systems, the distinction between fund and flow becomes fundamental to understand not only the way systems work, but also their sustainability over time. *Flow categories* are those elements that enter but do not exit the system representation or exit without having entered —e.g. fossil energy or a new product. Instead, *fund categories* are those agents that preserve their identity over the duration of the representations and transform input flows into output flows —e.g. capital, people, or Ricardian land. Funds are the elements to be sustained when speaking of sustainability: they have to be reproduced in the process. Another useful distinction is that of endosomatic and exosomatic metabolism. Endosomatic metabolism is one that refers to food energy and which is transformed inside the human body in order to maintain its activity and development. Exosomatic metabolism is one that refers to energy converted outside the human body, but still converted into applied power under human control, in order to facilitate the work associated with human activity, which gained special importance since the industrial revolution (Cottrell, 1955; Smil, 1987).

MuSIASEM is an accounting scheme which allows the linking of biophysical and socioeconomic variables in an integrated manner. This makes it possible to bridge two non-equivalent views of the metabolic pattern of a given society: (i) the external view dealing with potential environmental constraints such as availability of resources, waste generation and absorption capacity (feasibility of the metabolic pattern according to the characteristics of processes outside human control); and (ii) the internal view dealing with potential technical and economic constraints such as the technical coefficients and the requirement of production factors (viability of the metabolic pattern according to the characteristics of processes under human control).

In relation to the analysis of environmental constraints the MuSIASEM approach can be used to generate an Environmental Impact Matrix. Examples of applications are given in (Giampietro *et al.*, 2014). This requires mapping the flows metabolized by a society – both on the supply and the sink side – in spatial terms (using GIS) in order to be able to study the impact that these flows have on the metabolic pattern of embedding ecosystems. When mapping flows against ecological funds in spatial terms it becomes possible to check whether the density of the metabolized flows (both on the supply or the sink side) is harmful for the stability of environmental processes.

Regarding the analysis of socio-economic constraints, biophysical variables are combined with monetary ones to characterize the different activities making up the economy. This provides a biophysical overview of the economic process in the form of a quantitative representation of the metabolic pattern of a society described in relation to the profile of allocation of human activity in the different compartments of society. This analysis shows the interrelationships between demographic, economic and environmental constraints. To do this, MuSIASEM integrates data referring to different levels of organization and scales (national, regional, local and household) and different dimensions of analysis.

Finally, it should be noticed that the MuSIASEM is an accounting method and not a model. For this reason, the quantitative results depend on the choice of categories of accounting made when defining the characterization of the metabolic pattern. For example, in this case study, I accounted the energy consumed by private cars in the category: "energy consumption of the household", whereas this energy is accounted in official energy statistics in "transportation". For this reason, MuSIASEM requires a pre-analytical agreement about the relevance of the choice of accounting categories. In this case study, I did not consider the effects of trade, whereas this effect is considered in other applications of MuSIASEM (Giampietro *et al.*, 2014) and will be discussed in chapter 5. Finally, the accounting of MuSIASEM is static: it checks the congruence of the values of variables defined across different levels and scales within the chosen representation. However, it does not describe dynamics that can only be observed by adopting a scale at the time.

When studying the socio-economic side, biophysical variables can be combined with monetary ones to produce a 'record' of time use and exosomatic energy consumption in the different activities that make up the economy. This provides a biophysical overview of the economic process in the form of a quantitative representation of a metabolic pattern, showing the interrelationships between demographic, economic and environmental constraints.

In conclusion, MuSIASEM integrates data from different levels (national, regional, local and household) and different issues such as time use, land use and energy consumption of different activities and production sectors.

In this case study the chosen analytical framework (called in the MuSIASEM jargon "the grammar" (Giampietro, Mayumi and Sorman, 2012)) distinguishes between three levels of analysis (see Figure II-1): Level n, which reflects country-level variables; level n-1, which breaks down the values of level n between the paid work sector (PW, comprising all activities generating value added) and the household sector (HH); and level n-2, which breaks down the paid work sector among three lower level components - the agricultural sector (AG), the industrial and construction sector, including energy and mining (PS) and services and government (SG). The metabolic characteristics of the components defined at these different levels are defined using a combination of:

- Extensive variables: (i) Human Activity (FUND) – HAi, measured in hours of human activity in the sector over the year; and (ii) Energy Throughput (FLOW) – ETi, measured in GJ of exosomatic energy in the sector (expressed in Gross Energy Requirement thermal) over the year; and (iii) economic output (FLOW) – GDPi, measured in constant 2000 US$ in the conventional way;

- Intensive variables: (i) Exosomatic Metabolic Rate (FLOW-FUND ratio) – EMRi, measured in Gross Energy Requirement (thermal) per hour of human activity in the sector; and (ii) Economic Labor Productivity (FLOW-FUND ratio) – ELPi the amount of sectorial GDP per year divided by the hours of human activity in the paid work in that sector;

Data for total energy consumption and by sector were obtained from the Energy Balances of the International Energy Agency dataset (IEA, 2010). The energy consumption of transport has been distributed among domestic, industrial and services sectors using the following rule. The share of the household sector has been calculated on the basis of: (i) the number of private vehicles —motorcycles and cars (National Bureau of Statistics of China., 2011; SIAM, 2011); (ii) annual distance travelled (Ramachandra, 2009; Ou, Zhang and Chang, 2010); and (iii) average fuel consumption per year of motorcycles and cars (An *et al.*, 2007; MOSPI, 2012). For years in which these data are unavailable I have interpolated the values according to the available data on the basis of existing trends. For instance, that share was 26% in 1985 in the case of China, so I assumed a share of 25% for the previous years. In the case of India, I use a share of 25% for the years before the first observation (27% in year 2001) and 37% for the years after the last observation available (37% in 2006). The rest of energy consumption in transportation (total – household) was split between the services sector (80%) and the industry sector (20%) assuming that the majority of trucks used for transportation in these countries are owned by the drivers and therefore belong to the transportation sector (service) (Giampietro, Mayumi and Sorman, 2012).

Data concerning hours of total human activity were obtained from the population statistics of each country — National Bureau of Statistics of China (2011) and India from the OECD (2012) — and multiplied by 8.760 to calculate the total amount of human activity per year expressed in hours (using the convention of 365 days and 24 hours per day). The hours of human activity in the Paid Work sector (HA_{PW}) have been obtained from statistics of employment and hours of work per week by economic activity from the ILO (2012) and supplemented with World Bank (2012) figures. For China, 47 hours/week and 50 weeks/year have been assumed, making a total of 2.350 working hours per year. For India, 46 hours/week and 49 weeks/year have been assumed making a total of 2.254 working hours per year.

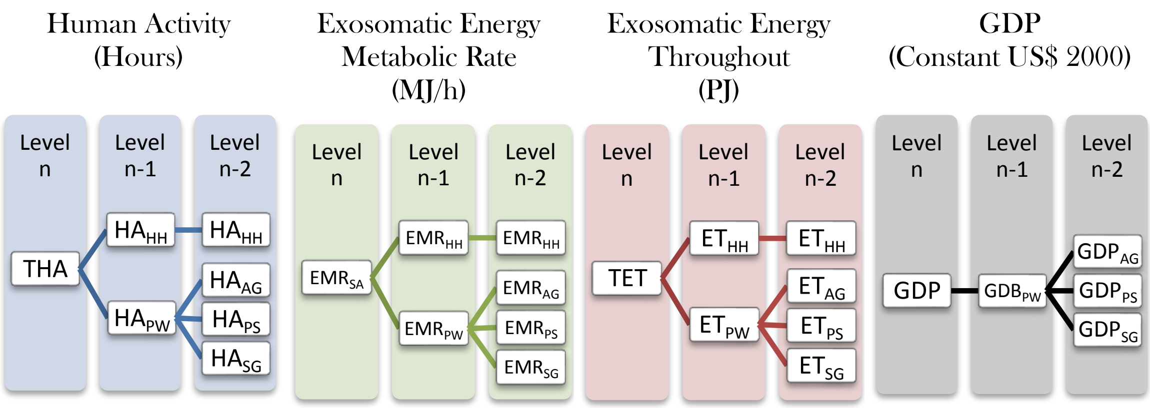


Figure II-1 Dendrograms of exosomatic energy metabolism and of GDP.

Source: Own elaboration.

Data concerning human activity in the Paid Work category by sector of economic activity —HA_{AG}, HA_{PS} and HA_{SG}— have been obtained from employment data by sector that is available for China in the NBSC (2011) and for India in the Planning Commission (2012). Hours of human activity for the household sector (HH) have been obtained by the difference between PW and the total (Total Human Activity = Population x 8.760): HA_{HH}=THA-HA_{PW}.

GDP statistics have been obtained from the World Bank (2012) and GDP by sector —GDP_{AG}, GDP_{PS} and GDP_{SG}— constructed from the share of GDP by economic sectors from UN (UN, 2011). The intensive variables such as EMRi, ELPi have been obtained using the following equations:

$$\boldsymbol{EMR_i = \frac{ET_i}{HA_i}} \qquad (1)$$

$$\boldsymbol{ELP_i = \frac{GDP_i}{HA_i}} \qquad (2)$$

In this way, it becomes possible to establish a relation between the changes in the Economic Energy Intensity of the whole country (EEI_{AS} - Average Society = TET/GDP) and the changes in the various compartments (EEIi – Sector *i* = EMRi/ELPi) according to the following relation:

$$EEI_{AS} = \frac{TET}{GDP} = \frac{\sum x_i \, EMR_i}{(\sum x_i \, ELP_i) * \frac{HA_{PW}}{THA}} \quad [where\ x_i = \frac{HA_i}{THA}] \qquad (3)$$

This relation makes it possible to study the factors determining changes in EEI across different hierarchical levels of analysis (at the level of economic sectors and subsectors). These factors refer to: (i) the biophysical characteristics of the various sectors (including the household sector) described by their EMRi and their size, measured in the fraction of hours per year over the Total Human Activity; (ii) the economic characteristics of the various sectors (only in relation to the compartments defined in the Paid Work) described by their ELPi and their size, measured in the fraction of hours per year over the Human Activity in Paid Work; and (iii) the demographic structure (dependency ratio) and other socio-economic variables (work load per year, unemployment) determining the ratio HA_{PW}/THA (the relative size of the hours of human activity per year in the PW sector and THA per year).

3 Results and discussion

3.1 At the level of the country (level *n*)

This level of analysis presents the main indicators aggregated at the country level such as the extensive variables TET, THA and GDP, and the intensive ones EMR_{AS} or GDP per capita.

Table A-1 and Table A-2 (see Appendix A) list the most relevant data for level n in China and India between 1971 and 2010. Figure II-2 and Figure II-3 show the evolution of the total energy consumption (TET) and the GDP in both countries between 1971 and 2010. In the case of China (Figure II-2a), the total energy consumption has increased more than six-fold in the 39-year period studied, implying a compounded annual growth rate (CAGR) of nearly 5% for the same period. Note that since 2001 — when China joined the World Trade Organization (WTO) — the CAGR has been around 8%, which means that the energy consumption has doubled in just nine years, going from 50.300 PJ in the year 2001 to 101.200 PJ in 2010. To emphasize the importance of this change, one should note that China has increased its share of global primary energy consumption from 11,9% in 2001to

18,9% in 2010. As regards to the GDP of China, it has shown a positive trend with a CAGR of 9%, particularly marked from China's entry into the WTO — as happened with energy — and which is around 11% for the latter period 2001-2010.

The correlation between TET and GDP is repeated in the case of India (Figure II-3a). However, India shows a more gradual evolution than China, and both variable values are considerably lower in absolute terms, a difference larger than what could be expected from the difference in population size between the two countries. Turning to the evolution of total energy consumption, India has increased more than 4 times in the 39-year period represented and shows a CAGR of 4%. Unlike China, India has not experimented an abrupt trend change in the first decade of the XXI century and the CAGR between 2001 and 2010 stood at 4,5%, only a half point higher than the average for the whole period studied (4%). In comparison, this value is nearly half of that of China for the same period (8%). Yet, the increase in energy consumption for the latter period is not negligible, and although it did not double as in the case of China, it increased almost 40% from 19.448 PJ in the year 2001 to 29.001 PJ in the year 2010. This implied that India moved from consuming 4,6% of World energy in 2001 to consuming 5,4% of World primary energy in 2010.

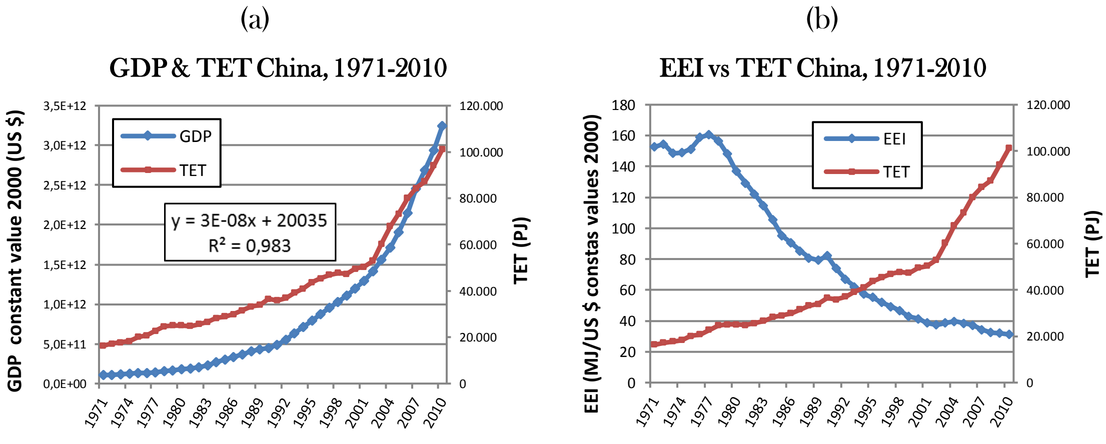


Figure II-2 a) Evolution of total energy consumption (TET) and GDP of China between 1971 and 2010. b) Evolution of TET and economic energy intensity (EEI) of China between 1971 and 2010. Sources: IEA (2010) & World Bank (2012)

It should be noted that both China's and India's increase in TET it is not only due to a growth in population (THA), but also to an increase in energy consumption per capita

(EMR) -Table A-1 and Table A-3-. As will be seen in the next section, this increase in energy consumption is mainly due to the greater capitalization of the Paid Work sector (EMRi of the sector within PW) and some increase in domestic consumption (the EMR_{HH} of the household sector).

With respect to the GDP of India, we can see a growing trend with a CAGR of about 5,5% between 1971 and 2010, which greatly increases during the stretch between 2001 and 2010 reaching almost 8%. Despite the difference in growth rates between China (11%) and India (8%) we are dealing with a very high value when compared to the performance of other countries in the same period from 2001 to 2010: Brazil 3,9%, Russia 4,8%, Chile 3,9%, Venezuela 3,1%, Germany 0,9%, Spain 1,9%, Australia 3,2%, Canada 1,9% and the USA 1,6% (World Databank, 2012).

(a) (b)

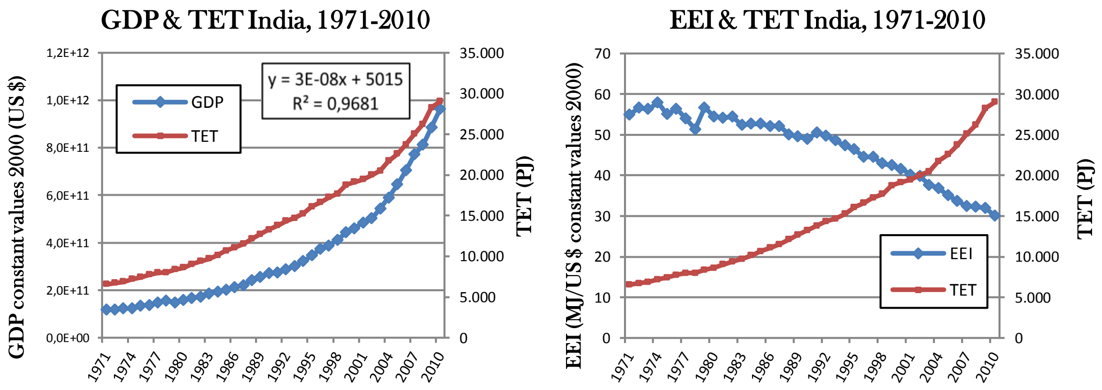


Figure II-3 a) Evolution of total energy consumption (TET) and GDP of India between 1971 and 2010. b) Evolution of TET and economic energy intensity (EEI) of India between 1971 and 2010. Sources: IEA (2010) & World Bank (2012)

Figure II-2b and Figure II-3b show the evolution of the total energy consumption (TET) and economic energy intensity (EEI_{AS}) for China and India between 1971 and 2010. As can be seen on these, values of EEI_{AS} —energy required to generate a unit of GDP— decreases significantly in the case of China and more tenuously in India. The Table A–1 and A-2 (see Appendix A) show how energy intensity for the period studied has been reduced approximately by a factor of 5 in China, while it has not even been halved in India. However, in spite of this reduction in the ratio TET/GDP, the total energy consumption has increased 6 times in China and over 4 times in India during the same period of time. This fact highlights the importance of avoiding to use an intensive variable determined by a ratio FLOW/FLOW (GDP/TET), as often done with EEI, to study the environmental effect of an increase in GDP. In fact, it is possible that the decrease in the ratio GDP/TET is offset by an increase in THA (population) and EMR (consumption per capita) associated with an increase in ELP (generation of added value per hour of human activity). As result of this fact, there is not any direct correlation between a reduction of GDP/TET and a reduction of environmental impact (for more on this see (Giampietro, Mayumi and Sorman, 2012)). It should also be noted that if one wants to use proxy variables to assess environmental impacts one has to use extensive variables – i.e. measuring the actual amount of flows required or dumped into the environment - since the use of intensive variables (reflecting ratios of flows over flows or flows over funds) can lead to this kind of errors. Thus, the environmental impact of the economic process (both on the supply and sink side) should be based on TET because it is strongly correlated with the consumption of materials and the generation of environmental liabilities (Ramos-Martín *et al.*, 2009). In this sense, Figure II-2b and Figure II-3b show that China and India have made impressive gains in their ability to use energy, but this has not reduced their dependency on fossil energy nor their environmental impact. Their GDPs are growing at an annual rate of around 10% —which implies doubling their size every 7-8 years— with their governments making plans to continue doing so. The strong correlation between GDP and TET suggests that the social and environmental impact will continue to increase in the coming years.

3.2 At the split between production and consumption (level n-1)

The performance of China and India at national level shown in the previous section can be better understood if the energy consumption, the generation of added value and the use of human activity within the economy are analyzed at a lower scale (level n-1), which distinguishes between activities where economic production takes place generating added value – in paid work sector (PW) - and activities where consumption takes place - in the household sector (HH). Households are responsible for the maintenance and reproduction of the fund "human activity" (HA), which means that the human activity, energy and materials are required to reproduce and enhance the FUND human activity, which is essential in the definition of a socio-economic system. In addition, when analyzing the metabolic pattern at this level of analysis it becomes possible to avoid the limitations of "per capita" indicators missing important information on the demographic structure of the society, which affects the performance of the economy. This analysis of the effect of the demographic structure is obtained by assessing the fraction of the FUND human activity in the paid work sector (HA_{PW} = hours per year in Paid Work) in relation to the total hours of human activity per year (THA = population x 8.760). This fraction depends on demographic and socio-economic characteristics (the dependency, the employed population, the weekly hours of work and holidays). Table A-3 and A-4 (see Appendix A) report the most relevant data from the level n-1 for China and India between 1971 and 2010.

From Table A-3 and A-4, it can be seen that in 1971 the energy consumption in the production and households was relatively similar: ET_{PW}=8.100 PJ and ET_{HH}=8.200 PJ - about 50%-50% in China; ET_{PW}=3.000 PJ and ET_{HH}=3.600 PJ - about 45%-55% in India. However, in 2010 energy consumption in production became much higher than in households, due to the strong capitalization processes that occurred in both countries: ET_{PW}=83.000 PJ and ET_{HH}=18.200 PJ - about 83%-17% in China; and ET_{PW}=20.900 PJ and ET_{HH}=8.100 PJ – about 72%-28% in India.

When considering the share of human activity allocated to paid work (HA_{PW}) out of total (THA) I get a much lower value for India - 10% of THA - than for China - 15% of THA - between 1990 and 2010. It should be noted that fraction of HA_{PW}/THA for China is very high when compared to other countries like Spain with 7,2% in 2006 (Ramos-Martín, 2001), Bulgaria and Hungary with 7-8%, Poland with 8-9% and 9-10% for Romania between 1995 and 2004 (Iorgulescu and Polimeni, 2009), Brazil with 9,3% and 11,3%, Chile with 7,8% and 9,9%, and Venezuela with 7,3% and 9,9% in 1980 and 2000 respectively (Eisenmenger, Ramos Martin and Schandl, 2007), or Australia with 9-10%, Canada with 8-9.5% and the U.S. around 10% between 1990 and 2008 (Chinbuah, 2010).

The main reason for the high value in China is the low dependency ratio that characterizes the demographic structure of China. This peculiarity is due to China's one-child policy, which has made the child dependency ratio very low in this country (24,4% in 2010), almost half as much as in India for the same year (46,6%) (Wolf *et al.*, 2011). However, in the coming years it is expected that due to the ageing of China's population the dependency ratio will increase (on the elderly side) reducing the effect of the low child dependency ratio. According to Wolf et al. (2011) it is expected that by 2030 China's dependency ratio will overtake that of India.

Following Cleveland et al. (1984), Hall et al, (1986), and Pastore et al. (2000) Giampietro et al. (2012) suggest that in the MuSIASEM approach the amount of energy consumed per hour of labor (EMR_{PW}) can be used as a proxy for the level of technical capitalization of the economy, and the amount of energy consumed per hour in household sector (EMR_{HH}) can be used as a proxy for the material standard of living. The first proxy is highly relevant in a context of cheap energy where the capitalization of the industry goes in the direction of investing in machinery to replace manual labor and thus increase the productivity of work. This results in greater mechanization and automation of production that will generate a direct increase in exosomatic energy consumption per hour of work (EMR_{PW}). In the second case, higher energy consumption in households (EMR_{HH}) is a clear indication that the households are enjoying more energy services (home appliances, mobility with private vehicles, heating and air conditioning, etc.), which make household chores easier, improve mobility and increase the overall comfort at home.

The pace of growth of EMR_{PW} of India and China in the period 1973-2010 is shown in Figure II-4. In a first period (1980-2001) India went from a value of EMR_{PW} of 7,46 MJ/h in 1980 to a value of 15,17 MJ/h in 2001, while China went from a value of EMR_{PW} of 14,72 MJ/h to a value of 21,91 MJ/h. These values reflect a similar growth pattern in the two countries. Things dramatically changed after the year 2001 (when China joined the WTO); in the second period (2001-2009) China had an annual growth rate of 8,8% whereas India has been growing at an annual growth rate of 3,9%. As a result, China managed to achieve a higher level of technical capitalization of its Paid Work sector throughout the period and the gap between the two countries increased abruptly after China's conversion into the world's factory.

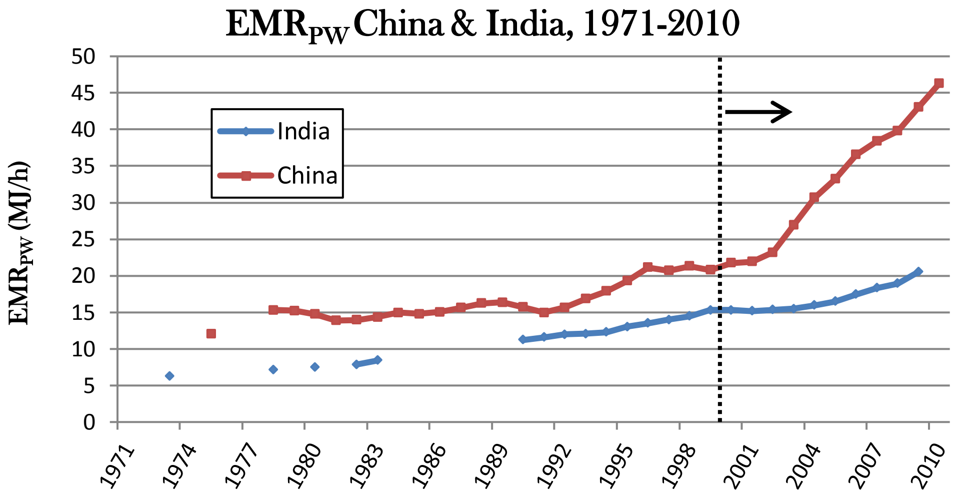


Figure II-4 Level of capitalization per worker in China and India between 1973 and 2010. Sources: IEA (2010), ILO (2012), NBSC (2011) and OECD (2012).

We can now study changes on the consumption side of the metabolic pattern, by focusing on the value of EMR_{HH} (Figure II-5). When doing this comparison, it can be clearly seen that India has been stagnating around 0,8 MJ/h from the beginning of the study period. This means that the duplication of energy consumption in the household sector —measured when using the extensive variable ET_{HH}— was due exclusively to the increase in population, and not to an increase in the material standard of living of the population. Considering the critical importance of energy consumption to cover basic needs (Department for International Development (DFID), 2002) and the several dramatic impacts of that —specially on women and children— pointed by Reddy and Nathan (2013), the stagnation on low values of EMR_{HH} during the last 40 years should be considered as a serious problem in India.

This fact flags the urgency of exploring alternative energies capable of providing basic services, putting as a priority the poorest households with an empowerment approach, as suggested by Reddy and Nathan (2013). When coming to the characteristics of metabolic pattern of the household sector, China shows an upward progression in the values of EMR_{HH} that are higher than those for India. They started around 1,4 MJ/h between 1978 and 2003, and soared to 1,8 MJ/h in 2010. The different CAGR of EMR_{HH} values are quite different: (i) between 1980 and 1990 it grew at 0,8% per year for China and 0,07% for India; (ii) between 2001 and 2009 the rate was 2,9% for China and 0,8% for India. It should be stressed that between 1998 and 2001 the EMR_{HH} of China was stagnant (Figure II-5) in spite of the robust increase in the values of EMR_{PW} (Figure II-4). The difference in the pace of growth of the two EMR shows clearly how China sacrificed household consumption to achieve a greater capitalization of paid work sector (EMR_{PW}) designed to enhance their international competitiveness in the light of its entry into the WTO in 2001.

The combination of two intensive variables for both countries is shown in Figure II-6. This graph clearly shows progression and scale differences between China and India. Specifically, the EMR_{HH} for India remained stagnant whereas in the case of China the EMR_{HH} as well as the EMR_{PW} soared in the last decade. An assessment of the material standard of living based on the proxy variable EMR_{HH} —the value of India is 0,8 MJ/h and the value of China is between 1,3 and 1,8 MJ/h in the period 1980-2009— can be compared with the corresponding value of other countries: Brazil 1,46-1,41 MJ/h; Chile 1,54-2,64 MJ/h; Venezuela 2,36-2,07 MJ/h in 1980 and 2000 (Eisenmenger, Ramos Martin and Schandl, 2007); Spain 1,67-3,27 MJ/h in 1976 and 1996 (Ramos-Martín, 2001); Australia 5,56-6,77 MJ/h, Canada 9,00-8,84 MJ/h and USA 9,47-10,2 MJ/h in 1990 and 2008 (Chinbuah, 2010). From this comparison, we can see that the value of EMR_{HH} is particularly low for India, but also for China: these values are low also for the standards of developing countries. This suggests that if in China and India industrialization levels will continue to rise with further economic growth (EMR_{PW}), the material living standards will have to rise as well (increasing the value of EMR_{HH}) toward the benchmarks typical of the so-called developed countries, a combination of change that will further increase the total energy consumption (TET)

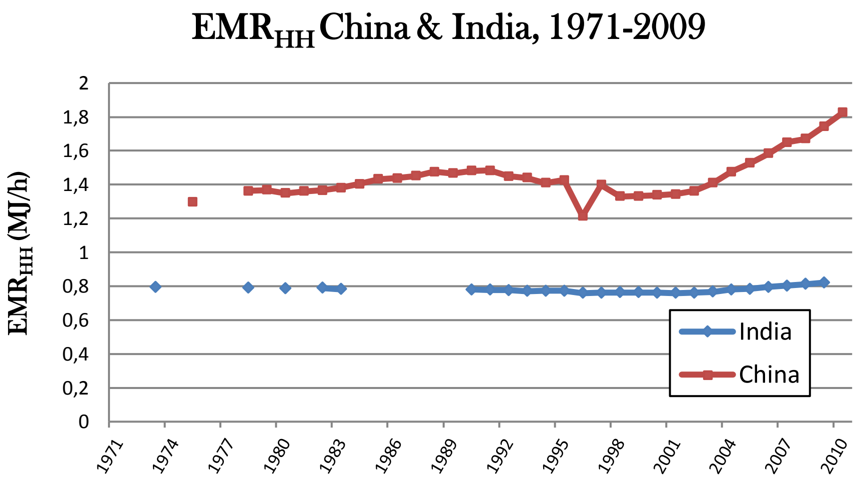


Figure II-5 Capitalization of the household sector in China and India between 1971 and 2010. Sources: IEA (2010), ILO (2012), NBSC (2011) and OECD (2012).

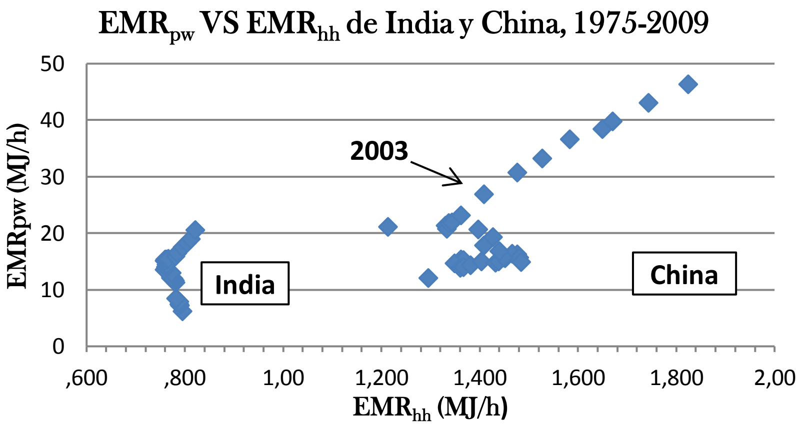


Figure II-6 EMR_{PW} vs. EMR_{HH} of China and India between 1973 y 2010. Sources: IEA (2010), ILO (2012), NBSC (2011) and OECD (2012).

The relationship between the energy consumption per hour of work (EMR_{PW}) and the economic labor productivity (ELP_{PW}) has been found in several studies of biophysical economics for countries like Spain (Ramos-Martín, 2001), Ecuador (Falconí-Benítez, 2001) and Australia (Chinbuah, 2010). This correlation is also given in the case of China and India as seen in Figure II-7 and Figure II-8. This relationship is logical if it is assumed that higher energy consumption per hour of work indicates greater capitalization of production, implying larger costs that will not be covered unless this change allows for greater economic labor productivity (ELP_{PW}). However, at level n-2 it will be seen that there are certain productive sectors more sensitive to this relationship than others.

Figure II-7a and Figure II-8a show the evolution of EMR_{PW} and ELP_{PW} between 1973 and 2009 for both countries. It can be seen that China has higher labor productivity (ELP_{PW}) and has grown significantly since 1990, but especially after 2003 (after settling into the WTO) this value has skyrocketed. For India the growth is lower, but still at a decent rhythm.

3.3 At the sector level (level n-2)

Once having seen that energy consumption and economic growth of a country do not necessarily lead to improvements in material standards of living for the population (it depends on where the surplus generated in this way is invested: either in more capitalization or in more final consumption), it is necessary to understand what happens within the productive sector (PW sector). In fact, macro-level changes (at the level n) are generated by changes in the internal components of the economy (Giampietro, Mayumi and Sorman, 2012): (i) qualitative changes in the relevant characteristics of the various sectors (ELPi and EMRi); and (ii) quantitative changes in the size of the various sectors (the profile of distribution of HAi). This is done by analyzing changes in the metabolic pattern at the level n-2 which characterizes the productive sectors of the economy.

Tables A-5 and A-6 (see Appendix A) list the most relevant data —referring to the level n-2— for the economic sectors of China and India, between 1971 and 2010. In the case of India, only employment data by sector for the years 1994, 2000 and 2005 could be obtained. Therefore, it was not possible to build a full representation based on all the extensive variables such as HA_{AG}, HA_{PS} and HA_{SG}; nor intensive ones arising from these: EMR_{AG}, EMR_{PS}, EMR_{SG}, ELP_{AG}, ELP_{PS} and ELP_{SG}.

Figure II-9a shows the evolution of the energy metabolism rate of productive sectors of China between 1975 and 2009. The industrial sector is undoubtedly the sector with the large rate of energy consumption per hour of labor (EMR_{PS}). This is due to the increasing use of machinery and the growth of infrastructures. The EMR_{PS} of China shows more or less stable behavior between 60 and 80 MJ/h between 1975 and 1999. Nevertheless, from 2000 the EMR_{PS} shoots up at a high rate and leads this indicator up to 148 MJ/h in 2010. Once again, it is China's entry into the WTO in 2001 which explains this sudden change.

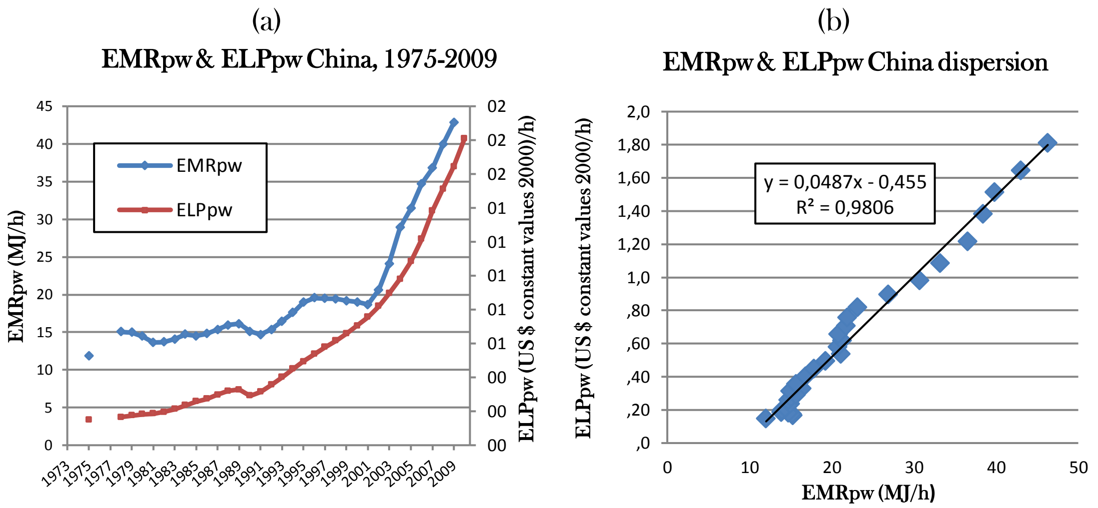


Figure II-7 a) Evolution of EMR_{PW} and ELP_{PW} of China between 1975 and 2009. b) EMR_{PW} vs. ELP_{PW} of China between 1975 and 2009. Sources: IEA (2010), ILO (2012), NBSC (2011), OECD (2012) and World bank (2012).

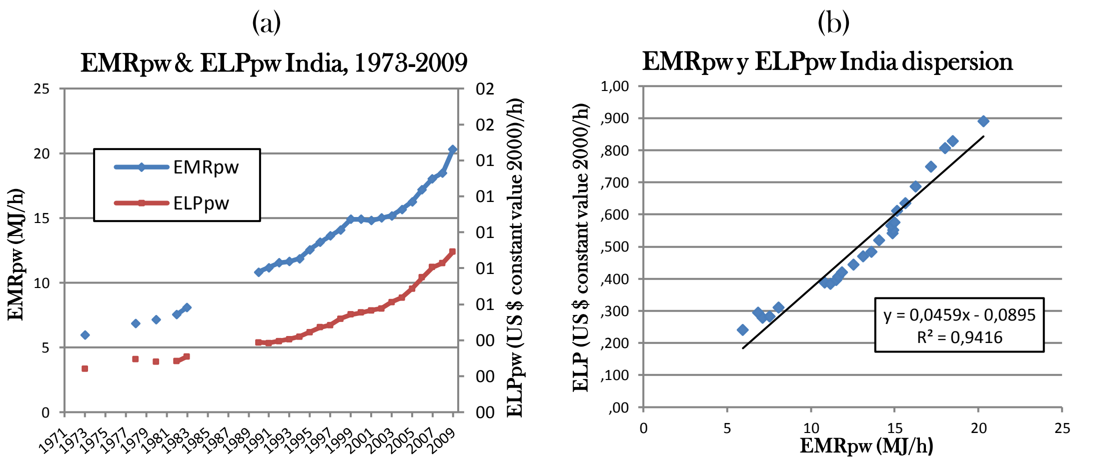


Figure II-8 a) Evolution of EMR_{PW} and ELP_{PW} of India between 1973 and 2009. b) EMR_{PW} vs. ELP_{PW} of India between 1973 and 2009. Sources: IEA (2010), ILO (2012), NBSC (2011), OECD (2012) and World bank (2012).

This moment of change also coincided with a growth of EMR_{AG}, which goes from 0,9 MJ/h in 2000 to 2 MJ/h in 2010 reflecting an increase in the use of inputs in the agriculture during this period (see Table A-5). This increase in the capitalization of agriculture can be explained by the move of huge amounts of workers from farming to go to the cities to work in industry (Ramos-Martin, Giampietro and Mayumi, 2007). Furthermore, the service sector shows a similar trend: rising from an EMR_{SG} of 7 MJ/h in 2000 to 9,4 MJ/h in 2010 (see Table A-5 Appendix A), indicating an increased use of motorized vehicles in transport and more computerization of administrative tasks.

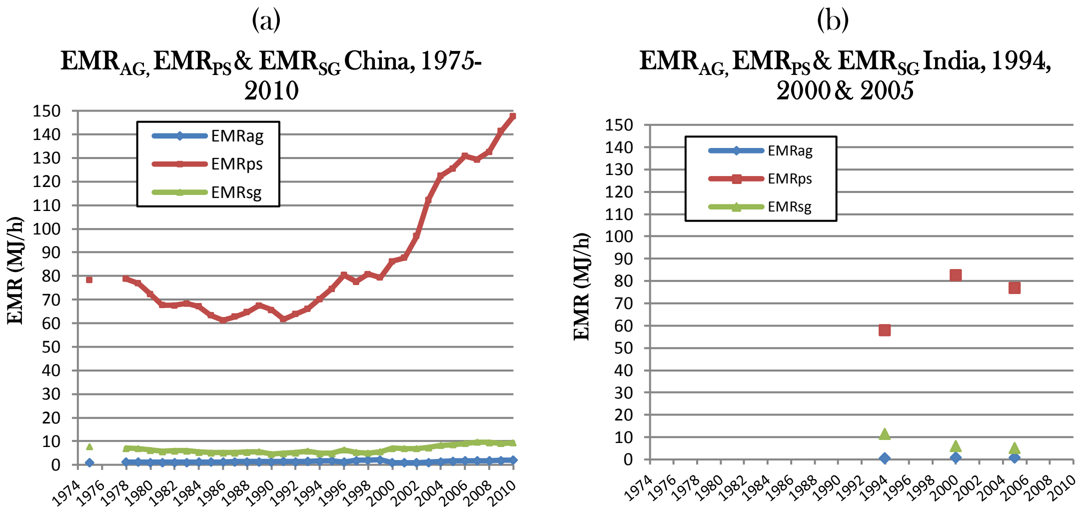
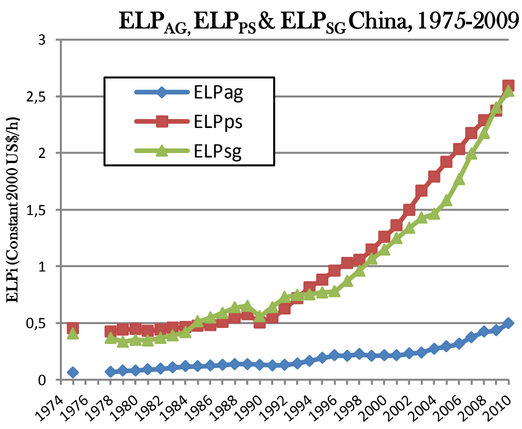


Figure II-9 a) Evolution of EMR_{AG}, EMR_{PS} & EMR_{SG} of China between 1975 and 2010. Sources: IEA (2010), ILO (2012) and NBSC (2011). b) Evolution of EMR_{AG}, EMR_{PS} & EMR_{SG} of India for 1994, 2000 & 2005. Sources: IEA (2010), ILO (2012), OECD (2012), World Bank (2012) and Planning Commission (2012).

In the case of India very little EMRi data is available due to the lack of information on the number of workers employed in each sector of the economy and their work-load per year. However, energy consumption per hour follows the same hierarchy than in China: EMR_{PS}> EMR_{SG}> EMR_{AG} (Figure II-9b). Moreover, India's industrial sector shows a rise in the EMR_{PS} since 1994 that seems stuck around 80 MJ/h between 2000 and 2005. These values are similar to those of China before the year 2000 –the EMR_{PS} of India is 82,7 MJ/h while it is 86,3 for China. Nonetheless, the decline of Indian EMR_{PS} to 76,9 MJ/h in 2005 and the evolution of its GDP and other indicators suggest that since then India's industrial sector has not had the same pattern of strong capitalization of China. As seen in the level n-1, the increase in energy consumption in India has not been enough to increase levels of technical capitalization (technical capital per worker indicated by the proxy EMRi) in industry or in households. It has only been able to offset the increase in population.

Figure II-10 show how the economic labor productivity of the agricultural sector (ELP_{AG}) was more or less the same in China than in India in 1994 – 0,18 $/h –, but in 2005 China's value was 26% higher – 0,29 $/h versus 0,23 $/h. Likewise, economic labor productivity of the industrial sector (ELP_{PS}) is much higher in China than in India: in 1994 it was 55% higher: 0,81 $/h versus 0,53 $/h; whereas it was 74% higher in 2000: 1,26 $/h compared to 0,72 $/h; and finally it was 165% higher in 2005: 1,92 $/h versus 0,73 $/h. This growing differential largely explains why China's GDP is greater than the Indian one. Finally, the economic labor productivity of the service sector was higher in India than in China —up 49% in 1994: 1,49 $/h vs. 0,75 $/h—, a fact that can be explained by the increase in service outsourcing, software companies and R&D in India (taking advantage of the more diffuse use of the English language). However, in recent years China has invested significantly in these areas and is reducing this difference: in 2005 Indian ELP_{SG} was only 4% above that of China: 1,65 $/h compared to 1.58 $/h. In 2010 the ELP_{SG} of China increased to 2,55 $/h which is likely to be greater than in India.

(a)



(b)

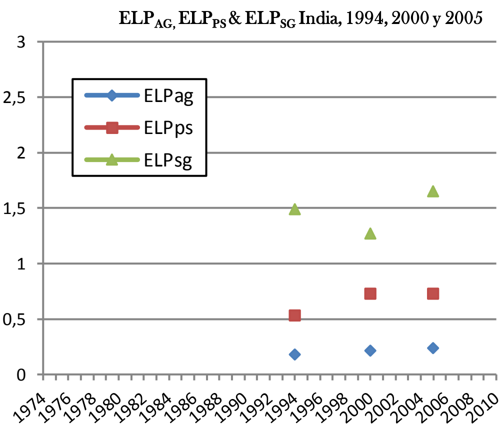


Figure II-10 a) Evolution of ELP_{AG}, ELP_{PS} and ELP_{SG} of China between 1975 and 2009. Sources: IEA (2010), ILO (2012) and NBSC (2011). b) Evolution of ELP_{AG}, ELP_{PS} and ELP_{SG} of India for the years 1994, 2000 y 2005. Sources: IEA (2010), ILO (2012), OECD (2012), World Bank (2012) and Planning Commission (2012).

As illustrated in Figure II-10a when considering China the values of ELP_{SG} and the ELP_{PS} are almost similar and following the same trend. This, fact shows clearly the labor intensive nature of the industrial sector of the Chinese economy that get a comparative advantage on the international market, thanks to the possibility of using cheap labor. The situation is even worse for the PS sector in India where, as explained before, the SG sector does better than the PS sector in terms of added value generated per hours of labor. Having seen this last level of analysis, one can say that the fact the ET_{PW} has grown much more in China than in

India stems from both the larger weight of GDP_{PS} in the Chinese economy (where $EMR_{PS} > EMR_{SG} > EMR_{AG}$) with a EMR_{PS} continuously increasing, meaning that the difference between Chinese and Indian EMR_{PS} is still rising.

4 Conclusions

In this chapter, we have seen a first application of MuSIASEM showing the diverging paths of economic development of China and India in relation to their energy consumption in different sectors. The MuSIASEM approach makes it possible to individuate a fragility in China's models and a systemic weakness in the Indian's model. In relation to China, the fast economic development depends on three specific factors: (i) the effects of the one child policy that gave to China the largest work force (both in number and in percentage over the population) in the world. However, this effect will vanish in a decade or two and will backfire (sudden aging of population); (ii) the relative supply of cheap oil. This factor will vanish too, because of the increasing demand worldwide coupled to an increasing cost of extraction of fossil energy; (iii) the possibility to re-invest the majority of the economic revenues in the capitalization of the economy, slowing down in the first period of economic growth the increase in the consumption of the households. Also in this case, the compression of final consumption cannot be kept for a long period of time, since this policy tends to generate growing inequalities and socio-environmental injustices[2] leading to social unrests[3]. In relation to India, the comparison shows a different story, the demographic momentum and a more relaxed control on the flows of investments in the economy did not result in a quick accumulation of capital per capita in the economy (a structural economic growth of the industrial sector). This leaves the economy of India with both a weak internal demand and a low competitiveness —in terms of industrial infrastructures— in relation to China on the international market.

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[2] http://www.utne.com/environment/environmental-activists-zm0z13jfzwil.aspx#axzz2WCmuAkrk, http://www.guardian.co.uk/environment/2012/jun/19/environment-activist-deaths_[accessed 16.05.17].
[3] https://chinastrikes.crowdmap.com/_[accessed 16.05.17].

The MuSIASEM approach makes it possible to quantify the factors determining these differences. The large differences in the levels of development between China and India are due to the greater size, capitalization level and pace of growth of China's industrial sector, especially since its entry into the WTO in 2001. In this regard, China has capitalized all sectors to a greater extent (EMRi) a fact that translates into a boosting of economic labor productivity (ELPi) and GDP, but also its total energy consumption (TET). Therefore, in this phase of industrialization China has at the moment an advantaged position over India, with a more developed infrastructure and a larger level of technical capitalization of economic sectors determining a higher economic labor productivity. However, when comparing China and India energy metabolic rates with the metabolic rates of other countries available from previous studies (Brazil, Chile, Venezuela (Eisenmenger, 2007); Spain (Ramos-Martín, 2001), Australia, Canada, USA (Chinbuah, 2010)) we can see that their EMR_{HH} and EMR_{PW} are still low. This fact reinforces the conclusion that the value of TET will further increase in the future in both countries. When looking at the Indian and Chinese energy mix, one can conclude that these achievements have been based on an increased dependency on fossil energy. This increased dependency has taken place at the very same moment in which it is becoming clear that a cheap supply of imported energy is no longer an option. In this sense, the strong correlation between GDP and TET (for an overview see table 1 of Coers and Sanders (2013)) suggests that the social and environmental impact will continue to increase in the coming years.

All these questions introduce uncertainty about the future metabolic pattern of China and India, but also about the stability of the future metabolic pattern of the rest of the world, due to the huge weight in the world economy of these two economies. The end of the era of cheap-oil (determined by the peak of conventional oil) and the threat of climate change will shape future energy policies. In fact, environmental degradation implied by the extraction of non-conventional fossil energy reserves and the combustion of fossil fuels of lower quality will become more and more relevant at the moment of developing new energy policies. The development of renewable energy sources will be a must in order to cope with the increases in future energy demand. However, according to the characterization given by MuSIASEM, alternative energy systems will have to be: (i) feasible (compatible with external constraints); (ii) viable (compatibility with internal constraints – i.e. requiring a limited amount of production factors and economic investments) and (iii) desirable (compatibility with human expectations). In relation to desirability a 100% alternative energy scenario will probably not deliver the same amount of (energy) services to which society is used to nowadays... (Giampietro *et al.*, 2014). The Economic Energy Intensity of a country can be reduced by structural changes: moving from industrial production to a service economy —as done by Europe (Giampietro, Mayumi and Sorman, 2012) and USA (Chinbuah, 2010) — however this does not imply dematerialization of the world's economy. The economies of EU and USA continue to consume industrial products produced elsewhere (China and India in this case). Therefore, these structural changes in developed economies imply just a cost shifting of social and environmental degradation to other countries. In a global economy, the effect of changes have to be analyzed at the global scale!

Finally, both China and India have still low levels of household energy consumption and a size of the agricultural sector —both in terms of workers and the relative sectorial share of GDP— much larger than other developed countries. This situation suggests that both India and China will continue to require strong injections of technical capitalization and will have to increase their total energy consumption in order to absorb labor from rural areas into the growing urban economy, to remain competitive internationally with their economies, increase domestic consumption, and boost their internal production of food for their food security. Failure to meet any of these points, especially the last two: a quick increase in household energy consumption —providing a badly needed increase in the energy services of the poorest fraction of the population— and the possibility of guarantee cheap food to the poor may trigger social unrest, given that inequalities and socioeconomic injustices are already serious in these countries.

From this analysis, some peculiarities of these countries can also be noted. For example, China shows a very high fraction of human activity allocated to paid work which makes its economy very competitive at the moment. This positive peculiarity is largely due to its demographic structure: a low dependency ratio because of the past one-child policy. However, this plus of the Chinese economy can become a major liability in the future with a sudden aging of the population, that is composed now of a vast majority of adults. A second peculiarity is represented by the fact that even though the economic energy intensity is decreasing significantly for both countries, the effect the strong pace of growth moving-up the value of the metabolic characteristics of their various sectors toward the benchmarks typical of developed countries (EMR_{PW} and EMR_{HH}) implies that such a decrease has no appreciable effect on the total energy consumption (TET) of the economy of both countries.

Considering the size of these two giants-countries and when considering the trends of change in the energetic metabolic pattern of China and India I can only conclude that it is extremely important to pay more attention to the biophysical roots of the economic process and to the existing link between the availability of resources and the ability of the economic process to guarantee an adequate production and consumption of goods and services for a changing population.

Chapter III

"Essentially, all models are wrong, but some are useful"

George Box

Energy uses analysis of the social metabolism compartments: presenting the protocol[4]

1 Introduction

Following the recognition of the existence of limits to the availability of natural resources – peak-oil (*ASPO*, 2017) and peak everything (Heinberg, 2007) – and the growing concern about climate change, recent years have witnessed a revival of interest in the bioeconomic performance of the economy, especially with regard to energy uses. Indeed, energy efficiency and decarbonization are an integral part of the EU 2020 Energy Strategy (European Commission, 2010) as well as USA energy policies (Leggett, Congressional Research Service and Leggett, 2014). Energy intensity and carbon intensity in particular have become popular indicators for assessing the bioeconomic performance of modern economies. Energy intensity is defined as the simple ratio between the 'energy used' by an economy and the amount of GDP generated during a defined time interval; similarly, the carbon intensity is the ratio between the amount of CO2 emissions and the GDP generated by the economic process. The biophysical intensity of the economy is a widely used way of measuring efficiency under the assumption that a more efficient economy will generate

[4] This chapter builds partly on paper under revision *Velasco-Fernández R, Giampietro M. and Bukkens, G. F. Sandra. A novel approach to the analysis of the energy efficiency of the industrial sector* in *Energy* and the report: *Giampietro M., Velasco-Fernández R. and Ripa M. Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers. March 2017 EUFORIE project*

more GDP with less use of energy and less carbon emissions (European Environment Agency, 2015).

In this chapter, I will show that despite their ubiquitous use, the concepts of energy efficiency and decarbonization and their relative indicators energy and carbon intensity can be highly misleading metrics for the assessment of the bioeconomic performance of the economy. In particular, I single out five factors related to the energy metabolism of modern society that influence the assessments of energy and carbon intensity of the economic process. These factors make cross-country comparisons and longitudinal studies based on aggregate data meaningless. In an attempt to overcome these shortcomings, I propose and illustrate a more holistic approach to societal energy use based on a multi-scale integrated analysis of the energy metabolism of social-ecological systems. I especially focus on the analysis of the metabolic pattern of the industrial sector (building and manufacturing) given its dominant role in determining the energy and carbon intensity of the economic process as we have already seen in chapter 2 with case studies from China and India. Among the innovative aspects of my analysis is the use of the concept of 'end-uses data array', a biophysical version of the production function in economics, to evaluate the bioeconomic performance of the economy.

In the following section (section 2) I first discuss the caveats of the use of energy intensity as an indicator for bioeconomic performance; in section 3, I propose a new take on societal energy use based on Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), and then, in section 4, I illustrate this approach by examining and comparing the industrial sector of three European countries, Bulgaria, Finland, and Spain at various hierarchical scales of analysis. Finally, in section 5, I conclude with a discussion of the pros and cons of the proposed approach to evaluate the bioeconomic performance of the economy. In chapter 4 I will present an extended application of this protocol covering more economic sectors and for all the 27 countries of the European Union.

2 Caveats of the use of energy intensity as an indicator for bioeconomic performance

In this section, I show that neither at the aggregate level of the whole economy nor at the level of individual economic sectors, energy intensity and energy efficiency are meaningful concepts. While a simple ratio, such as energy/GDP, is obviously attractive and easily calculated from available statistics, it has little information content if not properly contextualized within the larger metabolic process to which it refers. In order to illustrate the limitations to the use of energy intensity as an indicator for bioeconomic performance, I represent modern society as a social-ecological system, as shown in Figure III-1. In this representation, I single out the energy sector (on the left) and group the other sectors (on the right) including the industrial sector, service and government sector, transportation sector, and residential sector. The energy sector is where primary energy sources are exploited to produce energy carriers, the rest of the economic process uses energy carriers to express its functions.

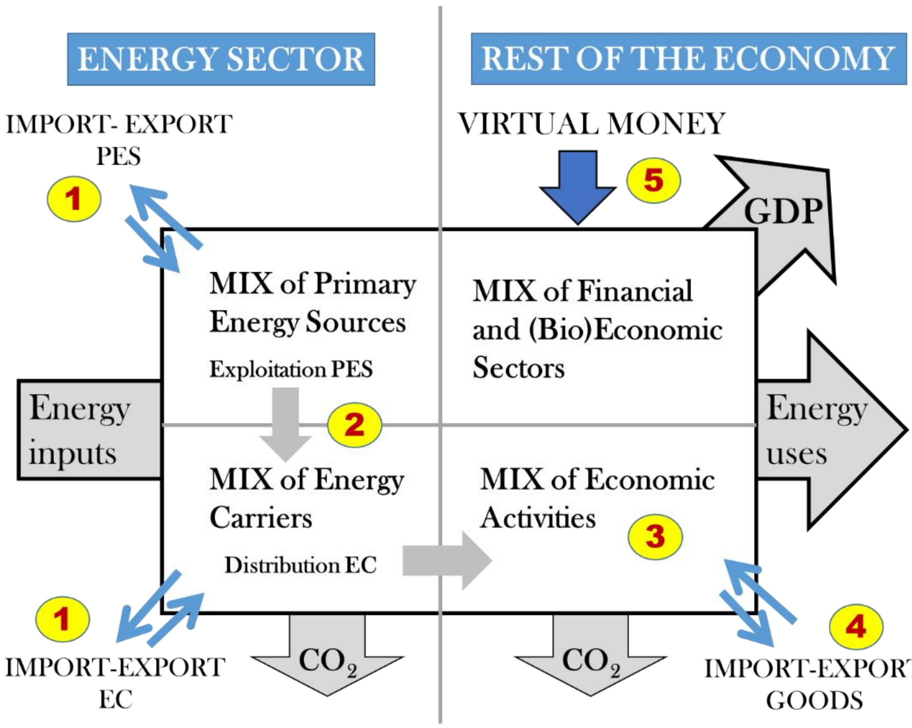


Figure III-1 The metabolic pattern of social-ecological systems and the different factors affecting the energy and carbon intensity of an economy. Abbreviations: PES = primary energy sources; EC = energy carriers; GDP = gross domestic product

In Figure III-1 I indicate five factors that influence the metabolism of a social-ecological system, and notably its energy use in relation to the GDP. These five factors need to be carefully addressed for energy intensity or energy efficiency to have any meaning at all:

1. the degree of openness of the energy sector;
2. the mix of primary energy sources and energy carriers used in society;
3. the mix of economic activities carried out in society;
4. selective externalization of economic activities (import of goods and services);
5. credit leverage and quantitative easing ('virtual money') boosting the GDP.

2.1 The openness of the energy sector

Fossil energy imports represent an externalization of the cost of producing energy carriers in terms of required investments in technology, labor, water, land use, and obviously primary energy sources. They also externalize the emissions of CO2 in the phases of extraction, refinery and transport. Indeed, energy import is key to maintaining a reduced consumption of primary energy sources and energy carriers in the operation of developed economies, notably in Europe. The importance of this factor becomes evident if we look at the energy consumption in oil exporting countries. When considering the oil consumed for oil extraction, refining, and transportation an additional 15-20% of energy consumption is embodied in the imported fossil energy consumed by developed countries (Smil, 2008; Hall and Klitgaard, 2012). This bonus is generally not considered in the calculation of the energy intensity of the economy.

2.2 The mix of primary energy sources and energy carriers

In Figure III-2, I show the three sets of categories that are relevant for the accounting of energy: primary energy sources, energy carriers, and end-uses (Giampietro, Mayumi and Sorman, 2013). For each category, I list various examples.

Primary energy sources (PES) are energy forms that cannot be produced by humans. Their (lack of) availability therefore represents an external constraint that limits the use of energy. Primary energy sources can be of various forms: mechanical (wind, hydro, waves), thermal (concentrated solar power, geothermal), chemical stocks (fossil energy such as coal, oil), or nuclear (generating thermal energy). Primary energy sources can be divided into renewable and non-renewable sources as shown in Figure III-2.

When a big difference exists among countries in the mix of primary energy sources used to generate electricity, we cannot compare the bioeconomic performance of the energy sector or national economy by simply measuring the energy or carbon intensity. For example, a country producing more than 90% of its electricity from hydropower, such as Norway, requires less fossil energy and emits less CO2 to supply the same amount of electricity than a country, such as Poland, relying predominantly on coal power plants (about 85%) (OECD/IEA, 2016). Indeed, the role of the efficiency of the technologies used in the power plants is completely irrelevant in determining the economic carbon intensity compared to that of the mix of primary energy sources used to produce electricity.

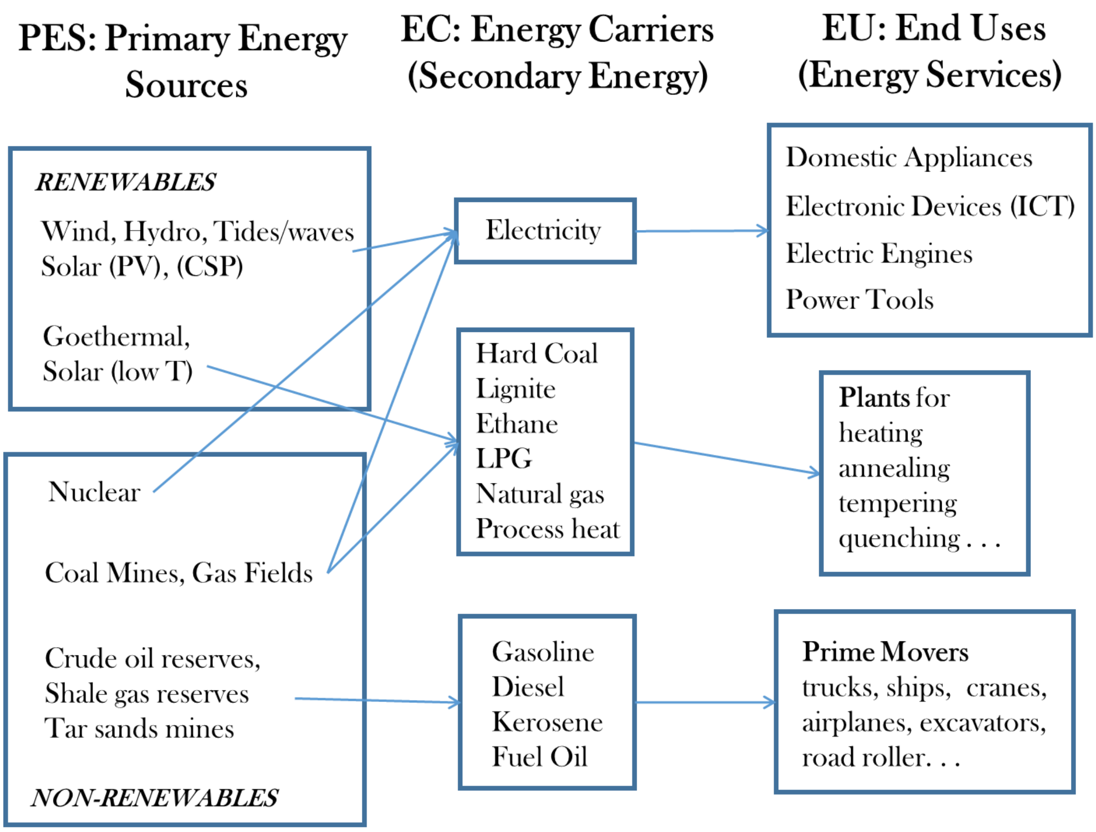


Figure III-2 Examples of different types of primary energy sources, energy carriers and end uses.

Energy carriers (EC) (or secondary energy) are energy forms under human control that are produced from available primary energy sources. As Cotrell indicated, it is the identity of the converter which defines the identity of the energy input, that is, the energy carrier (Cottrell, 2009). In relation to this point Figure III-2 shows how different types of energy carriers are used for different purposes (end uses) by different end users. Airplanes do not fly on electricity and laptops do not run on kerosene. If we want to assess the efficiency of a refrigerator we need data on the electricity it consumes; if we want to assess CO2 emissions we need data on the carbon-based fuels that have been burned. Hence it simply does not make sense to use a single quantitative assessment of 'energy use' in the analysis of energy (or carbon) intensity. Aggregated energy consumptions assessed in tonne of oil equivalent (toe) do not map onto a common value of tons of CO2 emissions.

The aggregation of different energy forms into a single quantitative assessment of 'energy use' implies loss of information by default (Giampietro, Mayumi and Sorman, 2013). For example, if we have a mix of 30 GJ of electricity and 70 GJ of fuel, we could aggregate them into a single assessment of 'energy use' using the partial substitution method: the joules of electricity are multiplied by a conversion factor of 2,65 before being summed to the thermal joules. In this case, I would arrive at a total of 150 GJ of gross energy requirement (virtual PES in thermal energy equivalent) or about 3,6 toe. Other methods of aggregation exist (e.g., the one adopted by Eurostat and IEA) that will (or not) result in a different gross energy requirement depending on the mix of primary energy sources used to generate electricity (Giampietro and Sorman, 2012).

2.3 The mix of economic activities carried out in society (structural factors)

The energy intensity of the economy as a whole is determined by the energy intensities of its end-use sectors (that is, by the mix of goods and services produced and consumed). Indeed, the relative weight of the more and less energy intensive end-uses (sectors, subsectors, processes) in the economy is a key factor in determining the energy intensity of the economy as a whole. For example, an economy deriving most of its GDP from metal, chemical and/or paper industries will have a higher energy intensity than an economy deriving most of its GDP from the financial sector. Also in this case, the mix of economic activities will result far more important in determining the overall economic energy intensity (or the carbon intensity) than the efficiency of the technologies used in each one of the individual end-uses. For example, a post-industrial society based on an outdated tourism sector will result less energy intensive than an industrial society based on state-of-the-art metallurgic production (Giampietro, Mayumi and Sorman, 2012). Indeed, a major structural factor behind reductions in the aggregate energy intensity of manufacturing in many countries has been the relative decline of the role of energy-intensive industries (e.g., primary metals, chemicals, and paper) in the generation of the GDP (Giampietro, Mayumi and Sorman, 2012).

2.4 Externalization of industrial production through imports

Related to the previous point, the energy intensity of an economy can be significantly reduced by externalizing the most energy intensive end-uses to other countries. For instance, through import of raw materials, semi-finished products or end-products, a society can externalize the consumption of energy (and relative carbon emissions) required to produce these goods. In this case we have that the relative energy (and material) consumption and emissions (as well as other socio-environmental impacts (EJOLT, 2017)) are *externalized* to the country producing the imported goods. As a matter of fact, by externalizing the burden of industrial production (the most energy-intensive economic sector) to countries like China, Russia, Brazil or India (Eurostat, 2017a), many developed countries have significantly reduced their energy and carbon intensity (decarbonization). This achievement has been associated with a process of de-industrialization of their economy (Serrenho *et al.*, 2014).

2.5 Credit leverage and quantitative easing

Reliance on credit leverage and quantitative easing (debt) can boost the national GDP without a concomitant increase in energy use and relative CO2 emissions. Indeed, a continuous massive injection of virtual money into the economy allows for the import of goods ‘free’ of the concomitant biophysical costs (externalized). If imported goods were to be paid with an equivalent amount of value added obtained by exporting goods, they would imply energy use (and CO2 emissions) for generating that value added. A recent report of the McKinsey Global Institute (McKinsey Global Institute, 2015) indicates that since 2007 the global debt (in the form of credit leverage or quantitative easing) has increased by 57 trillion USD, outpacing world GDP growth. The same study indicates that developed countries have the larger amount of and larger rate of increase in credit leverage and quantitative easing. If we relied on the economic energy intensity of the national economy (total energy consumption/GDP) as an indicator of performance, we would find that importing goods and paying them with virtual money is by far the most effective strategy to boost the biophysical efficiency of the economy. According to this indicator we simply have to print more money in order to reduce CO2 emission at the national level.

2.6 How to handle these factors?

Some of the problems in using energy intensity as a proxy for energy efficiency have already been discussed in the literature, including the importance of specifying the mix of primary energy sources and the mix of energy carriers used in the economic process (Turvey and Nobay, 1965; Hyman and Reed, 1995; Freeman, Niefer and Roop, 1997; Bernard and Côté, 2005; Bor, 2008; IEA, 2008; Morrison *et al.*, 2009; Sustainable Energy For All, 2012; Coers and Sanders, 2013; Kepplinger, Templ and Upadhyaya, 2013; Belzer, 2014). Indeed, the non-substitutability of energy forms was pointed out as early as 1965 by Turvey and Nobay (Turvey and Nobay, 1965) in relation to the economic measurement of energy consumption and by Cottrell (Cottrell, 2009) in relation to biophysical analysis. The Sustainable Energy For All (2012) report (Sustainable Energy For All, 2012) clearly makes the point that rigorous measurements of energy intensity are only possible at the level of individual technologies. When moving up to higher hierarchical levels, such as economic (sub)sectors and the national economy, the indicator is affected by the sectoral structure of the GDP. The discussion in the literature also addresses the existence of different options for accounting energy consumption: primary energy supply versus final energy consumption or biophysical versus monetary accounting (Hyman and Reed, 1995; Bernard and Côté, 2005). Indices based on a thermodynamic narrative have also been proposed to assess the differences in the quality of the energy inputs used by the economy (Ayres and Warr, 2005; Warr and Ayres, 2010; Serrenho *et al.*, 2014, 2016).

However, this earlier research remains focused on the analysis of the functioning of the economy seen as a black-box. While it is certainly useful to generate 'ad hoc' indicators of the energy intensity of single economies or economic sectors, earlier research does not properly address the impact of heterogeneity in 'energy uses' in cross-sectional studies (differences in the internal functioning of different black-boxes), nor does it provide a conceptual approach to study the effect of evolutionary changes in individual economies (structural changes in the characteristics and relative sizes of the parts of the black-box under analysis) (Coccia, 2010). For this reason, in this chapter I propose a quantitative method of analysis that addresses the challenge of how to deal with the fact that different societies use different mixes of energy inputs to express different functions in different functional elements (economic sectors and sub-sectors) and that these mixes may change over time. This challenge requires us to simultaneously assess both the relative size of these functional elements and the specific profile of different types of energy inputs consumed by each of them.

Essential and novel to my approach is the introduction of the concept of an 'end-uses data array'. The end-uses data array makes it possible to distinguish and quantify the energy throughput metabolized by each of the elements of the economy in terms of a mix of different energy forms of different quality. At the same time, the end-uses data array provides information on the size of the element, by means of the required labor input for the end-use/(sub)sector in question. This combination of information allows us to describe the energy consumption of a given (sub)sector or end-use simultaneously both in qualitative and quantitative terms. Finally, the proposed framework provides practical criteria to define and identity the various sectors and subsectors across different hierarchical levels of analysis. This information is essential for studying the different degrees of openness at which these sectors and subsectors are operating.

3 Methodology

3.1 Theoretical framework: MuSIASEM

When analyzing flows in a metabolic system to study the relation between 'the quantity of energy used' and 'the amount of GPD generated', we should not consider them in isolation. Metabolic flows are meaningful only if they are contextualized in relation to the larger metabolic process in which they are used as useful input and produced as useful output. Using the flow-fund model proposed by Georgescu-Roegen (Georgescu-Roegen, 1971) we can make an epistemological distinction between *flows* —quantities disappearing or appearing over a given period of analysis— and *funds* —structural elements of the metabolic system associated with agency (e.g., population, workers, technical capital or power capacity in energetic jargon) preserving their identity over the given period of analysis (Farrell and Mayumi, 2009; Giampietro, Mayumi and Sorman, 2012; Velasco-Fernández, Ramos-Martín and Giampietro, 2015). Within this model, the sizes of the various flows are determined by the characteristics of the various processes taking place inside society. In turn these processes are determined by the combination, the size and the characteristics of the fund elements controlling the flows. For example, using the flow-fund model we do not assess the flow of food consumption of a given society simply by measuring the flow as a quantity of nutritional kcal/year, but by establishing a relation between: (i) a variable chosen as a proxy of the size of society – the fund element population; and (ii) the metabolic pace of food consumption per capita per year. That is the size of the fund (population size – extensive variable, used as scaling factor) is multiplied by a flow/fund ratio (used as a qualitative benchmark of metabolic pace per unit of size) to obtain the flow of food consumption (Giampietro *et al.*, 2014).

I propose a system of accounting based on the MuSIASEM rationale to examine the energy use and economic productivity of the industrial sector. MuSIASEM builds on the flow-fund model of Georgescu-Roegen as well as on complexity theory. Its theoretical framework has been described in detail elsewhere (Giampietro and Mayumi, 1997b, 2000a, 2000b; Pastore, Giampietro and Mayumi, 2000; Giampietro, 2003; Giampietro, Allen and Mayumi, 2006; Ramos-Martin, Giampietro and Mayumi, 2007; Giampietro, Mayumi and

Ramos-Martin, 2009; Sorman and Giampietro, 2011; Giampietro and Sorman, 2012; Giampietro, Mayumi and Sorman, 2012, 2013). Key features relevant to the work presented here are briefly described below:

- Rather than reducing all energy forms into a semantically-void generic category of accounting, such as joules of energy commodities (used by Eurostat and IEA), I respect the specificity of the main energy carriers, electricity, heat and fuel (that are specific inputs for specific end uses) and maintain a separate accounting of these energy carriers throughout the analysis.
- I map the consumption of these energy carriers for all sectors and subsectors of the system and also consider an additional production factor: human labor (fund element), being a necessary ingredient to stabilize the energy flow. For all sectors and subsectors of the system, I map the allocation of fund and flow elements (biophysical inputs) onto the flows of value added generated.
- I define the size and hierarchical structure of the system on the basis of the allocation of the fund element human activity −defined in terms of time (hours/year)− to the various sectors and sub-sectors of the system. This taxonomy makes it possible to allocate to each (sub)sector of the system the relative flow elements (i.e., the different types of energy carriers and value added) associated to human activity.
- The social-ecological system (society) as a whole is defined as having a total size of: number of people × 8.760 (hours of human activity in a year). The size of the different economic sectors and sub-sectors within society is defined as: 'number of paid hours worked by employees per year in the given sector'.
- I use both extensive and intensive variables. Extensive variables assess the size of fund (e.g., hours of human activity in a year) and flow elements (e.g., throughput of energy carriers and quantities of value added generated in a year), while intensive variables refer to flow/fund ratios, such as the throughput of energy carrier per hour of human activity (average value per year) allocated to the end-uses and the quantity of value added generated per hour of human activity (average value per year) allocated to the end-uses.

In the end-use matrix adopted here, the data arrays assessing flows and funds are calculated for the following sectors: (i) agriculture, forestry and fishing AF; (ii) Manufacturing and Construction MC; (iii) Services and Government (private and public services) SG, (iv) Energy and Mining EM; and (v) the Household sector (HH, residential consumption including fuels consumed by private cars). The energy supply to society is guaranteed by two sources: (1) the Energy and Mining sector (EM) – domestic production; and (2) by imports.

Within this taxonomy, I distinguish between sectors expressing: (i) dissipative activities; and (ii) hypercyclic activities. Dissipative activities are those that consume biophysical flows and use exosomatic devices, without producing either of them (HH and SG). This implies that because of this fact, in the same society we must find other activities that generate a net supply of flows and exosomatic funds – in alternative the flows and exosomatic funds consumed have to be imported (the activities generating a net supply of flows and funds are externalized to other societies). The demand generated by dissipative activities defines the required net supply of flows and exosomatic funds. The hypercyclic compartment (a hypercycle is an autocatalytic loop in which the output is larger than the input) composed by AF, EM and MC should be able to provide this net supply (integrated by imports). The jargon of hypercycle vs. dissipative is taken from theoretical ecology (Ulanowicz, 1986) where it is used to describe the factors that stabilize complex metabolic networks in ecosystems. Examples of hypercycles are: (i) the agricultural sector (for food), which produces more vegetal and animal products than it consumes; (ii) the energy sector (for energy), which produces more electricity and fuels than it consumes; and (iii) manufacturing and construction sectors producing more exosomatic funds than they consume. For this reason, the primary and secondary sectors can provide a net flow of food, energy and exosomatic funds to the dissipative compartments of the society.

In conclusion, in MuSIASEM, we do not use the generic flow/flow ratio “energy use/GDP” to study the economic energy intensity of an economy. Rather I propose the combined use of two sets of flow/fund ratios calculated in relation to a ‘quantity of energy carrier per hour of labor’ (specified by energy carrier types and by job type) and a ‘quantity of added value per hour of labor’ (specified by job types) for each given compartment. These benchmarks can be multiplied by an assessment of the fund element ‘human activity’ (express in hours per year) invested in that element, that is used as scaling factor to get an assessment of the relative flow. The scaling factor is determined by the size of the fund human activity (labor hours) allocated to a given (sub)sector having a giving value of metabolic rate. In this way it becomes possible to scale-up its specific metabolic characteristics (defined by the flow/fund ratios per unit of size) to the value of the flow (extensive variable) metabolized by the (sub)sector. Hence the size of the flows associated with a given (sub)sector can be estimated as the product of an extensive variable (size of the fund – hours of labor) and an intensive variable (the flow/fund ratio – quantity of the flow per hour of labor) or directly measured in extensive terms (e.g. when consulting statistical data). Indeed, in MuSIASEM intensive variables provide useful benchmarks describing the qualitative metabolic characteristics of the system's elements (i.e., the inputs required per unit of output). This type of analysis is directly related to the concept of technological performance described using a production function. Extensive variables, on the other hand, reflect the size of the fund elements (human activity, the agent using and producing flows). The integrated use of intensive and extensive variable allows us to scale the metabolic characteristics of economic sectors and subsectors within a country, and compare the performance of specific (sub) sectors across different countries. The inclusion of the intensive variable economic job productivity of a given sector (EJPi) – the amount of value added generated per hour of labor in a specific (sub)sector i –is an important feature of MuSIASEM. It provides an indication – independent of energy use– of the convenience of externalizing economic activities (end-uses) to other countries. When the income provided by an economic activity is not or no longer competitive with other activities in the economic process (when it expresses a relatively low EJPi), then the activity is prone to shrink in size and eventually become externalized to low-income countries. This happened, for example, with the metallurgic sector in many European countries (Gualteri, 2015). The analysis of these dynamics using the variable EJPi makes it possible to establish a bridge between biophysical and economic analysis providing specific information on the (lack of) capacity of generating employment in the various sectors and subsectors considered.

3.2 System description: hierarchical organization of relevant economic sectors and subsectors

In order to study the relation between the mix of energy carriers and the mix of end uses useful for characterizing internal constraints, we need to establish a taxonomy of expected tasks/functions for the various specialized compartments of society. For this purpose, the metabolic pattern of the whole society is represented as the sum of the metabolic patterns expressed by its various functional compartments defined across different hierarchical levels. Then available data should be organized identifying the structural elements that within the socio-economic systems are used to express the functions defined in the taxonomy. This distinction between functional and structural elements is essential to define the level of openness of the economy. In fact, not necessarily does a functional compartment – the sub-sector producing iron and steel, or the agricultural sector – cover exactly the requirement of the country. Imports and exports are often used to handle the mismatch between the requirement of a specific typology of goods and services consumed by an economy and their domestic supply. Therefore, when defining a taxonomy of functional compartments, we are describing the organization of the various activities that are required to stabilize the pattern of production and consumption of a given set of goods and services in a society. Then using this taxonomy, we can identify the structural elements expressing the functions in a given geographic entity defined by specified boundaries. In this way, we can observe the activities generating the internal supply of the considered set of goods and services. Whenever the internal supply exceeds the internal consumption the socio-economic system has the option to export, whenever the internal supply does not cover the internal consumption the socio-economic system must import the missing quantities.

Therefore, scaling across hierarchical levels of organization of a social-ecological system (such as the economy) requires: (i) a semantic description of relevant compartments – to identify the functional elements; (ii) a definition of the boundaries of the system – to identify the structural elements; (iii) the relations across hierarchical levels of organization over the different metabolic characteristics of compartments and sub-compartments defined at different levels. In turn, this last step requires:

1. Defining the set of compartments, i.e. sectors and subsectors associated with end-uses. The size of the fund and flow elements accounted as belonging to the chosen compartments must provide closure at all levels according to the following two rules: (i) the sizes of the parts of an element defined at a given level must be equal to the size of the element containing the parts at the higher level; (ii) the definition of the size of the compartments is mutually exclusive (no double counting);
2. The data required to define both the size and the characteristics of individual compartments – in the structural view - must be amenable to the data provided by the subdivisions practiced in national statistics.

When I define a taxonomy of a function I select the country level as my focal level (level n). I then define within this 'whole' a set of lower-level compartments:

Level n: the whole country (the socio-economic system)

Level n-1: Paid Work (PW), Household (HH);

Level n-2: Energy and Mining (EM), Agriculture forestry and fishing (AF), Manufacturing and Construction (MC), Services and Government (SG);

Level n-3: (i) inside EM - Energy Sector (Energy, Mining and Quarrying for non-energy use (MQ); (ii) inside AF - Agriculture and Forestry (AFO), Fishing (FI); (iii) inside MC - Iron and Steel (IS), Non-ferrous Metals (NF), Chemicals and petrochemicals (CP), Non-metallic minerals (NM), Food and tobacco (FT), Textiles and leather (TL), Pulp, paper and print (PPP), Transport Equipment (TL), Machinery (Ma), Wood and Wood Products (WWP), Construction (Co), Non-specified-Industry (NS); (iv) inside SG - Services and government minus transport (SG_nTS), Transport Sector (TS).

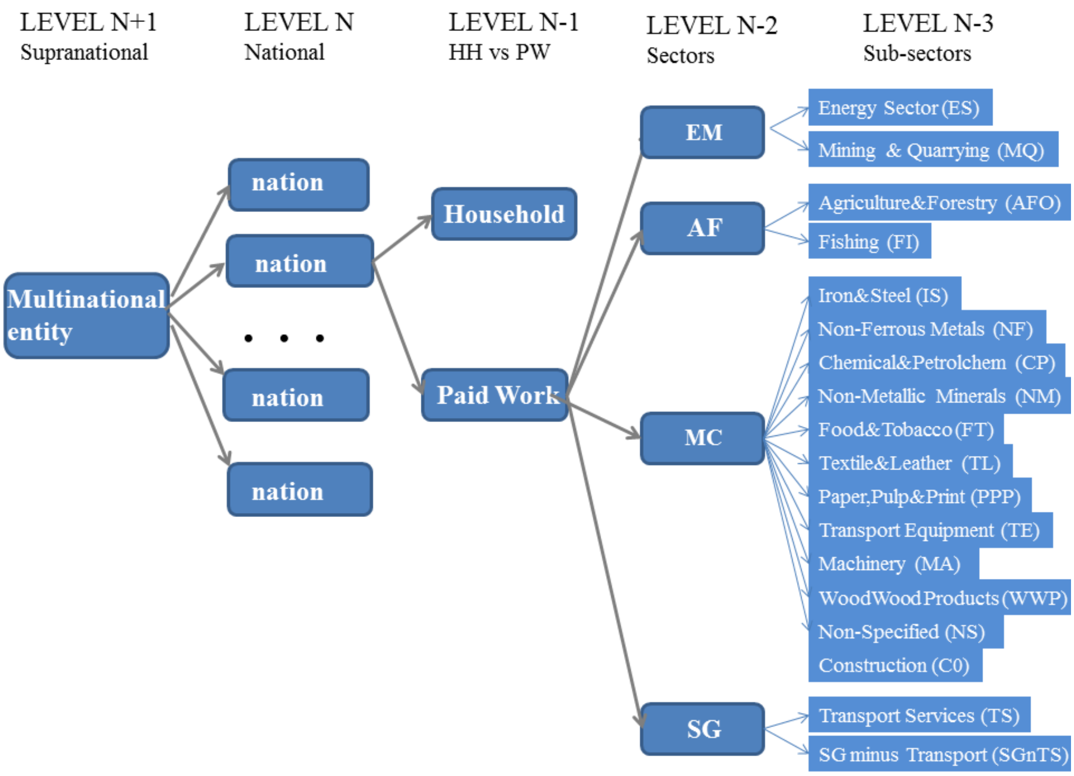


Figure III-3 The different hierarchical levels of analysis at which metabolic elements are defined

Then this generic taxonomy based on a definition of functional levels of organization should be applied to identify structural elements. As a matter of fact, for reasons of data availability, I will generate two distinct sets of multi-level end use matrices using the taxonomy illustrated in Figure III-3 The different hierarchical levels of analysis at which metabolic elements are defined. In the first application, I will consider the multinational entity as EU27+Norway (this implies considering 28 national levels represented by 27 EU countries plus Norway). In the second application, I will consider the multinational entity as EU22 (considering only 22 countries for the national level).

Another important observation to be made here is that in this way we can compare the metabolic characteristics of the various sectors and subsectors (defined at level n-1, n-2, and n-3) to:

(i) the metabolic characteristics of the other compartments in the same country – how the metabolic characteristics of the Energy and Mining (or Textile and Leather) of

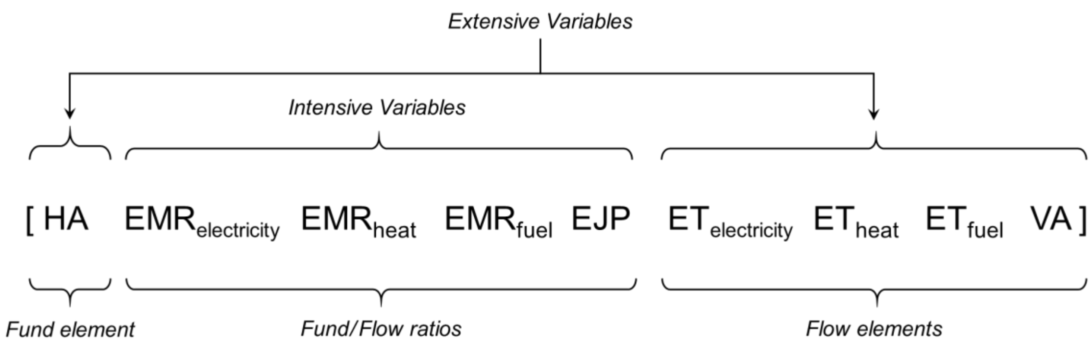
France compare with the average metabolic characteristics of other sectors of France;

(ii) the metabolic characteristics of homologous compartments in different countries – how the metabolic characteristics of the Energy and Mining (or Textile and Leather) of France compare with the analogous compartments in Germany or Finland

(iii) the metabolic characteristics of the same set of compartments included in the taxonomy calculated, this time, using the aggregated end use matrix of the supranational entity (e.g. EU27 + Norway). This higher-level end use matrix can be used to provide reference values referring to the typology of metabolic pattern of the considered group of similar socio-economic systems.

3.3 Data-arrays describing the metabolic characteristics of end-uses

Unlike in the previous chapter and many previous MuSIASEM applications where energy is expressed in just one unit (Gross Energy Requirement in virtual thermal equivalent units) this chapter is based on the adoption of a protocol used for characterizing energy metabolic rates in relation to different energy carriers' qualities (see Figure III-2). The advantages of this more elaborated disaggregation are described in Giampietro et al. 2013. For doing so, I characterize the metabolic characteristics of end-use sectors using the following data array (defined in relation to quantities calculated on a year basis):



Where:

- HA - Human activity (fund) allocated in the form of jobs to the end-use, measured in hours (h).
- ET_i - Amount of energy throughput metabolized in the form of energy carrier *i* by the end-use, where *i* is either electricity, heat or fuel, measured in joules (J);
- VA – Value Added generated by the end-use, measured in euros (€);
- EMR_i – Energy Metabolic Rates: the amount of energy carrier *i* metabolized per hour of work allocated to the end-use, measured in joules of EC_i per hour (J/h) different for the different typologies of energy carrier. This value is obtained by dividing a quantity of energy per year by a number of hours per year (referring to the same year);
- EJP – Economic Job Productivity: the value added (VA) generated per hour of work allocated to the end-use, measured in euros per hour of work (€/h). This value is obtained by dividing a quantity of VA per year by a number of hours per year (referring to the same year).

3.3.1 Scaling extensive Indicators: HA, ETs, VA

As already mentioned in the previous chapter and in accordance with Georgescu-Roegen's flow-fund scheme (Georgescu-Roegen, 1975), human activity (HA) is defined as a fund element, whereas energy throughputs (ETs) and value added (VA) are flow elements. All of them are extensive variables and can be used to characterize the size (weight) of the end-use. The impredicative relationships among flows (e.g. ETs) and funds belonging to the four levels can thereby expressed as follows:

$$\boldsymbol{TET(n) = ET_{PW}(n-1) + ET_{HH}\,(n-1)} \qquad (4)$$

$$\boldsymbol{TET(n) = [ET_{AF}(n-2) + ET_{EM}\,(n-2) + ET_{MC}\,(n-2) + ET_{SG}\,(n-2)] + ET_{HH}\,(n-1)}$$

$$\begin{aligned} \boldsymbol{TET\ (n)} = [&\boldsymbol{ET_{AFO}(n-3)} \\ &+ \boldsymbol{ET_{FI}(n-3)} + \boldsymbol{ET_{ES}\ (n-3)} \\ &+ \boldsymbol{ET_{MQ}\ (n-3)} \\ &+ \boldsymbol{ET_{IS}\ (n-3)} + \boldsymbol{ET_{NS}\ (n-3)} \\ &+ \boldsymbol{ET_{CP}\ (n-3)} + \boldsymbol{ET_{NM}\ (n-3)} \\ &+ \boldsymbol{ET_{FT}\ (n-3)} + \boldsymbol{ET_{TL}\ (n-3)} \\ &+ \boldsymbol{ET_{PPP}\ (n-3)} + \boldsymbol{ET_{TE}\ (n-3)} \\ &+ \boldsymbol{ET_{Ma}\ (n-3)} + \boldsymbol{ET_{WWP}\ (n-3)} \\ &+ \boldsymbol{ET_{Co}\ (n-3)} + \boldsymbol{ET_{NS}\ (n-3)} \\ &+ \boldsymbol{ET_{SG\_nTS}\ (n-3)} + \boldsymbol{ET_{TS}\ (n-3)}] \\ &+ \boldsymbol{ET_{HH}\ (n-1)} \end{aligned} \tag{5}$$

In the case of the supranational entity (level n+1), the values and their relations in the equations are constructed summing the extensive variables (quantities per year) of the countries included in the definition (EU22 and EU27+N in this case) for each of the sectors and subsectors. The intensive variables – EMRi and EJP – are then assessed by calculating the ratio over the two quantities per year.

3.3.2 Intensive Indicators: EMRs and EJP

Dividing flow by fund elements, we obtain the intensive variables EMRi and EJPi. Energy metabolic rates (EMRi) are calculated for each of the energy carriers: electricity, heat and fuel. As explained above, this strategy allows conserving valuable information about the quality and quantity of energy throughput in the form of different carriers metabolized in each end-use. The indicator of economic job productivity (EJPi) is a neologism introduced in the jargon of MuSIASEM and therefore it requires an explanation. This indicator represents the value added generated in a given end-use sector per hour of work required in that compartment. In past applications of MuSIASEM this indicator was called economic labor productivity (ELP, see the study in Chapter II). The change in the label follows a change in the logic of accounting introduced in the new generation of MuSIASEM analysis (what in jargon is called MuSIASEM 2.0). In the new logic, the accounting explicitly separates the characterization of functional elements (the identity of a job that is determined from what is expected by the context from the worker performing the job) from structural elements (the identity of the structural element – the worker – that is fulfilling the required role). This distinction makes it possible to have, in the future, more detailed end-use matrices. For example, the labor input can be divided in hours of work in high qualified jobs and in low qualified jobs. Put in another way, by using the term 'economic job productivity' we want to indicate that by adding additional categories of accounting we can handle qualitative aspects of human labor. In fact, not all working hours are the same, in the sense that depending on the type of job we can associate to it an expected requirement of investment of energy carriers and technological capital that in turn may imply a different requirement of know-how from the worker. For this reason, in the new generation of MuSIASEM studies end-use matrices are expected to be able to handle different categories of jobs (e.g., type of skills) in the same way as I have done for energy carriers.

Being intensive variables, EMR_{ij} (where *i* is the index identifying the type of energy carrier and *j* the index referring to the compartment) and EJP_j provide benchmark values; they characterize the metabolic characteristics of a specific typology of end-use independently of its size. Therefore, EMR_{ij} and EJP_j allow a comparison of the characteristics of analogous end-uses across countries, regions or sub-sectors with different sizes of the population and work force. For instance, we can compare the electricity throughput and value added per hour of work in the textile and leather sub-sector between Germany and Greece.

The information in the data array is purposely redundant (the intensive variables can be obtained by dividing the extensive variables by the fund element HA and, likewise, the extensive variables by multiplying the intensive variables by the fund element HA). It is exactly the redundancy in this information space that allows the scaling of information referring to specific compartments within the hierarchical structure of the system (Giampietro and Mayumi, 2000b).

The relations over EMR_{ij} can be defined according to the following equation:

$$\boldsymbol{EMR_{SA}(n)} = \frac{\boldsymbol{TET(n)}}{\boldsymbol{THA(n)}} = \frac{\boldsymbol{ET_{PW}(n-1) + ET_{HH}(n-1)}}{\boldsymbol{HA_{PW}(n-1) + HA_{HH}(n-1)}} = \dots \quad (6)$$

$$EMR_{AF}(n-1) = \frac{ET_{AF}(n-1)}{HA_{AF}\,(n-1)}$$

$$= \frac{TET\,(n) - \ ET_{PW}(n-1) + \ ET_{HH}(n-1)}{THA\,(n) - HA_{PW}(n-1) + \ HA_{HH}(n-)} = \cdots$$

The simultaneous accounting of: (a) size; and (b) throughput (defining a resulting value the pace of the flow per unit of size); for both parts and wholes within a nested metabolic system, translates into the establishment of a double system of mapping for the size of these parts and wholes. That is, we can define the size of parts and whole in two non-equivalent ways: (1) as perceived from within the black-box at the local scale (the relation over the intensive variables used to establish relations within the multi-level end use matrix); (2) as perceived from within the black-box at the large scale when looking at the inputs and outputs from/to the environment (the exchange of flows with the context).

As already pointed out, the quantitative analysis of social-ecological systems always demands the simultaneous consideration of multiple space-time scales and multiple dimensions of analysis. Thus, in the following section and next chapter the data-arrays for each analyzed country will be presented for each level. The data array includes multiple indicators and it is organized as shown in Table III-1:

Table III-1 Data array describing the indicators used in the analysis

Compartment of reference	HA (h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (€)	%HA_compartment/ HA_Supracompartment	% VA_compartment/ VA_Supracompartment	EEI (MJ/€)

Where:

- the 'compartment of reference' is the analyzed country and/or sector and/or sub-sector – this could the whole country, the whole sample of EU countries or a given sector or subsector – e.g. paper, pulp and print;
- HA_i is the fund element 'Human Activity' expressed in hours per year;
- EMR_elec$_i$, EMR_heat$_i$, EMR_fuel$_i$, expressed as MJ per hour of HA per year, are the fund/flow ratios 'Energy Metabolic Rates' referring to the energy carriers throughput electricity, heat and fuel, respectively,

- EJP_j, expressed as € per hour of HA per year, is the flow/fund ratio 'Average Productivity in relation to the Fund Element';
- ET_elec_j, ET_heat_j, ET_fuel_j, expressed as PJ per year, are the flow elements, i.e. Energy Throughput metabolized in form of Energy Carriers (Electricity, Heat and Fuel);
- VA_j, expressed as € per year, is the flow element 'Gross Value Added in monetary terms';
- %(HA_ compartment/HA_supra-compartment) is the proportion of labor allocated in each compartment in relation to the supracompartment of reference (e.g. %ha in industry over paid work in Bulgaria);
- %(VA_sub-compartment/VA_supra-compartment) is the proportion of VA generated in each compartment in reference to the supracompartment;
- EEI, expressed as MJ per € over a given year, is the Economic Energy Intensity Indicator, that is the ratio between ET (Energy Throughput) and VA (Value Added), widely used as index for assessing energy efficiency. The energy value of this coefficient is calculated here as virtual Joules thermals of Primary Energy Source (normally expressed in Tons of Oil Equivalent). In MuSIASEM, this is called Gross Energy Requirement (GER). This value is obtained by adopting the Partial Substitution Method (i.e. multiplying J of electricity by 2,61, heat by 1,1 and fuel by 1,38 – considering the average values for Spain 2003) (Giampietro, Mayumi and Sorman, 2013). The use of an aggregation method to assess an overall input of energy carriers (only for the calculation of the EEI indicator) does not affect in any case the elements of my critique as we will see afterwards.

It should be noted that the energy distribution losses are not considered in this analysis. They would decrease the GER value and the energy consumed by the Energy Sector in relation to other studies that analyze the relation between PES and EC. In this way, I am allocating the burden of the losses to the consumption of the energy sector. However, this issue does not affect the main goal of my analysis – studying the relation between EC-EU - except for the case of the characterization of the Energy Sector, as I will discuss in section 4.1.

3.3.3 Data representation: normalized chromatic intensity

While keeping data disaggregated is essential to preserve valuable information (e.g., the distinction between different typologies of energy carriers), the consequent proliferation of data records represents a challenge for the visualization of the quantitative characterization. I therefore use Normalized Chromatic Intensity (NCI) to help the reader in quickly detecting patterns in the data through gradients in color intensity. The generation of NCI for intensive variables (EMRs and EJP) is obtained in three steps: first, identifying the maximum and minimum values for each indicator over the set of data; second, calculating the range of values for each indicator (difference between maximum and minimum value of the series); and third, assigning proportional intensities of color for the intermediate values in relation to its normalized distance to the extremes of the interval (maximum intensity of the color for maximum values and no-color for minimum values). In this way, I obtain a chromatic visualization of the differences, helping with pattern recognition and with the detection of outliers in the data set.

3.4 Data sources and main assumptions

Data on hours worked and gross value added presented in section 4.2 are from National accounts aggregates by industry (up to NACE A*64) (nama_10_a64) (Eurostat, 2015e), while data presented in Sections 4.1 and 4.3 are from Annual detailed enterprise statistics for industry (sbs_na_ind_r2) (Eurostat, 2015b) and construction (sbs_na_con_r2) (Eurostat, 2015a) also provided by Eurostat (V16150 Number of hours worked by employees for HA and V12150: Value added at factor cost for VA). Due to the different methodologies of collecting data in these two sources, comparisons between the benchmarks presented in these sections (4.2 versus 4.1 and 4.3) are not reliable. This certainly represents a problem. However, within each one of the set of assessments the comparison can be done. The goal of this exercise is to illustrate the importance of multiscale analysis when dealing with the characterization of the performance of the metabolic pattern of modern societies in relation to the characteristics of its sectors and subsectors.

The Human Activity at Households (level n-1) is calculated as the difference between: (i) the total number of hours of human activity for the whole society - THA: number of people (Eurostat, 2015c) × 8.760 (hours of human activity in a year); and (ii) the working hours (PW) calculated from statistical data.

$$HA_{hh} = THA - HA_{pw} \tag{7}$$

Missing data in human activity (e.g. in the AF sector) were imputed by multiplying the numbers of full-time equivalent (FTE) workers from *Agricultural Labour Input Statistics* (aact_ali01) (Eurostat, 2015e) by the working hours in a year (working days/yr * full-time working hours/day). These values were further checked against the working hours data available in the National Account.

NOTE: FTE is equal to the ratio of the total number of paid hours during a period (part time, full time, contracted) by the number of working hours in that period Mondays through Fridays. The ratio units are FTE units or equivalent employees working full-time. In other words, one FTE is equivalent to one employee working full-time (*Business Dictionary*, no date).

Data on energy use are from Eurostat Energy Balances (Eurostat, 2015c). Energy throughputs are presented in the form of Energy Carriers. Unfortunately, as already discussed there is no perfect way to aggregate different kinds of energy forms into a single number. Therefore, I present a protocol capable of mapping how different end uses require different mixes of energy carriers to be reproduced. To do this, I group the long list of energy carriers in three broad categories explained in section 2.2: electricity, heat and fuel. In Table III-2 I present the operationalization of this protocol with the national energy balance from Eurostat. Missing data for some energy products were imputed by extrapolation considering time trends.

Table III-2 Aggregation of the different forms of the energy carriers electricity, heat, and fuel reported in the Energy Balances of Eurostat with their Eurostat codes (Eurostat, 2015c)

Electricity	Electricity	6000
Heat	Hard coal and derivatives	2100
	Lignite and derivatives	2200
	Oil Shale and Oil Sands	2410
	Refinery gas	3214
	Ethane	3215
	Liquified petroleum gas (LPG)	3220
	Total Fuel Oil	3270A
	Petroleum Coke	3285
	Gas	4000
	Solar thermal	5532
	Solid biofuels (excluding charcoal)	5541
	Biogas	5542
	Municipal waste (renewable)	55431
	Charcoal	5544
	Geothermal	5550
	Waste (non-renewable)	7200
Fuel	Gasoline (without biofuels)	3234
	Aviation Gasoline	3235
	Other Kerosene	3244
	Gasoline Type Jet Fuel	3246
	Kerosene type jet fuel (without biofuels)	3247
	Gas/diesel oil (without biofuels)	3260
	Liquid biofuels	5545

Energy consumption in the household sector has been calculated by summing residential consumption (from the Eurostat Energy Balances (Eurostat, 2015c)) and fuel consumption by private cars (hypothesis: 80% of the total fleet) and motorcycles (hypothesis: 90% of the total fleet). The fuel consumption of private cars has been estimated by multiplying the kilometers per year traveled by vehicles on national territory (Eurostat, 2012) and the average fuel consumption (The International Council on Clean Transportation (ICCT), 2016), taking into account the average age of the EU car fleet (European Automobile Manufacturers Association, 2017), the liters per ton and gross calorific value of gasoline and diesel fuels (OECD/IEA, 2005), while for motorcycles I simply assumed a consumption of 5 l/100km. Having calculated the fuel consumption in private cars and motorcycles (HH), this value has been subtracted from energy use in the Transport Sector (Land Transport).

All these data have been aggregated bottom-up-wise as shown in Table III-2 Aggregation of the different forms of the energy carriers electricity, heat, and fuel reported in the Energy Balances of Eurostat with their Eurostat codes *(Eurostat, 2015c)*to mostly match the categorization from the Energy Balances following the NACE Rev. 2 classification as its metadata establish (Eurostat, 2008a). The definition of sectors and subsectors matches this categorization with the one presented in section 3.2 in order to operationalize the multiscale accounting. I have carried out two rearrangements: (i) human activity accounted in the Households (HA_{hh}), which is accounted as the difference between THA (total population x 8760) minus HA_{pw}); (ii) the energy carriers consumed by private vehicles reallocated in household sector instead than in transport one (this represents transport with a command and control declared as an economic activity generating value added).

Note that the category of Mining and Quarrying in Table III-1 only considers mining of metal ores and quarrying of raw material other than primary energy sources, as well as their supporting activities (NACE categories B7, B8 and B9.9). Mining of coal and lignite (B5), extraction of crude petroleum and natural gas (B6) and support activities for petroleum and natural gas extraction (B9.1) are included in the Energy Sector (ES).

3.5 Selection of the countries used in the case studies

Part of the work presented in this and in the next chapters are part of a comprehensive study of energy efficiency in the EU within the context of the EU project EUFORIE (*European Futures for Energy Efficiency (EUFORIE). Horizon2020 Research and Innovation Programme*, 2015). The study includes EU27, which consists of Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovak Republic, Slovenia, Spain, Sweden and the United Kingdom, in the level n, n-1 and n-2.

Conversely, in the level n-3, the study comprises the 'EU22', which consists of the member countries of the European Union, apart from Cyprus, Denmark, Estonia, France, Luxembourg, Malta and Slovenia (excluded because of lack of required data for the analysis) and the addition of Norway (included as an example of a "quasi-EU country" with a large production of oil).

In this chapter, however, I focus only on the methodological aspects of the assessment of energy intensity, and for this purpose I single out three countries, Bulgaria, Finland and Spain (in chapter 4 I will present all the outputs, here the EU22 values are just used for illustrating the values of the upper lever in the Industrial level). I selected these countries because of their markedly different characteristics: Finland represents a wealthy country with an abundant endowment of natural resources. The exploitation and export of such resources requires considerable energy consumption. Spain represents an EU country with a limited endowment of natural resources and a fair level of economic development. Bulgaria only recently accessed the EU and represents an economy that is still struggling to improve its level of development to the European average.

4 Results

In this section, I present the results of my analysis of the bioeconomic performance of the industrial sectors of Bulgaria, Finland and Spain; and at the European context.

In Table III-4, I show the bioeconomic performance of the industrial sector as a whole (level n-1) for Bulgaria, Finland and Spain, using a data array that characterizes the end uses of flows and fund elements in this sector. The bioeconomic performance of the industrial sector of the EU22 (end-use data array calculated at level *n+1*) is also listed for reference. Scaling up national data to the EU22 level is useful to obtain more robust benchmark values for the industrial sector in the European context.

To scale up, I sum the extensive variables (HA, ETs and VA) of the national industrial sectors making up the EU-22 and then obtain the corresponding ratios by dividing by the total HA_{BM} of the EU-22. The data array shown in Table III-4 ([61 107 12] MJ/h and 33 €/h) can be used for internal comparison with national industrial sectors (inside Europe) or for external comparisons with analogous data referring to other world regions.

Table III-3 Correspondence between database categorization of economic activities for Energy Balance (Eurostat, 2015c) *and hours of work (human activity) and value added (NACE Rev.2)* (Eurostat, 2008b)

Codes	Energy Balance Data Categorization (IEA & Eurostat)	Human Activity and Value Added Data Categorization (NACE Rev. 2 Divisions)
HH	Residential	Human Activity is calculated in this study as THA-HA_pw
ES	Energy Sector	B5 - Mining of coal and lignite
		B6 - Extraction of crude petroleum and natural gas
		C19 - Manufacture of coke and refined petroleum products
		D35 - Electricity, gas, steam and air conditioning supply
AFO	Agriculture and Forestry	A1 - Crop and animal production, hunting and related service activities
		A2 - Forestry and logging
FI	Fishing	A3 - Fishing and aquaculture
IS	Iron and Steel	C24.1 - Manufacture of basic iron and steel and of ferro-alloys
		C24.2 - Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
		C24.3 - Manufacture of other products of first processing of steel
		C24.5.1 - Casting of iron
		C24.5.2 - Casting of steel
NF	Non-Ferrous Metals	C24.4 - Manufacture of basic precious and other non-ferrous metals
		C24.5.3 - Casting of light metals
		C24.5.4 - Casting of other non-ferrous metals
CP	Chemical and Petrochemical	C20 - Manufacture of chemicals and chemical products
		C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations
NM	Non-Metallic Minerals	C23 - Manufacture of other non-metallic mineral products
MQ	Mining and Quarrying	B7 - Mining of metal ores
		B8 - Other mining and quarrying
		B9.9 - Support activities for other mining and quarrying
FT	Food and Tobacco	C10 - Manufacture of food products
		C11 - Manufacture of beverages
		C12 - Manufacture of tobacco products
TL	Textile and Leather	C13 - Manufacture of textiles
		C14 - Manufacture of wearing apparel
		C15 - Manufacture of leather and related products
PPP	Paper, Pulp and Print	C17 - Manufacture of paper and paper products
		C18 - Printing and reproduction of recorded media
TE	Transport Equipment	C29 - Manufacture of motor vehicles, trailers and semi-trailers
		C30 - Manufacture of other transport equipment
Ma	Machinery	C25 - Manufacture of fabricated metal products, except machinery and equipment
		C26 - Manufacture of computer, electronic and optical products
		C27 - Manufacture of electrical equipment
		C28 - Manufacture of machinery and equipment n.e.c.
WWP	Wood and Wood Products	C16 - Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials
Co	Construction	F - Construction
NS	Non-specified (Industry)	C22 - Manufacture of rubber and plastic products
		C31 - Manufacture of furniture
		C32 - Other manufacturing
SG_nTS	Services	C33, 36, 37, 38, 39, 45, 46, 47, 52, 53, 55, 56, 58, 59, 60, 61, 62, 63, 64, 65, 66, 68, 69, 70, 71, 72, 73, 74, 75, 77, 78, 79, 80, 81, 82, 84 (excluding Class 8422), 85, 86, 87, 88, 90, 91, 92, 93, 94, 95, 96 & 99
TS	Transport	H49 - Land transport and transport via pipelines
		H50 - Water transport
		H51 - Air transport

As regards the internal comparison, I can analyze the various national industrial sectors in relation to the EU industrial cluster (data arrays calculated at levels *n-1* versus *n+1*) by looking at: (i) intensive variables (performance of processes, unitary values), and (ii) extensive variables (considering the size of the processes). For instance, as shown in Table

III-4, the industrial sector of Bulgaria shows poor performance within the European context with a vector of EMR_i of [29 51 3,4] MJ/h and an EJP of only 6 €/h. The Spanish industrial sector displays a metabolic pattern that is similar to the average European benchmarks, [61 129 13] MJ/h and 31 €/h, while Finland stands out well above the European average with [187 294 47] MJ/h and 44 €/h. Regarding size, we can deduct from Table III-4 that the industrial sector of Spain is a significant contributor to the European industrial sector, both in terms of labor time (7,9%) and value added (7,5%). We also see that the Finnish industry generates more value added for Europe than Bulgaria (VA contribution 1,8% versus 0,35%) with less labor hours (HA contribution 1,4% versus 1,9%).

Table III-4 Metabolic characteristics of the industrial sector as a whole of Bulgaria, Finland, Spain, and the EU22. The classic economic energy intensity (EE I) is listed for comparison only. Energy consumption for calculating the EEI is expressed in joules equivalent of gross energy requirement following the protocol of (Giampietro, Mayumi and Sorman, 2013)

Industry 2012	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9€)	%HA_BM/ HA_BM_EU22	%VA_BM/ VA_BM_EU22	EEI (MJ/€)
Europe	54	X	61	107	12	33	=	3.304	5.766	660	1.763	100%	100%	9
Bulgaria	1,0		29	51	3,4	6		30	53	3,5	6,2	1,9%	0,35%	23
Finland	0,74	X	187	294	47	44	=	137	216	35	32	1,4%	1,8%	20
Spain	4,3		61	129	13	31		261	551	57	132	7,9%	7,5%	10

Table III-4 also shows that looking only at the economic energy intensity (EEI) can be misleading at this level of analysis. For instance, while the EEIs of Bulgaria and Finland are more or less the same (23 and 20 MJ/€ respectively), they display a markedly different metabolic pattern, with the energy throughputs and value added per hour of labor in the Finnish industry being markedly higher than in Bulgaria. Indeed, as demonstrated in earlier studies (Giampietro, Mayumi and Sorman, 2012; Fiorito, 2013), because of a strong correlation between the total energy consumption and the GDP, one can find clusters of countries with very similar values of EEI but completely different levels of technological efficiency (Fiorito, 2013). In order to understand the relation between technological characteristics, economic performance, and energy and carbon intensity we have to open the black-box and move to lower hierarchical levels of analysis.

4.1 Bioeconomic performance of the main economic sectors at the national level

In this section, I examine the bioeconomic performance of the main economic sectors at the national level: the agricultural sector (AG), the energy sector (ES), the industrial sector (BM), the transport sector (TS), service and government (SG), and the household sector (HH). At this level, one can compare the performance of the various economic sectors within selected national economies, as well as selected economic sectors among various national economies. As mentioned earlier, given the different methodology of collecting data on hours worked between National Accounts (NA) used in this section and Structural Business Statistics (SBS) used in the other sections, comparisons among values of EMR or EJP have to be done with extreme caution (a difference of around 30% may be found).

As can be seen from Table III-5, Table III-6 and Table III-7, Bulgaria, Finland and Spain display a similar metabolic pattern in that the energy sector has the highest metabolic rate of electricity (EMRelec) and heat (EMRheat), and the transport sector the highest metabolic rate of fuel (EMRfuel). This is to be expected given that the energy sector is mainly powered by big machinery controlled by few hands (power plants, refineries, liquefaction and regasification plants, etc.), whereas the power capacity in the transport sector mainly consists in fuel converters (cars, motorcycles, trucks, airplanes). In addition, I should underlie that I do not considered distribution losses. When analyzing the relation between PES and EC, losses can be interpreted as a “virtual” consumption of the Energy Sector. Electricity is where there are more distribution losses. The relative balance between the electricity directly consumed by the energy sector and the losses in distribution is respectively: Bulgaria 41%-59%, Spain 41%-59% and Finland 58%-42%. The importance of losses is much lower when considering heat: Bulgaria 96%-4%, Spain 97%-3% and Finland 92%-8%. Distribution losses are negligible for fuel products.

Comparing metabolic patterns among countries, we find that Finland is the country with the highest overall metabolic rates ([6,4 7,0 6,0] MJ/h) at the level of the entire society. A cross-country comparison among the metabolic rates of the household sectors (level n-1) can give us an indication of the relative material standard of living (levels of consumption at the household level, outside of working hours). Electricity (EMRelec) and heat

(EMRheat) metabolic rates are the same (around 0,7 and 0,8 MJ/h, respectively) for Bulgaria and Spain, despite the colder winters in Bulgaria, but much higher for Finland (1,9 and 1,4 MJ/h, respectively). Different consumption of fuels (EMRfuel) between Bulgaria and Spain (0,34 versus 1,1 MJ/h) may reflect less cars per capita (0,4 versus 0,5) and km/vehicle/year (3.500 versus 8.900) in Bulgaria than in Spain. The difference with Finland is even more marked (EMRfuel=2,8 MJ/h) with almost 0,6 cars per capita and more than 15,000 km/vehicle/year (Eurostat, 2015g). Regarding the metabolic rates of the productive sectors, Finland has again the highest values with the exception of EMR values in TS and EMRheat in ES and SG, suggesting that it has on average the highest levels of mechanization or technological capitalization in its economic sectors (Giampietro, Mayumi and Sorman, 2012). The transport sector of Bulgaria deserves special mention. It presents the highest EMRheat (82 MJ/h) due to the large amount of natural gas consumed in pipeline transport (Eurostat, 2015c).

As regards the economic job productivity (EJP)[5] the three countries present a similar metabolic pattern: the highest EJP is found in the energy sector followed by the industry and service & government sectors, and the transport sector. The agricultural sector exhibits the lowest economic job productivity. This metabolic pattern is consistent with the general pattern in Europe (Giampietro, Mayumi and Sorman, 2012). Finland presents the highest EJP in all sectors, surpassed by Spain only in the energy sector (145 versus 176 €/h). Bulgaria lags behind in all sectors and its economy shows low competitiveness when comparing its EJP values with those of Finland and Spain. The low EMR values in the Bulgarian economic sectors could explain this fact, assuming that EMRs are a proxy of mechanization. Nonetheless, this cannot explain why the EJPs of Spain and Finland are quite similar despite the EMR values of Finland being about 3 times those of Spain. Understanding this difference requires us to open the 'black-box' of the industrial sector and examine the pattern of energy use at a lower level of analysis.

[5] The VA and EJP data reported in this section are only comparable between Tables 4, 5 and 6, but not with the tables in other sections of the chapter as they are obtained from a different database that uses another definition. Namely, for this section the EJP is calculated from the *Gross Value Added at basic prices* and *Total employment domestic concept* from the National Accounts (nama_nace10) facilitated by Eurostat (Eurostat, 2015d)

Table III-5 The metabolic pattern of the main economic sectors of Bulgaria. Data refer to 2012.

Bulgaria 2012	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA_sec/HA_AS	%GVA_sec/GVA_AS	EEI (MJ/€)
Average Society (AS)	64	x	1,9	2,3	1,7	0,6	=	122	147	112	36	100%	100%	18
Agriculture (AG)	0,97	x	1,0	1,4	5,8	2,0	=	0,97	1,4	5,6	1,9	1,5%	5,3%	6,1
Energy Sector (ES)	0,10		223	133	8,4	26		22	13	0,84	2,6	0,16%	7,1%	29
Building & Manufacturing (BM)	1,3		22	40	2,6	5,8		30	53	3,5	7,7	2,1%	21%	18
Transport (TS)	0,33		3,3	82	249	6,5		1,1	27	81	2,1	0,51%	5,9%	68
Services & Government (SG)	2,9		10	2,7	0	7,4		29	7,8	0,99	22	4,6%	60%	4,0
Household (HH)	59		0,67	0,77	0,34	0		39	45	20	0	91%	0%	-

Table III-6 The metabolic pattern of the main economic sectors of Finland. Data refer to 2012.

Finland 2012	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA_sec/HA_AS	%GVA_sec/GVA_AS	EEI (MJ/€)
Average Society (AS)	47	x	6,4	7,0	6,0	3,6	=	305	333	283	172	100%	100%	9,0
Agriculture (AG)	0,26	x	21,5	36	67	18	=	5,7	9,6	18	4,7	0,6%	2,7%	11
Energy Sector (ES)	0,037		387	1.142	58	145		14	43	2,2	5,4	0,1%	3,1%	16
Building & Manufacturing (BM)	0,97		142	223	35,8	41		137	216	35	40	2%	23%	16
Transport (TS)	0,26		10	1,9	367	34		2,7	0,50	96	8,9	0,6%	5,2%	16
Services & Government (SG)	2,7		24	1,9	4,5	43		64	4,9	12	114	5,6%	66%	1,7
Household (HH)	43		1,9	1,4	2,8	0		81	59	121	0	91%	0%	-

Table III-7 The metabolic pattern of the main economic sectors of Spain. Data refer to 2012.

Spain 2012	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA_sec/HA_AS	%GVA_sec/GVA_AS	EEI (MJ/€)
Average Society (AS)	410	x	2,2	3,1	4,0	2,3	=	914	1.275	1.625	954	100%	100%	6,3
Agriculture (AG)	1,5	x	9,9	21	47	16	=	14	31	68	24	0,36%	2,5%	6,9
Energy Sector (ES)	0,18		352	1.617	50	176		64	292	9,0	32	0,04%	3,3%	16
Building & Manufacturing (BM)	5,9		44	94	9,7	32		261	551	57	187	1,4%	20%	7,3
Transport (TS)	1,5		11	4,2	670	29		16	6,4	1.005	43	0,37%	4,5%	33
Services & Government (SG)	22		13	3,6	2,3	30		289	80	52	668	5,4%	70%	1,4
Household (HH)	379		0,71	0,83	1,1	0		270	315	434	0	92%	0%	-

4.2 Bioeconomic performance of industrial subsectors

In this section, I examine the industrial sector in detail. To this purpose, I construct a matrix formed by 13 data arrays that characterizes the metabolic pattern of the various sub-sectors (end-uses) for each country (Table III-8, Table III-9 and Table III-10). Structuring the data in this manner we can easily compare the metabolic performance among the various industrial subsectors (level *n-2*) making up the industrial sector within each country. We thus obtain a better understanding of: (i) the size and the proportion of the subsectors/end-uses composing the industrial sector, and (ii) the metabolic rates characterizing each of these subsectors/end-uses. Indeed, looking at these tables we see important differences among industrial subsectors of a country not only between the EJPs generated by the various subsectors, but also among the EMRs both in quantitative (MJ/h) and qualitative terms (the mix of electricity, heat and fuel).

For example, in Table III-8 we see that in Bulgaria 'mining and quarrying' generates the highest VA per hour of labor (32 €/h) and 'textile & leather' the lowest one (3 €/h). The two metallurgic subsectors, 'iron & steel' and 'non-ferrous metals', have the highest EMR_{elec} (250 and 343 MJ/h) but widely different EJPs (5 versus 28 €/h). This difference does not emerge from the corresponding economic energy intensities (175 versus 40). Indeed, Table III-8, Table III-9 and Table III-10 clearly show that the energy intensity of the whole (the entire industrial sector—'All industry') is determined by two factors related to the parts: the relative size of the fund element human activity (i.e., labor time) allocated to the subsectors and the metabolic characteristics of the subsectors (the flow/fund ratios – EMRs and EJP). This information is essential for understanding the dependency of production processes on different forms of energy carriers, hours of labors and VA, as well as the relation among these factors, but completely overlooked if only considering the economic energy intensity (EEI) of the industrial sector as whole.

In Table III-8, Table III-9 and Table III-10 data organization facilitates a comparison among industrial subsectors within a country. In the alternative, we can reorganize the data to facilitate a cross-country comparison of the metabolic performance of selected subsectors. This is illustrated in Table III-11 for 'iron & steel' and in Table III-12 for 'paper, pulp & print'. In these examples, European benchmarks are used to highlight the variability in the performance of the specific subsectors considered within the European context (comparison at level n-2 versus n+1). The usefulness of this alternative visualization can be better appreciated in the next chapter, which presents this tables for all EU-22 countries and of each subsector.

Table III-8 Metabolic data arrays for the BM sector and its subsectors for Bulgaria, year 2012

Bulgaria 2012	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA_sector/HA_AS	%VA_sector/VA_AS	EEI (MJ/€)
All Industry (BM)	1.039	x	29	51	3	6	=	30	53	3,5	6,2	100%	100%	23
Iron and Steel	10		250	204	0	5		2,6	2,1	0	0,05	1,0%	0,8%	175
Non-Ferrous Metals	9,0		343	118	89	28		3,1	1,1	0,80	0,26	0,9%	4,1%	40
Chemical and Petrochemical	35		118	388	5	10		4,2	14	0,17	0,37	3,4%	5,9%	71
Non-Metallic Minerals	34		80	533	10	8		2,7	18	0,32	0,28	3,2%	4,5%	96
Mining and Quarrying	18		190	3	16	32		3,4	0,051	0,28	0,57	1,7%	9,1%	17
Food and Tobacco	156		25	33	3	6		3,9	5,1	0,49	0,95	15%	15%	17
Textile and Leather	211	x	6	4	1	3	=	1,4	0,81	0,21	0,60	20%	9,6%	7,9
Paper, Pulp and Print	29		44	256	7	6		1,3	7,5	0,20	0,19	2,8%	3,0%	64
Transport Equipment	29		14	10	0	6		0,40	0,29	0	0,17	2,8%	2,8%	7,9
Machinery	179		18	9	1	6		3,2	1,6	0,17	1,1	17%	17%	9,6
Wood and Wood Products	24		27	69	0	4		0,65	1,7	0	0,09	2,3%	1,4%	39
Construction	219		5	3	4	6		1,0	0,63	0,88	1,2	21%	20%	3,6
Non-specified Industry	85		22	7	0	5		1,9	0,62	0	0,39	8,2%	6,2%	15

Table III-9 Metabolic data arrays for the BM sector and its subsectors for Finland, year 2012

Finland 2012	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA_sector/HA_AS	%VA_sector/VA_AS	EEI (MJ/€)
All Industry (BM)	735	x	187	294	47	44	=	137	216	35	32	100%	100%	20
Iron and Steel	18		664	1.658	308	33		12	30	5,6	0,60	2,5%	1,9%	120
Non-Ferrous Metals	5,4		1.251	313	152	69		6,7	1,7	0,82	0,37	0,7%	1,1%	56
Chemical and Petrochemical	26		663	402	47	96		17	10	1,2	2,5	3,5%	7,7%	23
Non-Metallic Minerals	24		117	290	36	45		2,8	7,0	0,87	1,1	3,3%	3,4%	15
Mining and Quarrying	8,4		576	33	175	69		4,8	0,28	1,5	0,58	1,1%	1,8%	26
Food and Tobacco	56		101	50	25	44		5,7	2,8	1,4	2,4	7,6%	7,6%	8,1
Textile and Leather	9,5	x	80	21	22	39	=	0,76	0,20	0,21	0,37	1,3%	1,1%	6,8
Paper, Pulp and Print	50		1.386	3.095	61	67		69	154	3,0	3,3	6,8%	10%	106
Transport Equipment	24		43	4,0	16	35		1,0	0,09	0,38	0,83	3,2%	2,6%	4,0
Machinery	212		36	3,3	3,2	38		7,7	0,69	0,67	8,0	29%	25%	2,7
Wood and Wood Products	34		212	222	19	32		7,1	7,5	0,63	1,1	4,6%	3,4%	25
Construction	231		6	0	66	41		1,3	0	15	9,4	31%	29%	2,6
Non-specified Industry	38		36	33	81	42		1,4	1,3	3,1	1,6	5,2%	5,0%	5,8

Table III-10 Metabolic data arrays for the BM sector and its subsectors for Spain, year 2012

Spain 2012	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA_sector/HA_AS	%VA_sector/VA_AS	EEI (MJ/€)
All Industry (BM)	4.269	x	61	129	13	31	=	261	551	57	132	100%	100%	10
Iron and Steel	69		689	1.037	39	35		48	72	2,7	2,4	1,6%	1,8%	86
Non-Ferrous Metals	30		1.283	232	89	51		38	6,9	2,7	1,5	0,7%	1,1%	74
Chemical and Petrochemical	201		151	667	40	55		30	134	8,1	11	4,7%	8,3%	22
Non-Metallic Minerals	167		139	765	39	29		23	128	6,5	4,9	3,9%	3,7%	43
Mining and Quarrying	32		152	193	86	49		4,8	6,1	2,7	1,6	0,7%	1,2%	15
Food and Tobacco	603		57	72	15	32		34	43	9,2	20	14%	15%	7,6
Textile and Leather	188	x	38	34	15	20	=	7,2	6,4	2,9	3,8	4,4%	2,9%	7,8
Paper, Pulp and Print	174		107	313	26	32		19	55	4,5	5,7	4,1%	4,3%	20
Transport Equipment	286		33	20	12	39		10	5,8	3,3	11	6,7%	8,4%	3,2
Machinery	686		20	21	3,4	30		13	14	2,3	20	16%	15%	2,6
Wood and Wood Products	80		62	188	8	20		5,0	15	0,62	1,6	1,9%	1,2%	19
Construction	1.453		6	24	3	28		8,9	35	5,1	41	34%	31%	1,7
Non-specified Industry	300		66	102	21	28		20	31	6,3	8,3	7,0%	6,3%	11

As can be seen from Table III-11 and Table III-12, the metabolic rates (EMR) of the same industrial subsector can differ widely among different countries in Europe. What is particularly important in this analysis is that these differences cannot simply be attributed to different efficiencies of the technologies employed, but are mostly due to location-specific conditions. Indeed, highly specific industrial processes (e.g., cutting massive quantities of trees to produce pulp) are often only possible in particular locations (e.g. where large forests to be exploited are available). These specific situations lead to specialization of tasks/processes at the international (e.g., EU) level. For instance, in the case of pulp and paper production – a process or sub-sub-sector that is extremely intensive in terms of electricity and heat consumption (MJ/h) (the most intensive of all industrial end-uses analyzed) – the availability of an abundant supply of wood is essential.

Table III-11 Metabolic pattern of the 'iron and steel' subsector for Bulgaria, Finland, Spain and the EU-22, year 2012

Iron and Steel 2012	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA_sector/ HA_EU_AS	%VA_sector/ VA_EU_AS	EEI (MJ/€)
Europe (Average Sector)	974	x	408	1523	34	35	=	397	1.484	33	34	1,8%	1,9%	80
Bulgaria	10		250	204	0	5,0		2,6	2,1	0	0,052	1,0%	0,8%	175
Finland	18	x	664	1.658	308	33	=	12	30	5,6	0,60	2,5%	1,9%	120
Spain	69		689	1.037	39	35		48	72	2,7	2,4	1,6%	1,8%	86

Table III-12 Metabolic pattern of the 'paper, pulp and print' subsector for Bulgaria, Finland, Spain and EU-22, year 2012

Paper, Pulp and Print 2012	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA_sector/ HA_EU_AS	%VA_sector/ VA_EU_AS	EEI (MJ/€)
Europe (Average Sector)	1.937	x	218	391	15	34	=	422	757	29	66	3,6%	3,8%	30
Bulgaria	29		44	256	7	6,3		1,3	7,5	0,20	0,19	2,8%	3,0%	64
Finland	50	x	1.386	3.095	61	67	=	69	154	3,0	3,3	6,8%	10%	106
Spain	174		107	313	26	32		19	55	4,5	5,7	4,1%	4,3%	20

Due to its favorable boundary conditions (cheap hydro-electricity and abundance of woods), Finland has a clear comparative advantage in this field and is the second producer of pulp (raw product in the subsector) in Europe with 10 million tonnes in 2012 (Sweden is top producer with 12 million tonnes and Germany a distant third with 3 million tonnes) (CEPI, 2012). Nonetheless, when considering the sub-sub-sector *paper and board* (finished product in the 'paper & pulp' subsector) Germany is the first largest producer, followed by Sweden and Finland (22, 11 and 11 million tonnes respectively) (CEPI, 2012). In fact, paper and board can be produced either from recycled paper and non-fibrous materials or from pulp. These two methods of production are quite different in terms of energy intensity (the kraft process is very energy intensive!). Hence if different countries rely on different mixes of production methods, the country relying on the most energy-demanding processes (e.g., pulp production in Finland) will exhibit the higher aggregate metabolic rate at the subsector level. However, when looking at these differences at this level of analysis it becomes clear that the different values observed depend on the specificity of the type of production (specialization) developed in the sub-sector and not on the *efficiency* of the technologies used in the process. In the same way, the characterization of the metabolic pattern of an industrial process can result completely irrelevant if that particular activity is extremely marginal in the national economy. This is for example the case with the production of pulp and paper in Italy, which relies entirely on imports for covering its domestic consumption (CEPI, 2012).

The analysis of the pulp and paper sub-sector clearly shows that any discussion over the issue of energy and carbon intensity of a country in relation to the efficiency of the technologies used in the economy should start from an analysis of the mix of economic activities carried out in the different sectors and the selective externalization of the most energy intensive economic activities by means of import/export of (semi-finished) products (factors 3 and 4 in Figure III-1 The metabolic pattern of social-ecological systems and the different factors affecting the energy and carbon intensity of an economy. Abbreviations: PES = primary energy sources; EC = energy carriers; GDP = gross domestic product). The mix of domestic production and the openness of the industrial sector are closely related and should be analyzed simultaneously. Moreover, in a globalized economy, none of these two factors is directly affected by local consumption patterns. This is an important point to consider in the evaluation of policies regarding the reduction of energy and carbon intensity. In chapter 5 I will present a preliminary exploration of the possibilities to extend the present protocol relating energy carriers, human activity and value added with information referring to the products in biophysical units.

4.3 Using the end-use matrix (data arrays) to identify and study relevant characteristics of the metabolic pattern of modern societies

In the introduction, I discussed the peculiar characteristics associated with the metabolic pattern of social-ecological systems: the different functions expressed by society are linked by an impredicative relation. That is, the set of functional sectors of a society produce outputs that are used as inputs by the others and they require inputs that are the outputs of the other (Giampietro *et al.*, no date; Giampietro, Mayumi and Sorman, 2012, 2013). This metabolic narrative flags the fact that in any metabolic system the characteristics of the whole "affect/depend on" the characteristics of the parts and vice versa through an impredicative relation (Giampietro and Mayumi, 2004). Studying the implications of this mutual dependence is essential if one wants to study the potentialities, the bottlenecks and the constraints of transitions to different metabolic patterns.

Using data referring to the three countries used in this pilot study I show in this section how the information provided by the end-uses matrix can be used as a diagnostic tool to identify and study relevant metabolic characteristics of a country. The three end-use matrices illustrated in Table III-13 describe the investments of energy carriers and human activity in the various sectors of the economy expressed in the form of extensive variables. A parallel accounting of the quantities of GVA is also added to the matrix.

This information can be transformed in another end-use matrix having in the cells values expressed as percentages. The percentages refer to the quantities of each one of the various inputs required to express the metabolic pattern used by the various sectors in relation to the total used by society: (i) the total of human activity; (ii) the total of electricity; (iii) the total of process heat; (iv) the total of fuels. This second type of end-use matrix is illustrated in Table III-14

Using this second type of end use matrix it is possible to study the factors determining the dynamic equilibrium between the Bio-Economic Pressure (what is the profile of the fractions of the total inputs required to express the expected functions in the dissipative compartments of the society: Households, Manufacturing & Construction and Service & Government) and the Strength of the Exosomatic Hypercycle (what is the profile of the fractions of the total inputs required to express the expected functions in the primary sectors of the society: Agriculture, Forestry & Fishing and Energy & Mining).The relative profiles of the fractions of the two sides are described in Table III-15.

Moving back to the use of extensive variables we can translate the profile of the fractions of total input uses in the dynamic equilibrium between dissipative and productive sectors onto a set of profiles of investments required in the different sectors of the society. This is illustrated in Figure III-4.

Table III-13 End-use matrix based on extensive variables – sectors/whole society

	Bulgaria	HA (10^9 h/year)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)
EXTENSIVE VALUES	Household	62	39	45	21	0
	Agriculture, Forestry & Fishing	0,75	0,97	1,4	5,6	2,2
	Energy & Mining	0,10	26	14	0,04	2,3
	Manufacturing & Construction	0,94	26	55	1,2	7,4
	Service & Government	1,3	30	35	80	22
	Average Society	65	122	151	108	34

	Finland	HA (10^9 h/year)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)
EXTENSIVE VALUES	Household	43	81	59	127	0
	Agriculture, Forestry & Fishing	0,26	5,7	10	17	4,7
	Energy & Mining	0,04	19	45	1,7	5,3
	Manufacturing & Construction	0,93	133	228	21	35
	Service & Government	2,9	67	9,5	97	120
	Average Society	47	305	352	264	165

	Spain	HA (10^9 h/year)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)
EXTENSIVE VALUES	Household	380	270	319	480	0
	Agriculture, Forestry & Fishing	1,5	14	31	68	23
	Energy & Mining	0,18	68	308	2,2	32
	Manufacturing & Construction	5,7	256	564	36	199
	Service & Government	23	305	93	1.000	686
	Average Society	410	914	1315	1585	940

Table III-14 End-use matrix based on percentages of total – sectors/whole society

	Bulgaria	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
PERCENTAGE OVER AS	Household	95%	32%	30%	20%	-
	Agriculture, Forestry & Fishing	1,2%	0,8%	0,9%	5,1%	6,4%
	Energy & Mining	0,2%	21%	9%	0,04%	6,9%
	Manufacturing & Construction	1,5%	22%	36%	1,1%	22%
	Service & Government	2,0%	25%	23%	74%	65%
	Average Society	100%	100%	100%	100%	100%

	Finland	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
PERCENTAGE OVER AS	Household	91%	26%	17%	48%	-
	Agriculture, Forestry & Fishing	0,56%	1,9%	2,9%	6,5%	2,8%
	Energy & Mining	0,08%	6,3%	13%	0,66%	3,2%
	Manufacturing & Construction	2,0%	43%	65%	7,9%	21%
	Service & Government	6,2%	22%	2,7%	37%	73%
	Average Society	100%	100%	100%	100%	100%

	Spain	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
PERCENTAGE OVER AS	Household	93%	30%	24%	30%	-
	Agriculture, Forestry & Fishing	0,36%	1,6%	2,4%	4,3%	2,5%
	Energy & Mining	0,04%	7,5%	23%	0,14%	3,4%
	Manufacturing & Construction	1,4%	28%	43%	2,2%	21%
	Service & Government	5,6%	33%	7,1%	63%	73%
	Average Society	100%	100%	100%	100%	100%

Table III-15 The profiles of investments (labor, electricity, process heat, fuels) generating a dynamic equilibrium between dissipative and productive sectors (expresses in %)

Bulgaria	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
Dissipative Sectors	99%	78%	90%	95%	87%
Primary Sectors	1,3%	22%	10%	5,2%	13%
Average Society	100%	100%	100%	100%	100%

Finland	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
Dissipative Sectors	99%	92%	84%	93%	94%
Primary Sectors	0,6%	8,2%	16%	7,1%	6,0%
Average Society	100%	100%	100%	100%	100%

Spain	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
Dissipative Sectors	99,6%	91%	74%	96%	94%
Primary Sectors	0,4%	9,1%	26%	4,4%	5,9%
Average Society	100%	100%	100%	100%	100%

At this point, using the methods of scaling provided by MuSIASEM one can move across different levels in order to describe the forced set of relations between the metabolic characteristics of the sectors and subsectors. This set of forced relations is essential to study the integrated set of changes that would be required in the different sectors and subsectors to generate different profiles of investments of energy carriers and human labor capable of achieving new feasible, viable and desirable states of dynamic equilibrium between BEP and SEH (Giampietro, Mayumi and Sorman, 2013).

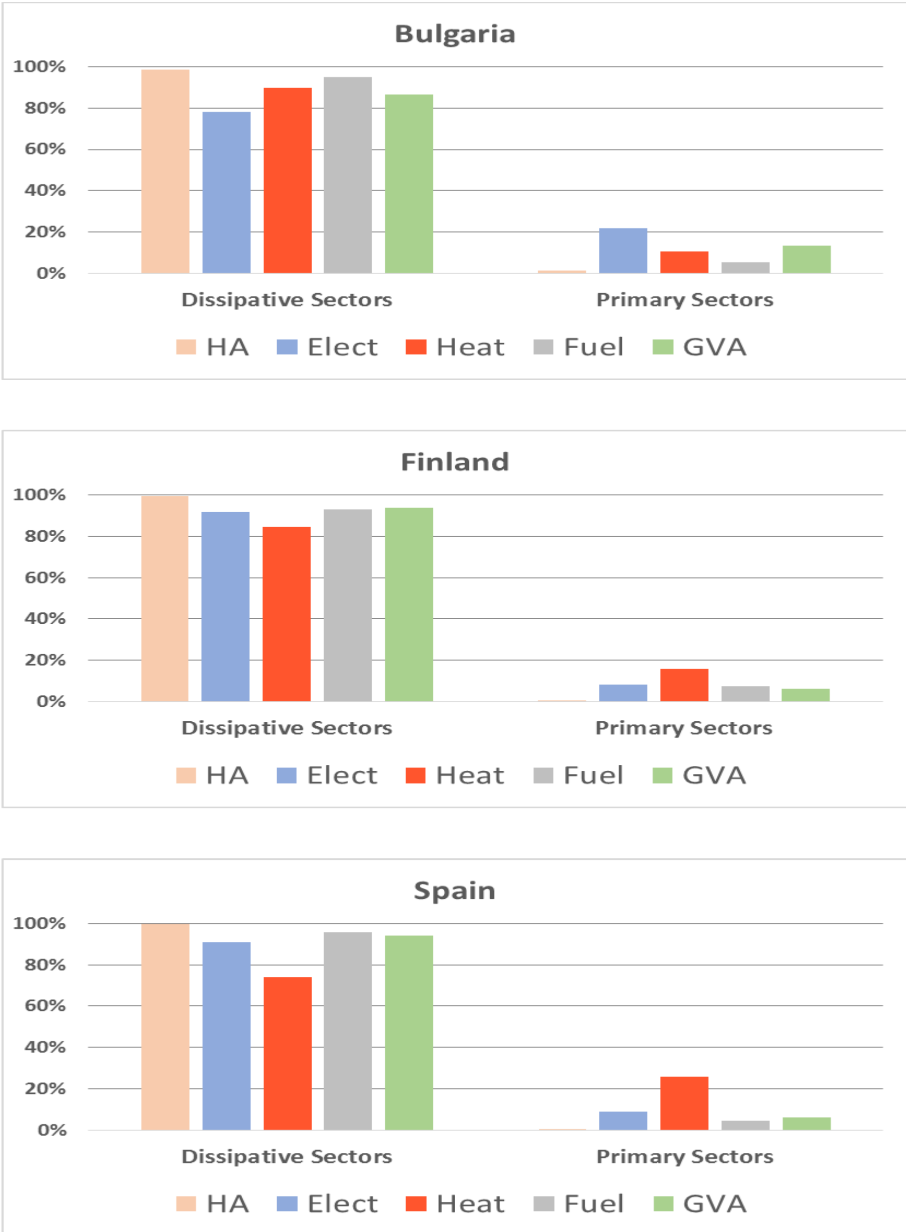


Figure III-4 The profiles of investments (labor, electricity, process heat, fuels) generating a dynamic equilibrium between dissipative and productive sectors (in extensive variables)

When looking at an end-use matrix quantified using "percentages of the total" Figure III-5 we are looking at a description of the profiles of investments of inputs which are required by the various sectors in order to express their specific functions. Therefore, this form of end-use matrix can be used to define "blue-prints" of metabolic patterns of socio-economic systems belonging to a common typology – e.g. European countries. The blue-prints of the typology of European countries can be generated by calculating the differences cell by cell of the values of the end-use matrix of the countries and the values of the end-use matrix of EU27+N. Examples of blue prints generated in this way are illustrated in Figure III-5.

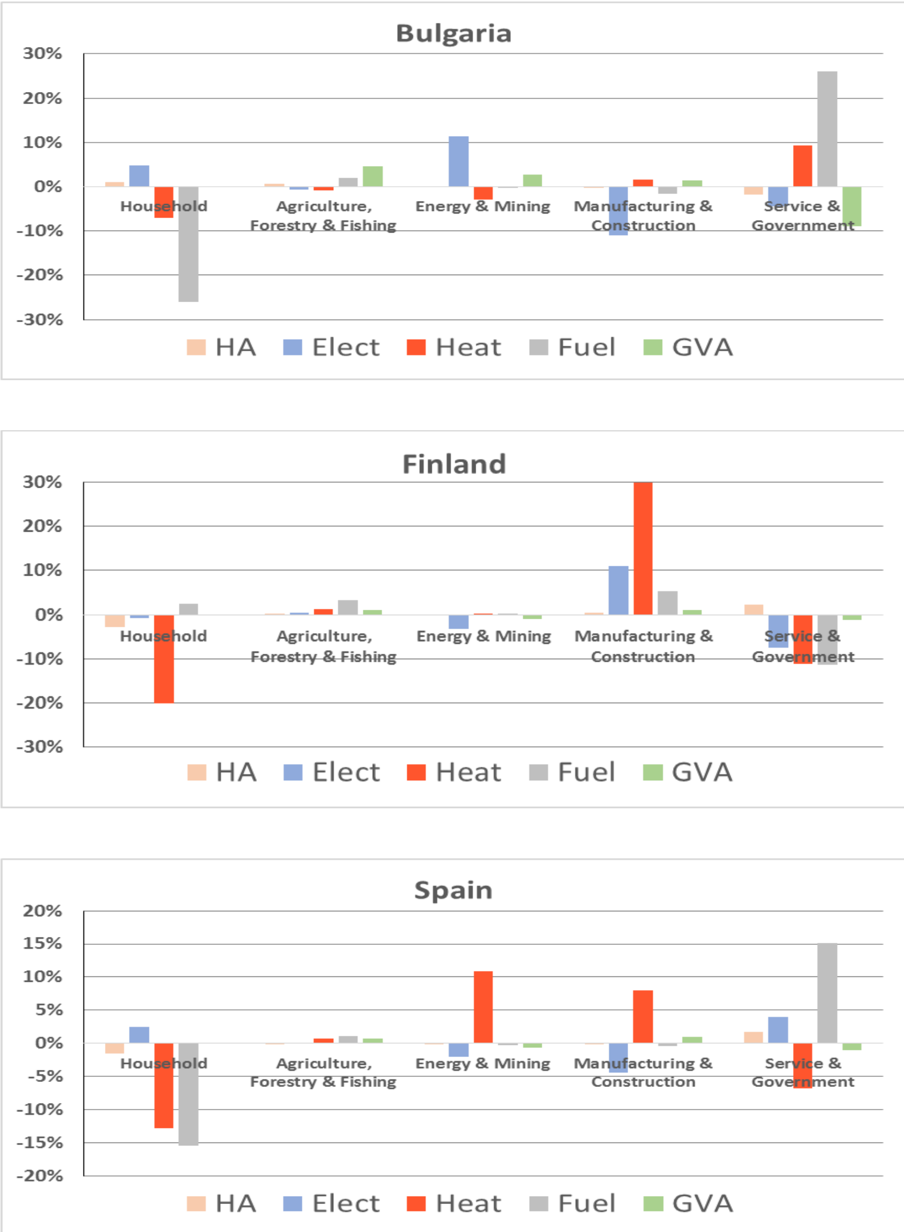


Figure III-5 Blue prints of the metabolic pattern of EU countries based on the differences in the profiles of investments (expressed in percentage) over EU 27 averages (benchmarks)

The metabolic blue prints illustrated in Figure III-5 show, for each one of the sectors of the society, the differences in the profile of investment of labor, electricity, process heat and fuel (and the resulting GVA) against the benchmarks calculated for EU27+N. In this way, the differences in the country values can be investigated looking for factors explaining what is “special” in the use of a particular input (e.g. electricity) in a specific compartment (e.g. energy and mining) in a particular country (e.g. Bulgaria).

This approach can also be used in the analysis of historic series to study the trends of changes and the substitutions over inputs (e.g. increasing electricity to save hours of labor) in the different sectors. In this study, I did not carry out an analysis based on temporal series.

5 Conclusions

A better understanding of how energy use is related to the functioning and the size of the economy and the use of other production factors (e.g., labor) is paramount for evaluating energy policies. Consider the following highly actual questions: Is the EU 20% energy efficiency target by 2020 (European Parliament, 2012) achievable? What has to be changed in the actual pattern of energy use in the industrial sector to achieve this goal? What would be the cost (or better the consequence) of achieving this target? Looking at this first analysis of the metabolic pattern of the industrial sector I can conclude that the quantitative analyses of the energy (carbon) intensity of the economy presently dominating the discussion of energy policies is not based on an adequate input of information. Answering this question would require a more informed analysis of where the different energy carriers are used to produce what. As it is illustrated in this thesis, at the moment this detailed analysis is missing and hence we can say that at present energy policies are made on the basis of wishful thinking.

The approach presented in this chapter is an attempt to characterize the bioeconomic performance of the industrial sector across hierarchical levels of organization by exploring the complex set of relations between energy consumption, requirement of human activity and value added generation. This analysis characterizes the quantitative (size) and qualitative (rates/intensities of flows) energy metabolic characteristics of the various sub-sectors and sub-sub-sectors of the all economic sector, with the economic job productivity (€/hour of labor) flagging the expected pattern of externalization. A key feature of this approach is the use of ‘end-uses data-arrays’ composed of extensive and intensive variables. Data arrays facilitate the extension of the analysis to include other additional resources (e.g., water, land use, technological capital) and sink-side impacts (emissions, discharges) see (Giampietro *et al.*, 2014) for an application to the water-energy-food nexus.

All the same, the analysis carried out at the level of the industrial sub-sector still leaves out important aspects as 'end-uses data-arrays' at this level may refer to end-uses that are still qualitatively very different (steel can be produced from scrap or ores, paper from wood/pulp or recycled paper). For this reason, it would be important to move further down to yet a lower level of analysis —that of production processes carried out at the level of sub-sub-sectors— in order to describe the end-uses in terms of technical coefficients (or biophysical production functions) referring to homogenous typologies of processes. In this way, the level of analysis can reach a point in which one establishes a bridge between bottom-up information (expected characteristics of specific technologies) and top-down information (statistical data referring to the categories provided by statistical offices). In this way, this method of accounting would become a powerful complement –offering the biophysical perspective– to the aggregate production function in neoclassical economics. That is, the information provided by production functions described in macroeconomics analysis could be scaled down tracking the biophysical roots of the economic process across levels. This integration could avoid some of the problems associated with the excessive reliance on neo-classical economic tools (Daly, 1997).

Unfortunately, the inclusion of lower levels of analysis beyond the industrial subsector is currently still problematic as it requires a better definition of the categories of accounting (hierarchical structure of the industrial sector) by the various statistical offices. Statistical offices should make a joint effort to offer energy balances, trade, and labor data using a uniform classification of all economic activities (e.g., NACE Rev 2) so that assessments of the consumption of energy carriers, hours of human activity (in different types of jobs), and monetary indicators match with each other at all levels of analysis, thus avoiding a comparison of apples with oranges in the same category of accounting.

Chapter IV

"Analytic work begins with material provided by our vision of things,
and this vision is ideological almost by definition. "

Joseph Alois Schumpeter

Energy uses analysis of European Countries from a multiscale perspective[6]

1 Introduction

In this chapter, I will present all the results of my analysis (based on the protocol illustrated in chapter 3). The goal is to show the potentiality of the innovative approach of accounting based on MuSIASEM making it possible to:

(1) characterize the pattern of consumption of energy carriers in Europe at different hierarchical levels of analysis, keeping the distinction between different types of energy carriers;

(2) establish a bridge between quantitative assessments of energy consumption, monetary flows, employment and the biophysical process of production;

(3) compare the energetic performance of different economies observed at different levels of analysis. Using the multi-level end uses matrix it becomes possible to study the different effects that: (i) the mix of Primary Energy Sources; (ii) the mix of Energy Carriers; (iii) the mix of economic activities (reflected in the relative mix of end-uses in the different sectors and sub-sectors); (iv) the characteristics

[6] This chapter builds partly in the report: *Giampietro M., Velasco-Fernández R. and Ripa M. Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers. March 2017 EUFORIE project*

of specific biophysical processes taking place, at the local scale, to express functions at the level of sub-sectors – have on the performance of the economy;

(4) individuate the existence of problems with the available database – especially when moving to the level of subsectors – in order to start a discussion over the possibility of improving the material provided by statistical offices.

As mentioned in the methodological section in the previous chapter, a characterization of the pattern of consumption of a modern economy based on data arrays implies the handling of an enormous quantity of information. This variety of information organized in a redundant way using both extensive and intensive variables is essential because it makes it possible to compare:

(1) the vectors of end uses over themselves – e.g. looking at the profile of investment of energy carriers and labor in the textile and leather of different countries. Using intensive variables (benchmarks) we can compare the performance of Germany and Malta, whereas using extensive variables (actual quantities) we can compare the relative size of the flows in Europe and in relation to the local environment;

(2) the vectors of end uses over the rest of the economy – e.g. looking at how much the profile of investments of energy carriers and labor of a given sector or subsector is affecting the possibility of investing in other sector, given the total capability of investments of the country. Using an end-use matrix we can assess what is the fraction of the total consumption of electricity used by the service and government sector versus the total electricity consumed by the economy. In alternative, we can compare the hours of labor of Agriculture and Forestry versus the Manufacturing and Construction sector;

(3) the profile of the vectors of end use of countries (sector by sector) with the profile of the vectors of end use of the average of EU27 (sector by sector) to study differences among countries. The profile of investments of energy carriers and labors within sectors and across sectors can be used to identify typologies of economies. To obtain this result one can use the average values of EU as reference to normalize the data of individual countries. How different is the profile of allocation of production factors (end uses) in the different countries in

relation to the average in EU? What are the differences found in this way? (e.g. households in Italy are using more fuels for commuting, Finland is using more electricity in the service sector than the EU average). Then these differences can be studied by studying the relations over vectors as described in point (1) and (2).

Due to the large number of data and the even larger set of possible combinations of them for metabolic analysis an effective illustration of how to use this database would require an interactive session on a computer in which the different types of comparisons that are possible using the information provided by end-uses matrix could be illustrated in practical applications.

For this reason, I presented in the previous chapter a pilot case study based on the analysis of only three countries – Bulgaria, Spain and Finland chosen for their different metabolic characteristics – before presenting in this chapter the entire set of tables describing the end-uses matrices of EU27 across the levels n+1/n/n-1/n-2/n-3. The database on EU countries is organized in two different sections. This split is due to the incompatibility among data sources referring to the assessments of Human Activity (hours of labor) and Gross Value Added (GVA) of the different sectors when considered across different levels (section 3.4 in previous chapter: Data sources and main assumptions), the information required to generate the Energy End Use matrix:

Section 2 – the tables of end-uses for EU27 + Norway covering the characterization of the metabolic pattern across: (i) level n+1 EU averages; (ii) level n Average society; (iii) level n-1 and n-2 the main economic sectors; and (iv) only some of the subsectors defined at the level n-3 (Agriculture & Forestry, Fishing, Transport Service and Service & Government without Transport). In this part, I do not open the Manufacturing and Construction sector (defined at level n-2) to study its sub-sectors (at the level n-3).

Section 3 - the tables of end uses for EU22 presenting end-use matrices covering: (i) the level n-2: Manufacturing & Construction and Energy & Mining; and (ii) the level n-3 covering the remaining subsectors of these two sectors. The data source for the end-use matrices of this second group has been the structural business statistics (SBS), providing very detailed data for the industrial subsectors. However, this data set does not provide data for the whole set of indicators used for the EU27 countries study (based on data from National Accounts (NAMA)). For this reason, this second group of end-use matrices include less countries - EU22. Moving the analysis to lower hierarchical levels is essential for the study of efficiency, because it is at the lower levels of analysis – the performance of specific biophysical processes producing specific outputs – that becomes possible to study the characteristics of "production functions" – the technical coefficients determining input/output relations.

2 EU27 end-use matrices across different hierarchical levels of analysis (n, n-1, n-2, n-3)

I present here a characterization of the metabolic pattern of socio-economic systems based on data arrays for EU27 + Norway. The data are organized in sectors and subsectors in the form of energy End Use Matrix. This makes it possible to illustrate how the metabolic rates of functional elements described at higher levels (Average Society or Paid Work & Households) are determined by: (i) the metabolic characteristics of structural and functional elements operating at the lower levels; and (ii) their specific combinations. This multiscale approach is crucial to separate and individuate the factors determining the economic energy intensity of an economy. In this way, it becomes possible to study where and how the economy consumes more energy carriers and generate more or less value added, as well as which part is consumed by the households. The end-use matrix makes it possible to put in context the characteristics of individual sub-sectors with the rest of the economy or to compare the characteristics of individual subsectors across different economies. In this way policy discussions on how to change the metabolic pattern in relation to defining targets for efficiency, environmental impact, and energy transitions could be better informed.

2.1 The diversity of end-uses across sectors and subsectors in EU27 + Norway

The differences among the values of end-uses in the various sectors: (i) average society (level n); (ii) Household vs Paid Work (level n-1) and the economic sectors (level n-2) have been calculated for a macro-economic entity "EU27 + Norway". They are illustrated in Table IV-1 and Table IV-2Figure IV-1 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n to Level n-3 of EU27+Norway for year 2012.

Table IV-1 Average End use matrix for the region considered (EU27+Norway), all sectors from Level n to Level N-3 for year 2012

EU27+N	HA (10^9 h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA_Level_x/ HA_Level_x-1	%GVA_Level_x/ GVA_Level_x-1	EEI (MJ/€)
Average Society	4.422	2,6	4,3	3,9	2,6	11.415	19.110	17.243	11.631	100%	100%	6,4
Household	4.167	0,74	1,7	1,9	0	3.098	7.078	7.889	0	94%	0%	-
Paid Work	255	33	47	37	46	8.317	12.033	9.354	11.631	5,8%	100%	4,1
Agriculture, Forestry & Fishing	21	8,0	15	26	9,3	171	326	556	198	8,4%	1,7%	7,9
Energy & Mining	3,9	280	612	17	122	1.092	2.386	68	475	1,5%	4,1%	12
Manufacturing & Construction	65	57	103	7,1	36	3.706	6.664	459	2.347	25%	20%	7,5
Service & Government	172	19	15	48	50	3.348	2.657	8.271	8.611	68%	74%	2,7
Agriculture & Forestry	20	8,4	16	25	9,3	169	322	495	188	95%	95%	7,9
Fishing	0,23	8,5	16	260	36	2,0	3,6	61	8,4	1,1%	4,2%	11
Services & Government (without Transport)	166	19	14	3,7	41	3.116	2.255	607	6.827	96%	79%	1,7
Transport Services	6,3	37	64	1.224	17	232	401	7.663	109	3,6%	1,3%	107

The households sector is characterized by a very high level of human activity allocation, which reflects the amount of time that society spend in activities not taking place in the paid work sector. It is important to remind that the hours of Human Activity in HH includes not only the full time of unemployed and of the people outside of the work force (e.g. children or retired people) but also the human time of adults belonging to the work force required for physiological maintenance such as resting, eating, personal care and other activities such as leisure, commuting, religious and cultural activities.

When looking at the level n-2, we can see how Energy & Mining sector is the sector with the largest Energy Metabolic Rates (EMRs) for electricity (280 MJ/h) and heat (612 MJ/h) carriers. At the same time, it has the largest Economic Job Productivity (122 €/h). Conversely, the largest consumption of fuels - EMR (48 MJ/h) - is in Service & Government due to the Transport Service subsector (level n-3) consuming 1224 MJ/h. Coming back to the level n-2, we can see that Energy & Mining it is the most energy-intensive sector although it accounts only for the 1,5% of the human activity allocated in the paid work sector. Manufacturing & Construction presents the second largest EMRs for electricity (57 MJ/h) and heat (103 MJ/h) and the largest values of Energy Throughputs (3706 and 6664 PJ) even though it uses just the 25% of the paid labor (HA) allocated to this sector. On the other hand, the "dematerialized" sector of Service & Government without Transport, generates 41 €/h consuming only 19, 14 and 3,7 MJ of electricity, heat and fuel per hour, respectively.

The last column of the Table IV-1 on the right shows the Economic Energy Intensity, a popular indicator in literature in relation to energy efficiency. Here we can clearly see the weakness of this indicator when it is used at aggregated levels of analysis – see Figure IV-1.

The large difference of the values of this indicator for different economic sectors implies that the overall economic energy intensity of the economy, depends on the relative importance of the economic activities expressed by the different sectors (the structure of the GDP) and not on the specific technological performance of local processes (as already pointed out by (Cleveland *et al.*, 1984)). Talking of variability of the Economic Energy Intensity of the different sectors and sub-sectors the value of EEI within the two sub-sectors of Service and Government goes from 107 MJ/€ in the subsector of Transport Service sector, to 1,7 MJ/€ when considering the remaining part – Table IV-1.

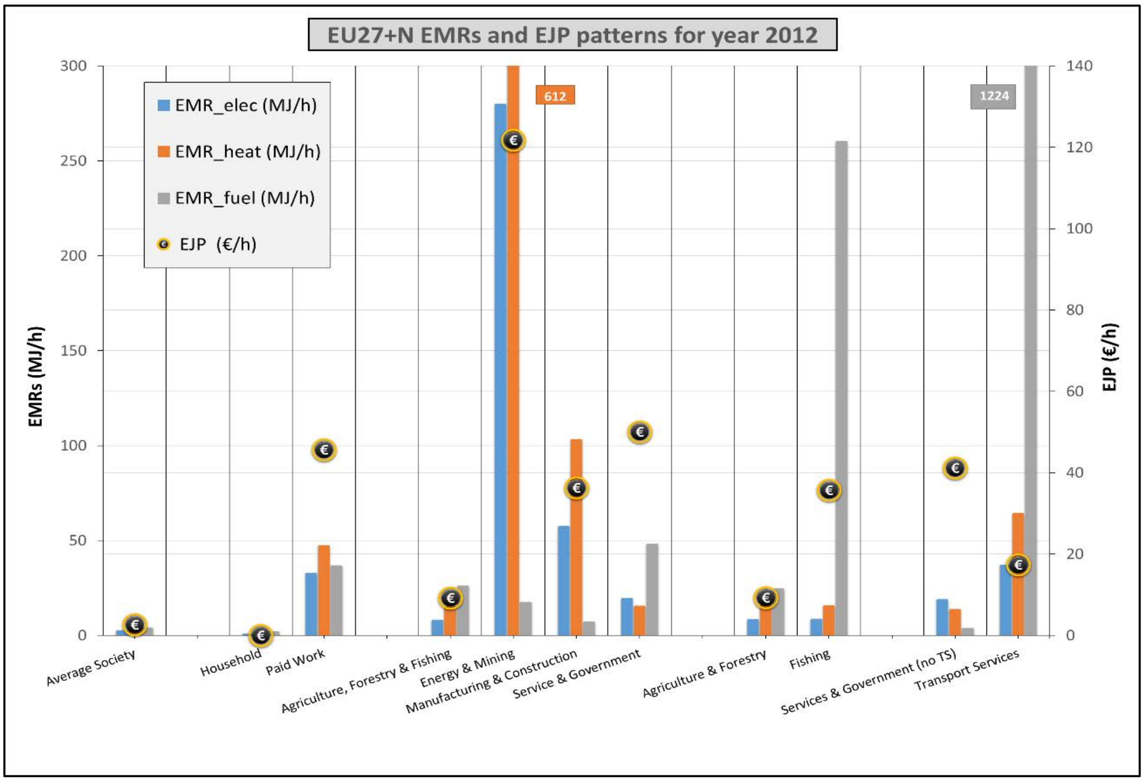


Figure IV-1 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n to Level n-3 of EU27+Norway for year 2012

When moving to national analysis we use the same set of levels as illustrated in Figure IV-2, but this time the values are calculated for data referring to processes taking place within the national boundaries.

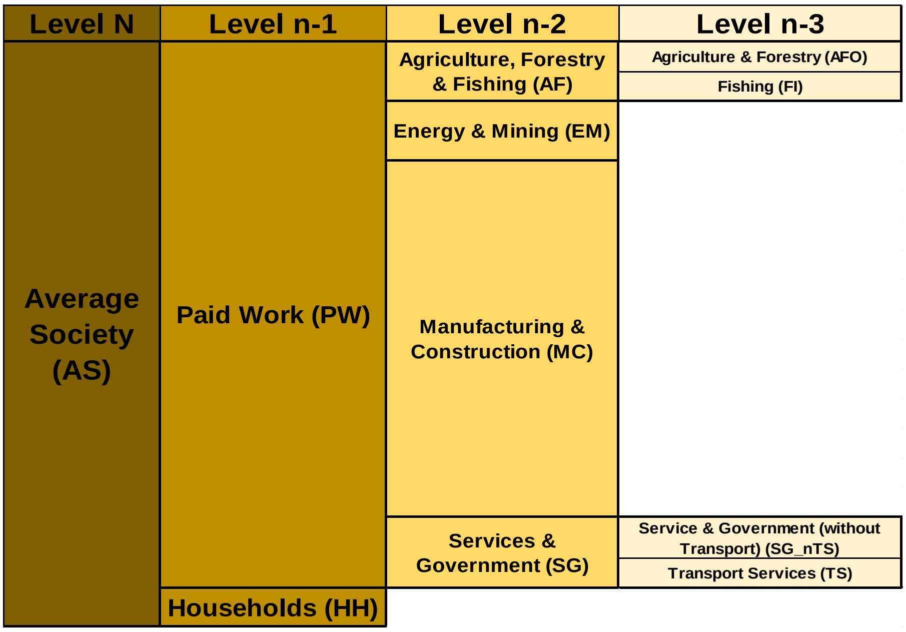


Figure IV-2 Dendrogram of the different levels and compartments of analysis

2.2 National level: Average Society

The assessments of end uses presented in this section refers to the aggregated values calculated at the level of the whole society – considered as national state. The variability of EMRs and EJP at this level are quite high, especially because of the influence of small countries, such as Malta, Cyprus or Luxembourg (all together less than 0,5% of the population and the value added generated in the EU27+N cluster). Small countries such as Luxembourg tend to be outliers when coming to metabolic analysis because the structural elements required to express the functions associated with their reproduction are not all operating within their border. For example, people working in Luxemburg may live in Belgium or Germany, eat food and use appliances produced elsewhere.

The data reporting the value calculated for the 27 EU countries and Norway are presented in Table IV-2 and Figure IV-3.

Table IV-2 Average Society End use matrix of EU27+Norway for the year 2012

AS	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA / HA_EU27+N	%GVA / GVA_EU27+N	EEI (MJ/€)
EU27+N	4.422	x	2,6	4,3	3,9	2,6	=	11.415	19.110	17.243	11.631	100%	100%	6,4
Austria	74		3,4	6,4	5,6	3,8		252	472	414	277	1,7%	2,4%	6,3
Belgium	97		3,2	6,2	5,9	3,4		315	602	571	334	2,2%	2,9%	6,8
Bulgaria	64		1,9	2,4	1,7	0,53		122	151	108	34	1,5%	0,3%	19
Cyprus	7,6		2,1	1,4	6,2	2,1		16	11	47	16	0,2%	0,1%	7,5
Czech Republic	92		2,5	5,0	2,8	1,5		230	459	261	137	2,1%	1,2%	11
Denmark	49		2,5	3,6	5,0	4,3		122	174	246	208	1,1%	1,8%	4,1
Estonia	12		2,7	3,1	3,5	1,3		32	36	41	15	0,3%	0,1%	12
Finland	47		6,4	7,4	5,6	3,5		305	352	264	165	1,1%	1,4%	9,4
France	572		3,0	3,6	4,4	3,2		1724	2064	2521	1.814	13%	16%	5,7
Germany	704		3,0	5,0	4,8	3,3		2083	3530	3347	2.349	16%	20%	5,9
Greece	97		2,3	2,3	3,5	1,8		219	226	343	172	2,2%	1,5%	7,5
Hungary	87		1,5	3,6	2,0	0,9		131	316	175	81	2,0%	0,7%	11
Ireland	40		2,3	3,0	6,0	3,5		91	120	242	141	0,9%	1,2%	5,0
Italy	520		2,2	4,6	3,3	2,7		1150	2411	1700	1.398	12%	12%	5,7
Latvia	18	x	1,5	4,0	2,9	0,93	=	26	72	51	16,6	0,4%	0,1%	13
Lithuania	26		1,4	3,5	2,3	1,05		37	93	62	28	0,6%	0,2%	10
Luxembourg	4,6		5,3	6,8	26	7,2		24,3	31	118	33	0,1%	0,3%	7,9
Malta	3,7		2,0	0,47	3,4	1,6		7,2	1,7	13	5,7	0,1%	0,0%	6,7
Netherlands	147		2,8	7,5	4,4	3,7		417	1095	645	536	3,3%	4,6%	5,9
Norway	44		9,8	6,6	6,1	7,1		428	287	268	308	1,0%	2,7%	5,8
Poland	333		1,6	4,2	2,2	0,98		535	1416	739	326	7,5%	2,8%	12
Portugal	92		1,9	2,4	3,1	1,6		176	224	290	143	2,1%	1,2%	7,7
Romania	176		1,1	3,1	1,4	0,7		188	546	252	115	4,0%	1,0%	13
Slovakia	47		2,1	5,3	1,9	1,4		99	251	90	65	1,1%	0,6%	10
Slovenia	18		2,8	3,0	5,3	1,7		50	53	96	31	0,4%	0,3%	10
Spain	410		2,2	3,2	3,9	2,3		914	1315	1585	940	9,3%	8,1%	6,4
Sweden	83		5,8	4,6	4,4	4,3		483	385	363	356	1,9%	3,1%	6,1
United Kingdom	556		2,2	4,3	4,3	2,9		1238	2416	2390	1.587	13%	14%	5,8

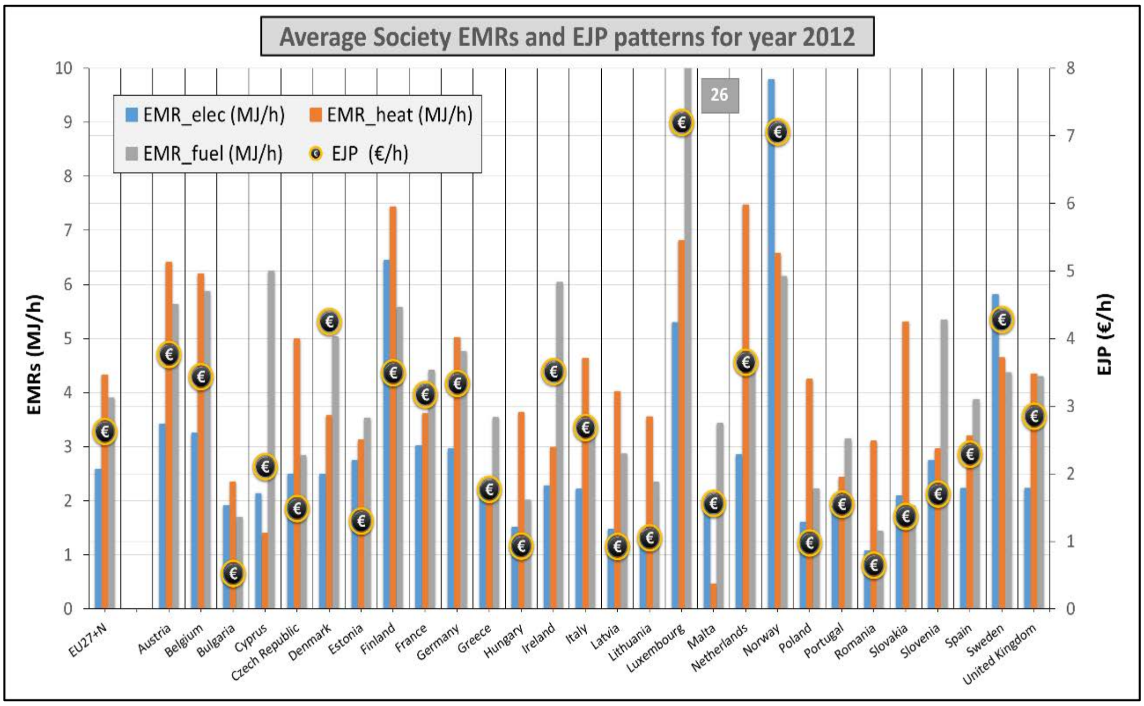


Figure IV-3 Average Society Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.3 Sectors of national economies Level n-1

2.3.1 Paid Work

Paid Work includes all the remunerated human activities performed in the economic sectors. This sector includes all the compartments producing goods and services and therefore its metabolic rates are quite higher than the Household sector. Table IV-3 and Figure IV-4 shows the values of Energy Metabolic Rates and the Economic Job Productivity. As discussed in previous work (Giampietro et al. 2012) the values of EMRs (especially the electricity one in this case) can be used as proxy of the level of technical capitalization of the sector. In relation to this indicator, Belgium presents the largest values of EMRs ([76_{elect} 133_{heat} 94_{fuel}] MJ/h) associated with the values of EJP (104 €/h) whereas Romania presents the lowest [9 19 11] MJ/h and 7,3 €/h.

Table IV-3 Paid Work End use matrix of EU27+Norway for the year 2012

PW	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	255	x	33	47	37	46	=	8.317	12.033	9.354	11.631	100%	100%	4,1
Austria	6,9		27	49	33	40		189	341	230	277	2,7%	2,4%	4,3
Belgium	3,2		76	133	94	104		244	428	302	334	1,3%	2,9%	4,6
Bulgaria	2,4		35	45	37	14		83	106	87	34	0,9%	0,3%	13
Cyprus	0,7		15	9,2	48	24		10	6,1	32	16	0,3%	0,1%	4,9
Czech Republic	9,0		20	33	20	15		177	300	179	137	3,5%	1,2%	7,6
Denmark	3,9		22	29	35	53		86	111	136	208	1,5%	1,8%	2,6
Estonia	1,1		22	15	21	14		25	17	24	15	0,4%	0,1%	7,7
Finland	4,2		54	70	33	40		224	292	136	165	1,6%	1,4%	6,6
France	20		58	59	72	90		1.155	1.177	1.441	1.814	7,9%	16%	3,5
Germany	27		58	85	53	86		1.590	2.309	1.439	2.349	11%	20%	3,7
Greece	8,3		18	20	14	21		151	165	113	172	3,3%	1,5%	4,3
Hungary	7,0		13	23	17	12		93	161	116	81	2,7%	0,7%	7,2
Ireland	3,2		20	23	42	45		62	72	133	141	1,2%	1,2%	3,0
Italy	17	x	52	76	39	81	=	900	1.318	667	1.398	6,8%	12%	3,4
Latvia	0,49		40	78	62	34		20	38	31	16,6	0,2%	0,1%	8,2
Lithuania	1,0		27	58	25	27		27	59	26	28	0,4%	0,2%	6,2
Luxembourg	0,49		43	45	212	67		21	22	104	33	0,2%	0,3%	6,7
Malta	0,29		17	2,6	32	20		5,0	0,76	9,2	5,7	0,1%	0,0%	4,7
Netherlands	12		26	62	30	43		327	767	373	536	4,9%	4,6%	4,1
Norway	3,8		76	68	51	81		290	259	193	308	1,5%	2,7%	4,2
Poland	32		14	26	13	10		433	833	411	326	12%	2,8%	8,0
Portugal	8,3		16	19	22	17		129	160	183	143	3,3%	1,2%	5,3
Romania	16		9,3	19	11	7,3		145	292	179	115	6,1%	1,0%	8,2
Slovakia	4,0		21	51	10	16		82	202	41	65	1,6%	0,6%	7,6
Slovenia	1,5		25	17	36	20		38	26	55	31	0,6%	0,3%	6,7
Spain	30		21	33	36	31		644	996	1.105	940	12%	8,1%	4,6
Sweden	7,3		47	45	26	48		343	332	189	356	2,9%	3,1%	4,3
United Kingdom	23		36	54	62	69		825	1.242	1.419	1.587	9,0%	14%	3,5

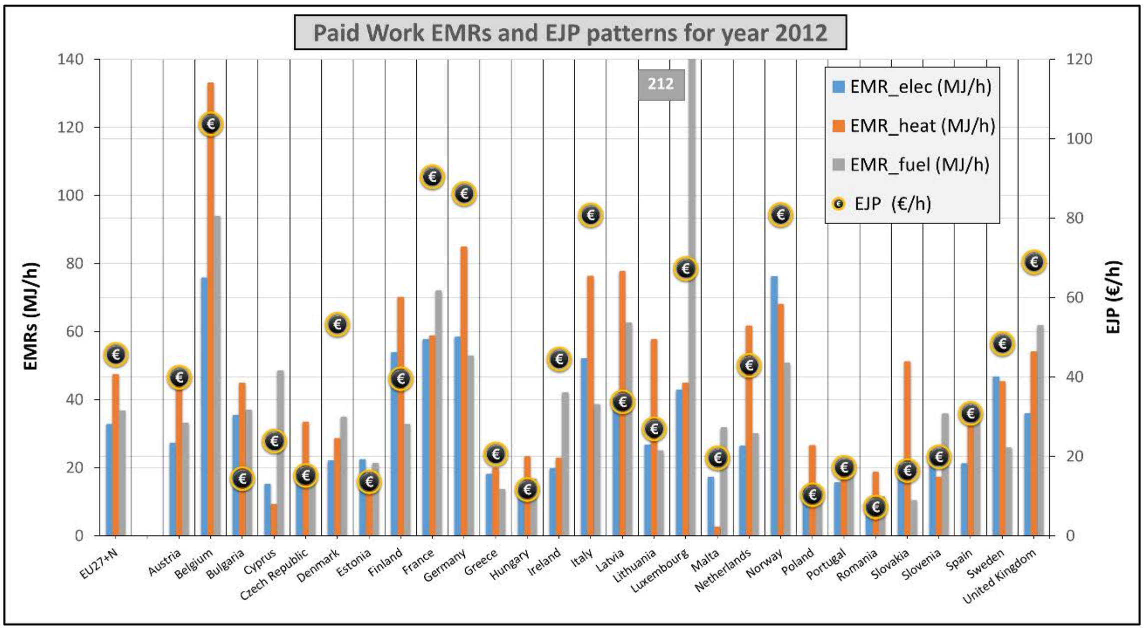


Figure IV-4 Paid Work Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.3.2 Household

In the MuSIASEM accounting framework the Household sector do not generate any value added by definition, so that the monetary indicators are excluded from its characterization. Nonetheless, the metabolic rates associated with the end uses in this sector are very relevant because they can be used as a proxy of people's material standard of living as we see in chapter 2. Table IV-4 displays Norway as an outlier for EMR_{elect}. This can be explained by the fact that the country produces more than 90% of electricity from cheap hydro and the cold weather requiring large consumption for heating. Differences in EMR_i can be explained using specific data in relation to household appliances, ownership and use of cars, heating necessities in relation to local climate conditions and type of households' structure (compact apartments or isolated houses, etc.). The metabolic pattern of the whole cluster (EU27+N) could be interpreted in terms of an average of the expected pattern of energy carriers consumed per hour (EMR) in the Household sector in EU27 + Norway is [0,74 1,7 1,89] MJ/h for electricity, heat and fuel, respectively.

Table IV-4 Household End use matrix of EU27+Norway for the year 2012

HH	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA/ HA_EU27+N
EU27+N	4.167	x	0,74	1,7	1,89	-	=	3.098	7.078	7.889	0	100%
Austria	67		0,95	2,0	2,8	-		63	131	184	0	1,6%
Belgium	94		0,76	1,9	2,9	-		71	174	268	0	2,3%
Bulgaria	62		0,63	0,73	0,35	-		39	45	21	0	1,5%
Cyprus	6,9		0,87	0,64	2,2	-		6,0	4,4	15	0	0,2%
Czech Republic	83		0,63	1,9	0,98	-		52	159	81	0	2,0%
Denmark	45		0,80	1,4	2,4	-		36	63	110	0	1,1%
Estonia	10		0,67	1,8	1,7	-		7,0	19	17	0	0,3%
Finland	43		1,9	1,4	3,0	-		81	59	127	0	1,0%
France	552		1,0	1,6	2,0	-		570	887	1.079	0	13%
Germany	676		0,73	1,8	2,8	-		493	1.221	1.908	0	16%
Greece	89		0,77	0,69	2,6	-		69	61	230	0	2,1%
Hungary	80		0,48	1,9	0,73	-		38	154	59	0	1,9%
Ireland	37		0,79	1,3	3,0	-		29	48	109	0	0,9%
Italy	503	x	0,50	2,2	2,1	-	=	250	1.092	1.033	0	12%
Latvia	17		0,37	1,9	1,2	-		6,4	34	21	0	0,4%
Lithuania	25		0,38	1,4	1,4	-		9,5	34	36	0	0,6%
Luxembourg	4,1		0,80	2,3	3,4	-		3,3	9,3	14	0	0,1%
Malta	3,4		0,66	0,28	0,98	-		2,2	0,9	3,3	0	0,1%
Netherlands	134		0,67	2,4	2,0	-		90	328	272	0	3,2%
Norway	40		3,5	0,70	1,9	-		138	28	75	0	1,0%
Poland	302		0,34	1,9	1,1	-		102	583	328	0	7,2%
Portugal	84		0,55	0,76	1,3	-		46	64	107	0	2,0%
Romania	160		0,27	1,6	0,46	-		43	254	73	0	3,8%
Slovakia	43		0,39	1,1	1,1	-		17	49	49	0	1,0%
Slovenia	16		0,69	1,6	2,5	-		11	27	41	0	0,4%
Spain	380		0,71	0,84	1,3	-		270	319	480	0	9,1%
Sweden	76		1,8	0,71	2,3	-		140	54	173	0	1,8%
United Kingdom	533		0,77	2,2	1,8	-		413	1.174	972	0	13%

The data about the end-uses in the Household are visualized in Figure IV-5.

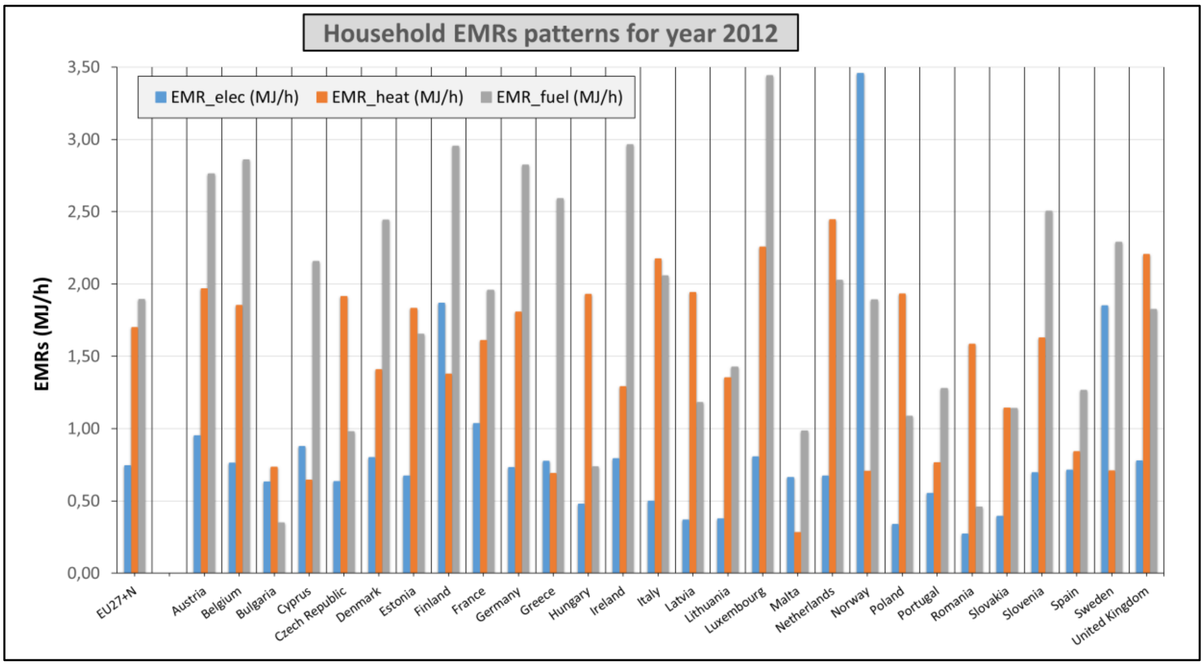


Figure IV-5 Household Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.4 Level n-2 – economic sectors

In this section, I open the Paid Work splitting it into four main economic sectors. Two are primary sectors - Energy & Mining and Agriculture, Forestry and Fishing - producing raw materials for the society (the primary flows). One is the secondary sector - Manufacturing & Construction - processing raw materials in goods and generating funds (converters) needed for reproducing and maintaining the infrastructures of the society. The last one is the tertiary sector - Service & Government – reproducing and running the institutions in the society.

2.4.1 Energy & Mining

The characteristics of the end uses in the Energy & Mining sector varies a lot from one country to another –Table IV-5 and Figure IV-6. In fact, they strongly depend on resource availability (determining the option of domestic production) and the openness of the economy (measuring the level of externalization of the domestic supply to other countries). The vast majority of European countries import crude oil to cover their consumption, some refine it, while other just import directly the refined products. A similar pattern is found for the supply of minerals. This implies that if we want to understand the factors determining the performance of this sector we have to look at data referring to lower levels of analysis – characterizing the efficiency of the processes of exploitation of different Primary Energy Sources – and consider the levels of importation and exportation of the different products (in the next chapter I will present an extension of the data array with indicators referring to products that allows to deal with this type of inferences). In general, the metabolic patterns of this sector (especially electricity and heat) reflects the large requirement of energy investments that are needed to exploit primary energy sources. This sector tends to achieve high levels of Gross Value Added per working hour (the largest one is Norway with almost 800 €/h thanks to its oil reserves).

Table IV-5 Energy & Mining End use matrix of EU27+Norway for the year 2012

EM	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	3.901	x	280	612	17	122	=	1.092	2.386	68	100%	100%	12
Austria	60		487	671	4,3	119		29	40	0,26	1,5%	1,5%	17
Belgium	43		556	1.686	2,0	201		24	73	0,085	1,1%	1,8%	16
Bulgaria	100		257	144	0	23		26	14	0,042	2,6%	0,5%	35
Cyprus	3,9		202	0	56	97		0,78	0	0,22	0,1%	0,1%	6,2
Czech Republic	117		301	284	5,1	60		35	33	0,60	3,0%	1,5%	18
Denmark	29		310	1.459	27	401		8,9	42	0,77	0,7%	2,4%	6,1
Estonia	28		245	79	34	32		6,8	2,2	0,93	0,7%	0,2%	24
Finland	37		517	1.200	46	141		19	45	1,7	1,0%	1,1%	19
France	236		720	591	17	142		170	139	3,9	6,0%	7,1%	18
Germany	508		387	661	6,3	115		196	336	3,2	13%	12%	15
Greece	69		469	884	19	90		32	61	1,3	1,8%	1,3%	25
Hungary	90		149	274	3,7	39		13	25	0,34	2,3%	0,7%	18
Ireland	31		217	131	55	110		6,8	4,1	1,7	0,8%	0,7%	7,1
Italy	241		349	898	6,9	121		84	217	1,7	6,2%	6,1%	16
Latvia	30	x	55	35	10	28	=	1,7	1,0	0,30	0,8%	0,2%	6,9
Lithuania	31		161	712	5,6	32		4,9	22	0,17	0,8%	0,2%	38
Luxembourg	2,6		684	1,9	0	118		1,8	0	0	0,1%	0,1%	15
Malta	-		-	-	-	-		-	-	-	-	-	-
Netherlands	62		559	2.645	8,3	565		35	164	0,51	1,6%	7,4%	7,8
Norway	128		245	1.392	95	794		31	178	12	3,3%	21%	2,9
Poland	906		111	161	4,5	26		101	146	4,1	23%	5,0%	18
Portugal	41		268	400	31	117		11	17	1,3	1,1%	1,0%	10
Romania	361		101	186	8,2	22		36	67	3,0	9,3%	1,7%	21
Slovakia	47		269	507	7,2	65		13	24	0,34	1,2%	0,6%	20
Slovenia	19		251	12	4,5	54		4,7	0,22	0,085	0,5%	0,2%	13
Spain	181		379	1.704	12	177		68	308	2,2	4,6%	6,7%	16
Sweden	72		503	632	12	299		36	46	0,90	1,9%	4,5%	6,8
United Kingdom	428		220	897	62	151		94	384	27	11%	14%	11

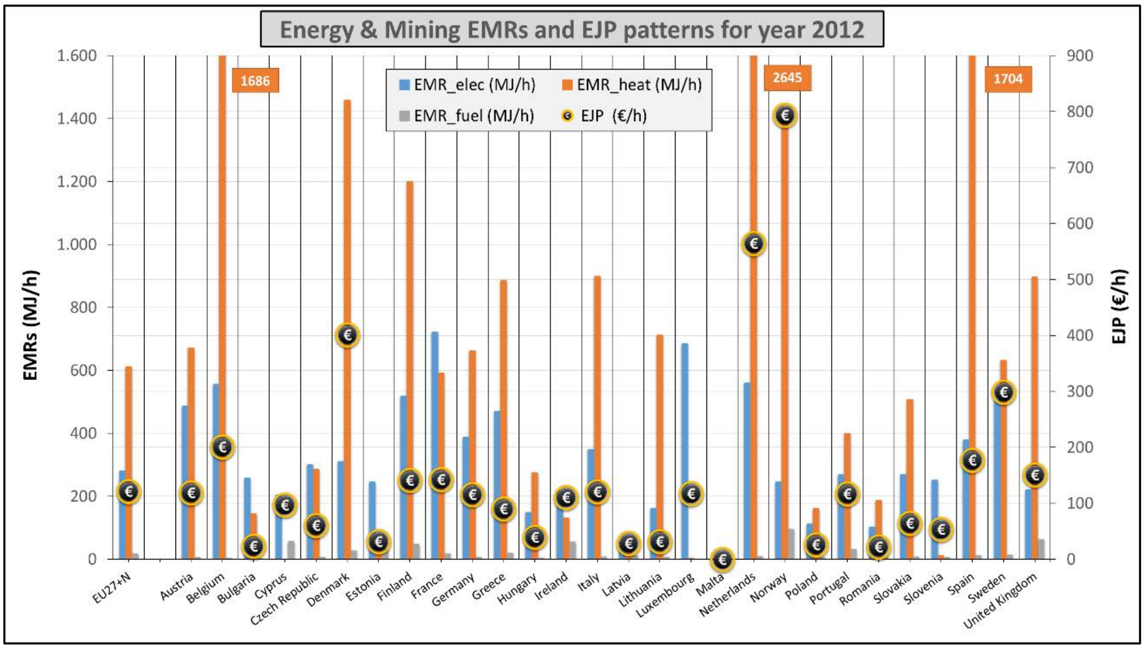


Figure IV-6 Energy & Mining Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.4.2 Agriculture, Forestry & Fishing

Agriculture, Forestry & Fishing (AF) sector presents the lowest Energy Metabolic Rates, as well as the lowest Economic Job Productivity –Table IV-6 and Figure IV-7. The comparison between this sector and the Energy Sector allows to easily understand why a multiscale analysis is crucial in showing differences in sectors, not detectable at the upper scale of analysis (i.e. level n-1 where ES and AF have been aggregated under the paid work sector). Nevertheless, AF is a fundamental sector for producing food, consuming water and managing land, therefore, and this explains the heavy presence of subsidies in this sector (Giampietro *et al.*, 2014). As shown in Table IV-6, AF is characterized by a profile of benchmarks [8 15 26] MJ/h as EMRs and 9 €/h EJP. The converters of this sector use basically fuel (tractors and other agriculture machinery, fishing vessels or wood cutting vehicles), fuel EMRs are quite high in comparison with other sectors, but when compared with the Transport Sector.

Table IV-6 Agriculture, Forestry and Fishing End use matrix of EU27+Norway for the year 2012

AF	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	21.286	x	8	15	26	9	=	171	326	556	100%	100%	7,9
Austria	451		6,3	23	22	9,8		2,9	10	10	2,1%	2,2%	7,4
Belgium	125		12	85	126	20		1,5	11	16	0,6%	1,3%	15
Bulgaria	745		1,3	1,9	7,5	2,9		0,97	1,4	5,6	3,5%	1,1%	5,4
Cyprus	54		8,6	4,2	19	7,5		0,47	0,23	1,0	0,3%	0,2%	7,1
Czech Republic	321		11	19	43	10		3,6	6,2	14	1,5%	1,6%	11
Denmark	107		69	74	180	28		7,4	7,9	19	0,5%	1,5%	18
Estonia	54		15	9,0	61	12		0,79	0,48	3,3	0,3%	0,3%	11
Finland	264		22	38	65	18		5,7	10,1	17	1,2%	2,4%	11
France	1.665		18	19	75	22		29,3	30,9	126	7,8%	18%	7,9
Germany	1.122		-	-	-	18		-	-	-	5,3%	10%	-
Greece	980		10	2,3	1,2	6,1		9,8	2,2	1,2	4,6%	3,0%	4,9
Hungary	530		5,3	9,8	16	7,3		2,8	5,2	8,7	2,5%	1,9%	6,5
Ireland	184		11	0	45	13		2,0	0	8,2	0,9%	1,2%	7,1
Italy	2.301	x	9,3	4,2	38	12	=	21,3	9,6	87	11%	14%	6,6
Latvia	212		2,5	5,7	20	4,7		0,53	1,2	4,2	1,0%	0,5%	8,6
Lithuania	321		2,0	5,6	6,2	3,7		0,66	1,8	2,0	1,5%	0,6%	5,4
Luxembourg	2,8		49	61	256	47		0,14	0,17	0,72	0,01%	0,1%	12
Malta	10		3,6	0	17	9,7		0,036	0,0	0,17	0,05%	0,05%	3,4
Netherlands	364		79	248	54	25		28,8	90,4	20	1,7%	4,6%	22
Norway	123		61	9,3	218	33		7,5	1,2	27	0,6%	2,1%	14
Poland	3.864		1,5	19	19	3,4		5,6	72,2	75	18%	6,7%	15
Portugal	764		4,7	1,0	17	4,3		3,6	0,79	13	3,6%	1,7%	8,5
Romania	4.099		0,72	0,88	3,2	1,6		3,0	3,6	13	19%	3,2%	4,6
Slovakia	134		7,7	16	21	15		1,0	2,1	2,8	0,6%	1,0%	4,4
Slovenia	153		0	2,0	19	5,4		0	0,31	2,9	0,7%	0,4%	5,2
Spain	1.461		9,9	22	46	16		14,4	31,5	68	6,9%	12%	7,1
Sweden	226		14	45	25	25		3,1	10,2	5,7	1,1%	2,8%	4,9
United Kingdom	648		21	23	10	16		13,9	14,9	6,5	3,0%	5,3%	5,9

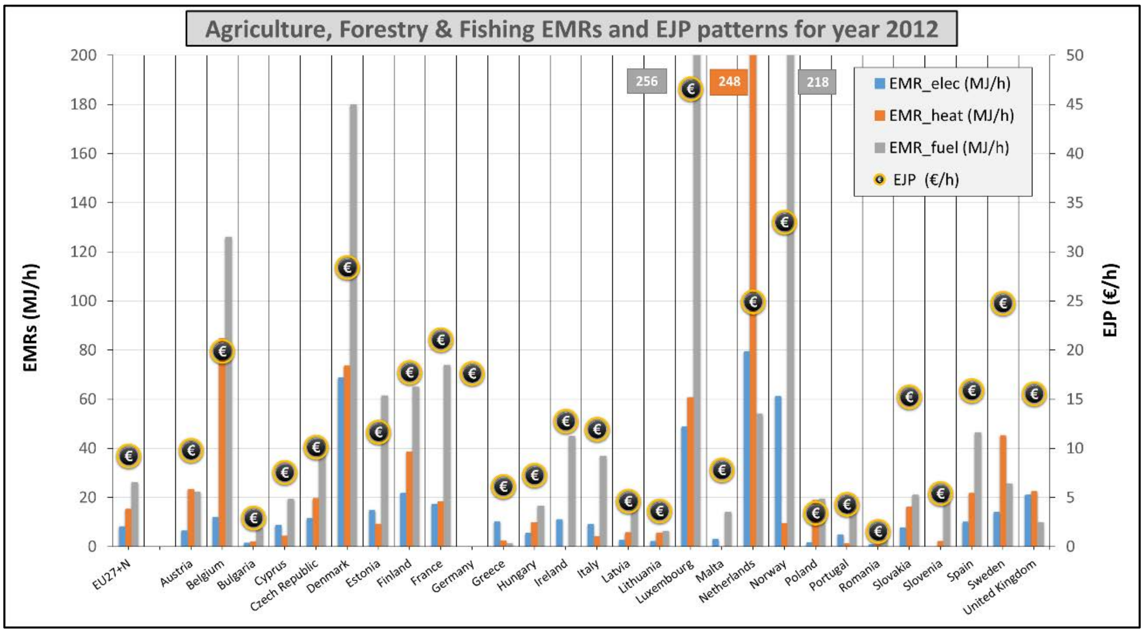


Figure IV-7 Agriculture, Forestry & Fishing Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.4.3 Manufacturing & Construction

The metabolic pattern of the industrial sector for the EU27+N countries is shown in Table IV-7 and Figure IV-8. Here we can see the relation between the levels of EMRs and EJP: Belgium presents the largest Economic Job Productivity (73 €/h) with one of the largest Energy Metabolic rates [158 316 12] MJ/h, while Finland shows a medium EJP (37 €/h) with a really high EMRs [142 244 22] MJ/h. However, how we will see in the next section when opening this sector and looking at the manufacturing subsectors, there is a very strong heterogeneity in the values of the benchmarks found there. This means that without looking at the characteristics (the mix and the relative importance of the manufacturing sub-sectors) data aggregated at these levels are not really useful to study energy efficiency.

Table IV-7 Manufacturing & Construction End use matrix of EU27+Norway for the year 2012

MC	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	64.613	x	57	103	7,1	36	=	3.706	6.664	459	100%	100%	7,5
Austria	1.489		65	170	11	45		97	253	17	2,3%	2,8%	8,3
Belgium	843		158	316	12	73		133	266	9,9	1,3%	2,6%	11
Bulgaria	943		28	58	1,3	7,8		26	55	1,2	1,5%	0,3%	18
Cyprus	120		14	37	5,7	15		1,6	4,5	0,7	0,2%	0,1%	5,5
Czech Republic	3.014		27	65	0,91	14		80	197	2,8	4,7%	1,7%	11
Denmark	694		44	73	12	47		31	51	8,1	1,1%	1,4%	4,5
Estonia	293		27	42	6,6	11		7,8	12	1,9	0,5%	0,1%	11
Finland	934		142	244	22	37		133	228	21	1,4%	1,5%	18
France	5.051		81	134	6,1	55		409	674	31	7,8%	12%	6,7
Germany	8.969		90	164	5,4	70		808	1.472	49	14%	27%	6,1
Greece	1.109		37	65	9,1	16		42	72	10	1,7%	0,7%	11
Hungary	1.781		18	35	2,5	11		32	63	4,5	2,8%	0,8%	8,0
Ireland	577		53	85	14	63		31	49	8,2	0,9%	1,6%	4,0
Italy	6.543	x	66	99	5,7	46	=	430	649	37	10%	13%	6,3
Latvia	120		59	212	18	22		7,1	26	2,1	0,2%	0,1%	19
Lithuania	360		29	61	2,9	19		10	22	1,0	0,6%	0,3%	7,6
Luxembourg	80		115	185	5,8	36		9,2	15	0,47	0,1%	0,1%	14
Malta	44		32	2,9	3,9	18		1,4	0,13	0,17	0,1%	0,0%	5,2
Netherlands	2.085		60	140	8,6	42		124	292	18	3,2%	3,8%	7,6
Norway	658		235	110	21	56		154	72	14	1,0%	1,6%	14
Poland	8.456		18	48	1,6	9,2		155	402	14	13%	3,3%	11
Portugal	1.837		30	67	3,7	15		55	123	6,8	2,8%	1,2%	10
Romania	4.005		18	46	3,1	9,3		73	186	13	6,2%	1,6%	11
Slovakia	1.138		38	117	0,67	16		43	133	0,77	1,8%	0,8%	14
Slovenia	409		51	60	5,5	19		21	24	2,3	0,6%	0,3%	11
Spain	5.704		45	99	6,2	35		256	564	36	9%	8,5%	6,7
Sweden	1.518		120	171	6,5	43		183	260	9,9	2,3%	2,8%	12
United Kingdom	5.839		60	86	24	43		352	501	140	9,0%	11%	6,6

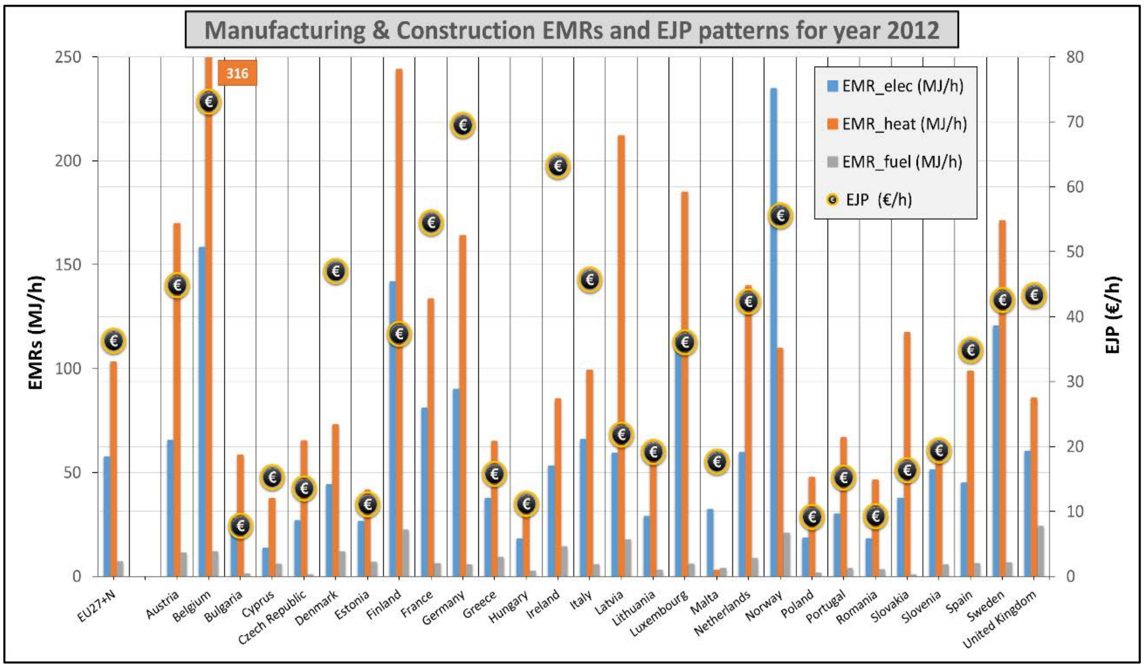


Figure IV-8 Manufacturing & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.4.4 Service & Government

Service & Government sector could be considered a dematerialized productive sector when compared with Manufacturing & Construction due to its higher Economic Job Productivity and lower Energetic Metabolic Rates. As have been already indicated in the literature (Giampietro, Mayumi and Sorman, 2012), this fact is the common misunderstanding behind the Environmental Kuznets Curve hypothesis and the assumption of dematerialization of developed economies when looking the Economic Energy Intensity (EEI). One more time, we see that this indicator cannot properly explain the relation between the energy and value-added generation: Germany and Greece present the same EEI (2,4 MJ/€) in spite of expressing really different energy patterns (Germany [33 28 78] MJ/h and (93 €/h), while Greece [11 4,8 16] MJ/h and (23 €/h)).

On the other hand, remaining in the analysis of the Service and Government sector, looking at Table IV-8 and Figure IV-9 we can see that the EMR_{fuel} is quite high for this sector (48 MJ/h); but this value is determined only by the consumption of the Transport sector.

Table IV-8 Service & Government End use matrix of EU27+Norway for the year 2012

SG	HA (10^9 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 €)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	172	x	19	15	48	50	=	3.348	2.657	8.271	8.611	100%	100%	2,7
Austria	4,9		12	7,4	41	40		59	37	203	199	2,9%	2,3%	2,4
Belgium	2,3		36	34	119	112		85	78	276	261	1,4%	3,0%	2,6
Bulgaria	1,3		23	27	61	17		30	35	80	22	0,8%	0,3%	10
Cyprus	0,49		15	2,9	62	27		7,2	1,4	30	13	0,3%	0,2%	4,7
Czech Republic	5,5		11	12	29	16		58	64	162	86	3,2%	1,0%	5,2
Denmark	3,1		13	3,6	35	52		39	11	108	161	1,8%	1,9%	1,6
Estonia	0,74		13	3,0	24	14		9,4	2,2	17	10	0,4%	0,1%	4,9
Finland	2,9		23	3,2	33	41		67	9,5	97	120	1,7%	1,4%	2,6
France	15		37	23	87	100		546	332	1.281	1.469	8,6%	17%	2,4
Germany	18		33	28	78	93		585	501	1.387	1.647	10%	19%	2,4
Greece	6,2		11	4,8	16	23		67	30	101	142	3,6%	1,7%	2,4
Hungary	4,6		9,9	15	23	12		45	69	103	54	2,6%	0,6%	6,2
Ireland	2,4		9,6	7,9	48	42		23	19	115	99	1,4%	1,1%	2,4
Italy	11	x	35	42	52	99	=	364	442	541	1.042	6,1%	12%	2,1
Latvia	0,34		31	31	71	36		11	10	24	12,1	0,2%	0,1%	6,0
Lithuania	0,64		18	22	35	29		11	14	22	18,7	0,4%	0,2%	4,1
Luxembourg	0,41		24	17	254	73		9,9	7,1	103	30	0,2%	0,3%	5,9
Malta	0,23		14	2,8	39	21		3,1	0,63	8,9	4,8	0,1%	0,1%	4,4
Netherlands	10		14	22	34	41		139	222	335	403	5,8%	4,7%	2,7
Norway	2,9		33	2,8	48	57		97	8,0	140	166	1,7%	1,9%	2,7
Poland	18		9,4	12	17	11,5		171	213	319	211	11%	2,5%	5,3
Portugal	5,7		10	3,6	29	19		59	20	162	107	3,3%	1,2%	3,7
Romania	7,2		4,6	5,0	21	8,8		33	36	150	63	4,2%	0,7%	5,3
Slovakia	2,6		9,6	16	14	16		25	42	37	41	1,5%	0,5%	4,0
Slovenia	0,96		13	1,5	52	22		12	1,5	50	21	0,6%	0,2%	4,9
Spain	23		13	4,0	43	30		305	93	1.000	686	13%	8,0%	3,3
Sweden	5,5		22	2,9	31	48		120	16	173	264	3,2%	3,1%	2,2
United Kingdom	17		22	20	74	75		365	342	1.245	1.258	9,7%	15%	2,4

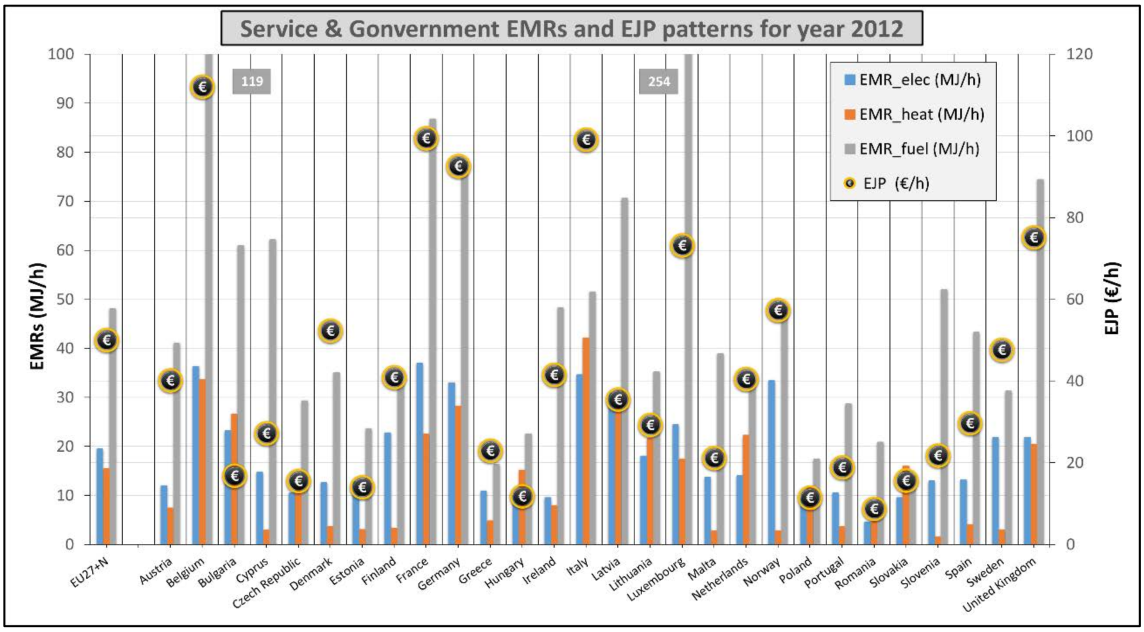


Figure IV-9 Service & Government Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.5 Level n-3

At this level of analysis, I split the agricultural sector in two: (i) Agriculture & Forestry; and (ii) Fishing; and I split the service and government sector in two: (i) Transport Service; and (ii) Service & Government. I present here only these 4 subsectors defined at the level n-3 because, due to inconsistency of the metadata across scales, it is not possible to open the Manufacturing & Construction sector and the Energy & Mining sector. This will be done using a different source of data in Section 3.

Generating end use matrices at this level of desegregation present some problems due to the occurrence of missing data – e.g. in the Transport and Fishing sector.

2.5.1 Agriculture & Forestry

Analyzing the Agriculture & Forestry sector energy End Use matrix we can see how the use of energy carriers is related with the labor productivity. As Table IV-9 and Figure II-1Figure IV-10 shows, high Economic Job Productivity is clearly obtained when Energy Metabolic Rate are high (e.g. Denmark [71 76 140] MJ/h and 26 €/h vs Romania [0,72 0,88 3,2] MJ/h and 1,6 €/h). This relation just shows that the intensive use of machinery for replacing human labor is more important in terms of energy consumption that the savings that one efficient technology could provide. That is to say, human activity role is essential to understand the relation between energy consumption and added value generation when talking about energy efficiency. For example, the Economic Energy Intensity of Denmark 17 MJ/€ is much higher than Romania 4,7 MJ/€. But in Denmark technology (and energy) is used as improver of the productivity of labor: endosomatic energy (human labor) is replace by exosomatic energy (electricity, heat and fuels energy carriers). I will illustrate this with more detail in the next chapter, where I will discuss the role of the productivity of labor (production per hour of labor) in relation to energy consumption.

Table IV-9 Agriculture & Forestry End use matrix of EU27+Norway for the year 2012

AFO	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	20.191	x	8,4	16	25	9,3	=	169	322	495	100%	100%	7,9
Austria	450		6,3	23	22	9,8		2,9	10	10	2,2%	2,3%	7,4
Belgium	125		12	85	126	20		1,5	11	16	0,6%	1,3%	15
Bulgaria	745		1,3	1,9	7,4	2,9		0,95	1,4	5,5	3,7%	1,2%	5,4
Cyprus	53		8,6	4,3	20	7,4		0,45	0,23	1,0	0,3%	0,2%	7,3
Czech Republic	318		11	20	44	10		3,6	6,2	14	1,6%	1,7%	11
Denmark	104		71	76	140	29		7,4	7,9	15	0,5%	1,6%	16
Estonia	52		15	9,3	64	11		0,76	0,48	3,3	0,3%	0,3%	12
Finland	252		23	40	62	18		5,7	10	16	1,2%	2,4%	10
France	1.665		17	18	67	21		29	30	112	8%	19%	7,5
Germany	1.122		-	-	-	18		-	-	-	6%	10%	-
Greece	933		11	2,2	0,09	5,7		9,8	2,0	0,086	4,6%	2,9%	5,2
Hungary	528		5,3	9,8	16	7,3		2,8	5,2	8,7	2,6%	2,0%	6,5
Ireland	180		11	0	46	12		2,0	0	8,2	0,9%	1,1%	7,7
Italy	2.301	x	9,1	3,8	35	12	=	21	8,7	80	11%	14%	6,5
Latvia	-		-	-	-	-		0,50	1,2	3,9	-	-	-
Lithuania	321		2,0	5,6	5,9	3,6		0,64	1,8	1,9	1,6%	0,6%	5,4
Luxembourg	2,8		49	61	256	47		0,14	0,17	0,72	0,01%	0,1%	12
Malta	10		3,2	0	17	7,4		0,032	0	0,17	0,05%	0,04%	4,4
Netherlands	358		81	247	41	25		29	89	15	1,8%	4,8%	22
Norway	95		72	11	60	23		6,8	1,1	5,7	0,5%	1,2%	12
Poland	3.852		1,5	19	19	3,4		5,6	72	75	19%	7,0%	15
Portugal	737		4,5	0,96	13	4,0		3,3	0,71	9,4	3,6%	1,6%	7,7
Romania	4.095		0,72	0,88	3,2	1,6		3,0	3,6	13	20%	3,4%	4,7
Slovakia	134		7,7	16	21	15		1,0	2,1	2,8	0,7%	1,1%	4,4
Slovenia	153		0	2,1	19	5,4		0	0,31	2,9	0,8%	0,4%	5,2
Spain	1.383		10	23	48	15		14	31	66	6,8%	11%	7,8
Sweden	223		14	46	21	25		3,1	10	4,8	1,1%	3%	4,7
United Kingdom	-		-	-	-	-		14	15	6,5	-	5%	6,3

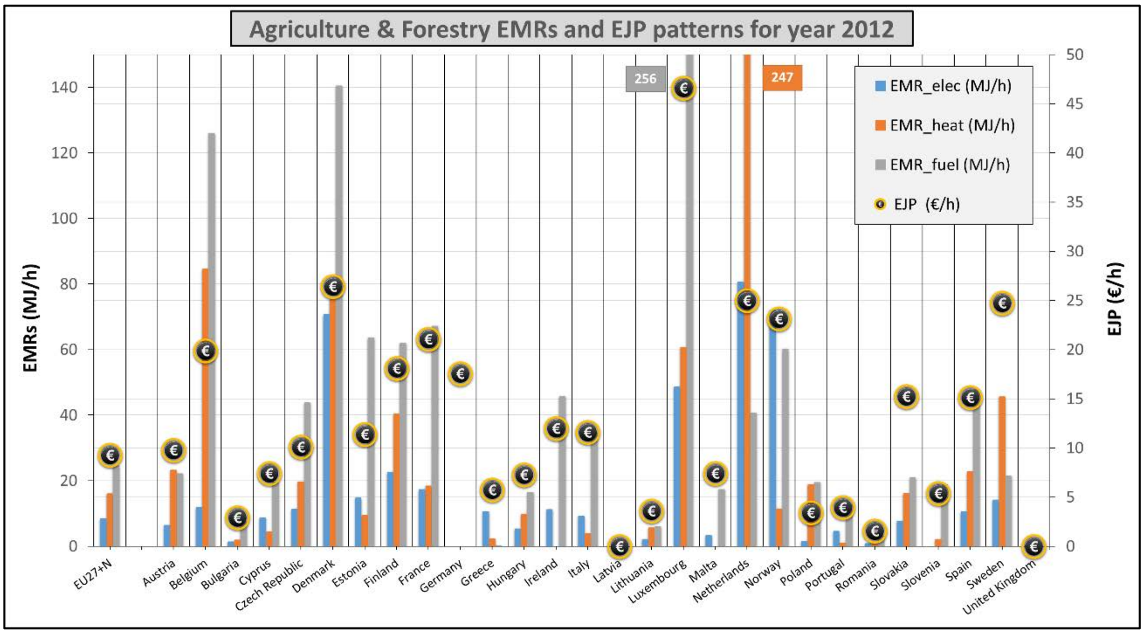


Figure IV-10 Agriculture & Forestry Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.5.2 Fishing

Although there are too many missing data for getting reliable metabolic patterns for the majority of countries studied, we can have an idea of the values of the pattern of benchmarks for the EU27+N: [9 16 206] MJ/h and 36 €/h – Table IV-10 and Figure IV-11 (this values are generated using values from the countries with more reliable data). As we can see, the fishing sector has a large consumption of fuels due to heavy reliance on engines in fishing vessels (and generator for the electricity self-produced in the vessels). The increasing importance of aquaculture in many countries may make other energy carriers also relevant in the near future.

Table IV-10 Fishing End use matrix of EU27+Norway for the year 2012

FI	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (TJ/year)	ET_heat (TJ/year)	ET_fuel (TJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	234	x	9	16	260	36	=	1.996	3.637	60.974	100%	100%	11
Austria	0,72		0	37	0	28		0	27	0	0,3%	0,2%	1,5
Belgium	-		-	-	-	-		-	-	-	-	-	-
Bulgaria	-		-	-	-	-		18	0	42	-	0,2%	5,7
Cyprus	1,1		10	0	0	13		11	0	0	0,5%	0,2%	1,9
Czech Republic	2,8		15	0	0	9,0		40	0	0	1,2%	0,3%	4,2
Denmark	3,0		0	0	1.567	99		0	0	4.654	1,3%	4%	22
Estonia	1,9		17	0	0	19		32	0	0	0,8%	0,4%	2,3
Finland	12		0	0	129	11		0	0	1.540	5,1%	1,5%	17
France	-		-	-	-	-		443	464	13.857	-	9,2%	27
Germany	-		-	-	-	-		0	0	0	-	3%	0
Greece	46		0	5	24	13		0	212	1.115	20%	7%	2,9
Hungary	2,5		10	6	0	5		25	14	0	1,1%	0,1%	6,8
Ireland	3,8		0	0	0	50		0	0	0	1,6%	2,3%	0
Italy	-	x	-	-	-	-	=	364	908	7.029	-	17%	8,1
Latvia	-		-	-	-	-		29	5	297	-	-	-
Lithuania	-		-	-	-	-		11	0	86	-	0%	6,7
Luxembourg	-		-	-	-	-		-	-	-	-	-	-
Malta	-		-	-	-	-		4,0	0	0	-	0,3%	0,45
Netherlands	5,9		0	313	856	20		0	1.840	5.039	2,5%	1,4%	77
Norway	29		25	3	736	66		724	80	21.167	12%	23%	17
Poland	12			-	-	4		-	-	-	5,3%	1%	-
Portugal	27		11	3	128	20		295	82	3.511	12%	7%	10
Romania	3,8		-	-	-	13		-	-	-	1,6%	0,6%	-
Slovakia	0,32		-	-	-	5		-	-	-	0,1%	0,0%	-
Slovenia	0,39		-	-	-	11		-	-	-	0,2%	0,1%	-
Spain	78		0	0	21	14		0	5,0	1.650	33%	14%	2,0
Sweden	2,9		0	0	336	28		0	0	987	1,3%	1%	17
United Kingdom	-		-	-	-	-		-	-	-	-	7%	-

UNRELIABLE – MISSING DATA

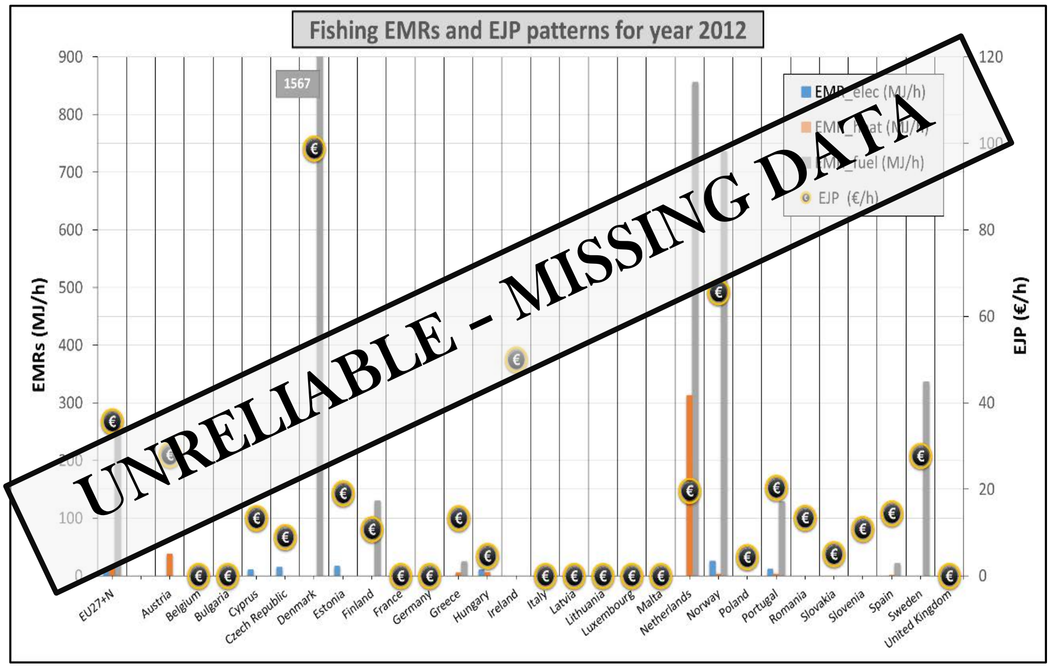


Figure IV-11 Fishing Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.5.3 Transport Service

The great majority of the consumption of energy carriers is in the form of fuels (for trucks, cars, ships, planes) - gasoline, diesel or kerosene - EMR_{fuel} in this sector is by far the largest one. To this one should add trains running on electricity and vehicles running on gas. However, despite the unreliability of the data, the estimates of EMRs of electricity and heat (37 and 64 MJ/h) seem to be 2 orders of magnitude lower than fuel EMR (1224 MJ/h) for the average calculated for the EU27+N cluster (see Table IV-11 and Figure IV-12). This sector is one of the best to illustrate the structural difference of Luxemburg determining its nature of outlier. In fact, the extremely high EMR_{fuel} (almost 4000 MJ/h) found in Luxemburg depends on the low prices of fuels there. This fact provokes that many vehicles going though Luxemburg or people of other countries living near the boarders fill their tanks there. This fact is reflected in statistics as an extremely high consumption of fuels. A more reliable assessment of fuels consumption in Luxemburg would require a bottom-up approach: estimating consumption from traffic and vehicles type data).

Table IV-11 Transport Sector End use matrix of EU27+Norway for the year 2012

TS	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	6.260	x	37	64	1.224	17	=	232	401	7.663	100%	100%	107
Austria	243		46	34	827	31		11,0	8,4	201	3,9%	6,8%	42
Belgium	-		-	-	-	-		5,7	3,8	242	-	-	-
Bulgaria	-		-	-	-	-		1,1	26,7	80	-	1,6%	83
Cyprus	17		0	0	1.779	15		0	0	30	0,3%	0,2%	161
Czech Republic	363		22	14	445	13		8,0	5,3	162	5,8%	4,4%	52
Denmark	139		10	4,3	759	-		1,4	0,6	105	2,2%	-	
Estonia	67		4,3	0	236	7,5		0,28	0	16	1,1%	0,5%	45
Finland	189		14	15	458	32		2,7	2,9	86	3,0%	5,5%	21
France	-		-	-	-	-		45	15	1.184	-	44%	37
Germany	-		-	-	-	-		44	49	1.088	-	-	-
Greece	353		1,9	50	279	-		0,68	18	98	5,6%	-	-
Hungary	267		13	3,9	383	9,5		3,5	1,0	102	4,3%	2,3%	59
Ireland	112		1,4	7,6	828	36		0,16	0,85	90	1,8%	3,7%	34
Italy	-		-	-	-	-		39	113	533	-	-	-
Latvia	-		-	-	-	-		0,46	1,9	22	-	-	-
Lithuania	-		-	-	-	-		0,27	7,7	22	-	-	-
Luxembourg	25		18	3,6	3.980	36		0,46	0,092	100	0%	0,8%	155
Malta	8,6		0	0	992	7,2		0	0	8,6	0%	0,1%	190
Netherlands	420		15	32	787	31		6,5	14	331	6,7%	12,0%	37
Norway	215		11	24	617	51		2,5	5,1	132	3,4%	10%	18
Poland	1.470		7,8	58	205	-		12	85	301	23%	-	-
Portugal	227		6,4	24	700	-		1,4	5,3	159	3,6%	-	-
Romania	661		6,7	4,2	224	8,5		4,4	2,8	148	11%	5,1%	39
Slovakia	147		14	67	251	18		2,0	9,8	37	2,3%	2,4%	25
Slovenia	54		11	7,3	838	19		0,57	0,40	45	0,9%	0,9%	64
Spain	1.009		16	11	941	-		16	11	950	16%	-	-
Sweden	276		35	25	581	-		9,7	7,0	160	4,4%	-	-
United Kingdom	-		-	-	-	-		15	8,2	1.220	-	-	-

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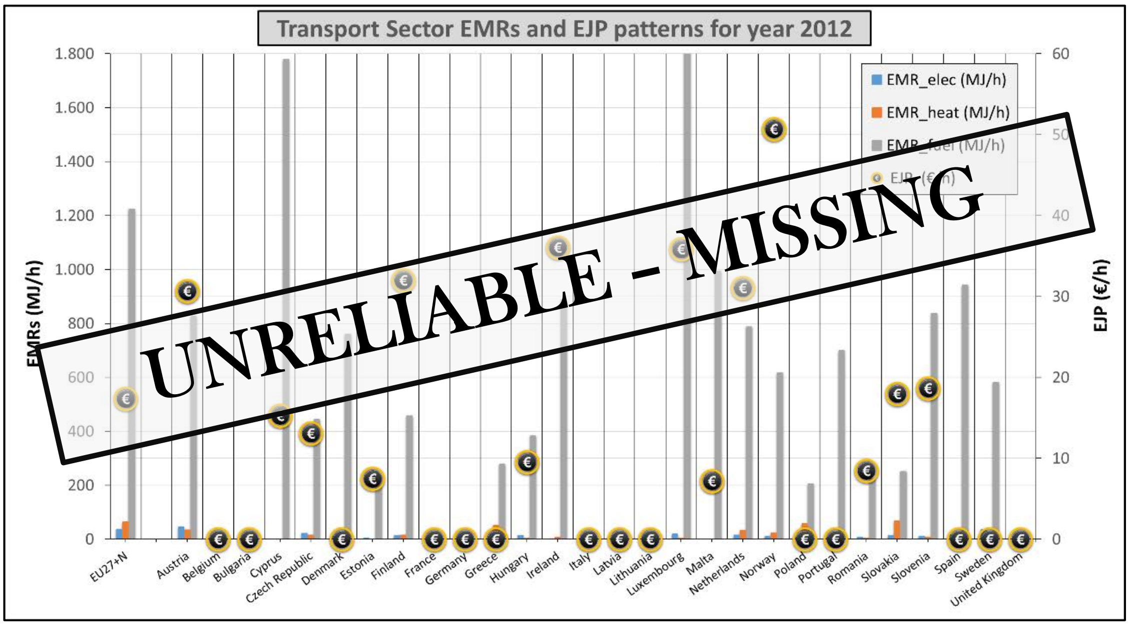


Figure IV-12 Transport Sector Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

2.5.4 Services & Government (without Transport)

Once we have taken out transport from Service & Government, we can see how this sector can produce a lot of value added consuming small quantities of energy carriers. The analysis carried out at this level shows that the financial sector would be the "star sector" in terms of efficiency when using the indicator of Economic Energy Intensity Table IV-12 and Figure IV-13. Unlike the other sectors, we can see that in the financial sector the electricity EMR (19 MJ/h) is higher than heat EMR (14 MJ/h) and fuel EMR (3,7 MJ/h). This fact could be explained due to the high utilization of electric and electronic devices like computers, lights or other office equipment and the low consumption of heat and fuels. National energy balances from Eurostat, IEA and other national statistical offices do not split the data about the consumption of energy carriers in the service sector more in detail. The disaggregation of the service sector in lower sub-compartment can be done for Human Activity and Value added through Nacional Accountings and Structural Business Statistics, but not for energy. Better information about the metabolic characteristics of the Service and Government would be very valuable in the European context and this represent a pending task of the statistical offices. In fact, the Service & Government sector (minus Transport) generates almost 60% of the Gross Value Added and they require more than 65% of the hours of labor in the paid work sector. Moreover, it consumes around 37% of electricity and 19% of the heat of the paid work. A better understanding of the biophysical characteristics of this compartment is mandatory for having an informed discussion over transitions to a lower carbon economy.

Table IV-12 Service & Government without Transport End use matrix of EU27+Norway for the year 2012

SG_nTS	HA (10^6 h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	%HA/ HA_EU27+N	%GVA/ GVA_EU27+N	EEI (MJ/€)
EU27+N	165.785	x	19	14	3,7	41	=	3.116	2.255	607	100%	100%	1,7
Austria	4.706		10	6,0	0,51	41		48	28	2,4	2,8%	2,8%	0,84
Belgium	2.332		34	32	15	109		79	75	35	1,4%	3,7%	1,3
Bulgaria	1.317		22	6,3	0,42	16		29	8,3	0,55	0,8%	0,3%	4,2
Cyprus	472		15	3,0	1,5	28		7,2	1,4	0,69	0,3%	0,2%	1,6
Czech Republic	5.169		9,7	11	0,067	16		50	59	0,34	3,1%	1,2%	2,4
Denmark	2.933		13	3,6	0,82	52		37	10	2,4	1,8%	2,2%	0,74
Estonia	669		14	3,3	2,5	15		9,1	2,2	1,7	0,4%	0,1%	2,9
Finland	2.750		23	2,4	3,7	42		64	6,6	10	1,7%	1,7%	1,7
France	14.759		34	22	6,5	96		502	318	96	8,9%	21%	1,3
Germany	17.764		31	25	17	90		542	452	299	11%	23%	1,5
Greece	5.829		11	2,1	0,42	-		66	12	2,5	3,5%	-	-
Hungary	4.286		9,7	16	0,059	12		41	68	0,25	2,6%	0,8%	3,6
Ireland	2.263		10	8,0	6,7	42		23	18	15	1,4%	1,4%	1,1
Italy	10.506	x	31	31	0,75	94	=	325	330	7,9	6,3%	14%	1,2
Latvia	342		29	25	5,0	33		10	8,6	1,7	0,2%	0,2%	3,4
Lithuania	638		18	9,5	0,20	26		11	6,0	0,13	0,4%	0,2%	2,2
Luxembourg	381		25	18	6,8	76		9,5	7,0	2,6	0,2%	0,4%	1,2
Malta	220		14	2,9	1,4	22		3,1	0,63	0,30	0,1%	0,1%	1,9
Netherlands	9.531		14	22	0,49	41		133	208	4,6	5,7%	5,7%	1,5
Norway	2.684		35	1,1	3,0	58		94	2,9	8,1	1,6%	2,3%	1,7
Poland	16.808		9,5	7,6	1,1	12		160	129	18	10%	2,9%	2,9
Portugal	5.424		11	2,8	0,57	-		58	15	3,1	3,3%	-	-
Romania	6.536		4,3	5,1	0,35	8,8		28	33	2,3	3,9%	0,8%	2,0
Slovakia	2.487		9,3	13	0,017	16		23	32	0,042	1,5%	0,6%	2,5
Slovenia	903		13	1,2	4,9	22		12	1,1	4,4	0,5%	0,3%	1,9
Spain	22.096		13	3,7	2,2	30		289	82	50	13%	9,7%	1,4
Sweden	5.249		21	1,7	2,4	48		111	9,2	13	3,2%	3,7%	1,3
United Kingdom	16.732		21	20	1,5	-		350	333	25	10%	-	-

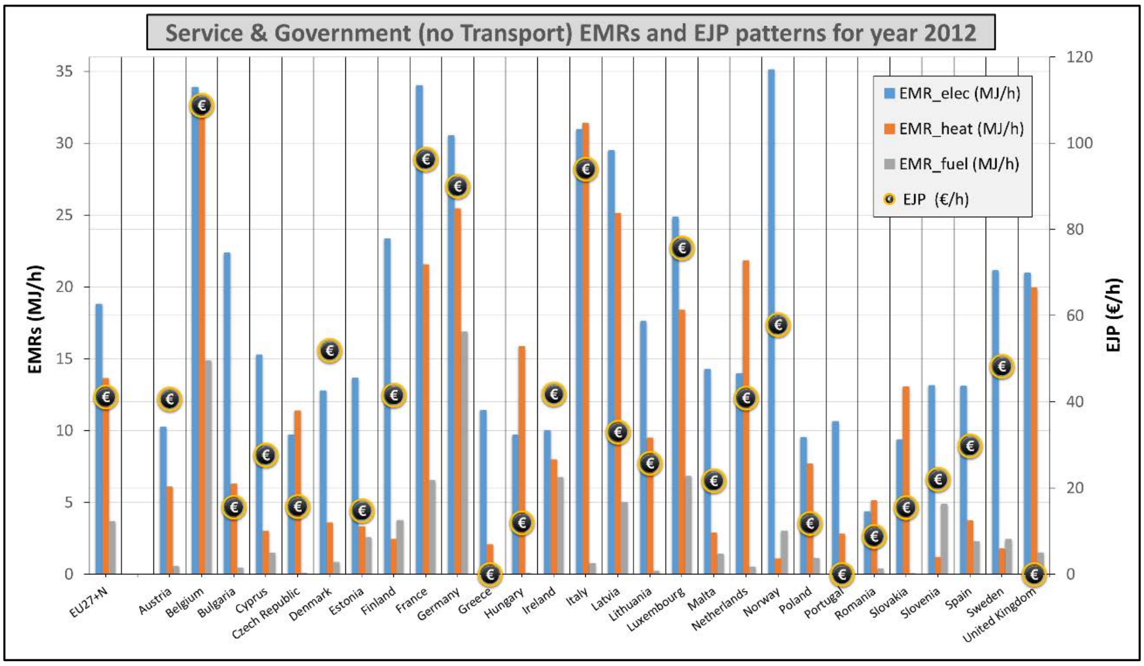


Figure IV-13 Service & Government without Transport Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

3 EU end-use matrices across different hierarchical levels of analysis (n-2, n-3), opening the black-box of the industrial sector.

Moving the analysis of end uses down to lower hierarchical levels is essential for the study the biophysical performance or just to understand the variation in the metabolic patterns expressed by each country. In fact, it is at the local level of analysis – the performance of specific biophysical processes producing specific outputs – that becomes possible to study the specific characteristics of "production functions" – the technical coefficients determining input/output relations – associated with the concept of technical efficiency.

For this reason, I tried to go as low as possible in the analysis of the Manufacturing and Construction sector, even if this has implied the need of moving to a different data source. Since this is a first exploratory assessment, the goal of the analysis is to check the potentiality of the approach and the possibility of generating end use matrices at this level.

This section presents end-use matrices describing the metabolic characteristics of sub-sectors at: (i) the level n-2: Manufacturing & Construction and Energy & Mining; and (ii) the subsectors of these two sectors. The data source for the end-use matrices of this second group has been the structural business statistics (SBS), providing a very detailed dataset for the industrial subsectors. However, this source does not provide all the data required for an analysis of the EU27 countries considered in the previous section. For this reason, this second group of end-use matrices include less countries – EU22. The problem with the missing data refer to the categorization of working hours and value added generation across the elements of the taxonomy.

Data in this section are important because they clearly show that inside the Manufacturing sectors there are very large metabolic differences when considering the pattern of end uses across subsectors. Therefore, the information gathered at this level of analysis is crucial to put in context and evaluate energy efficiency policies, as well as to understand the metabolic peculiarities of each country. It is important to be able to identify whether the economic energy intensity of a sub-sector is determined by the specificity of the production process, or by the technical solutions or by the combination of different production processes accounted in the same category. This detailed information is also needed to assess the tradeoffs between labor and value added that can be obtained by using different mixes of energy carriers (e.g. increasing the consumption of electricity to save labor).

The 22 countries included in this section (the structural elements observed by the statistics) are: Austria, Belgium, Bulgaria, Croatia, Czech Republic, Finland, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, the Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Spain, Sweden and United Kingdom. I will refer as EU-22 to the cluster conforming all these countries.

As regard the functional levels of analysis, the end use matrix of all EU-22 countries includes the following compartments and levels (illustrated in Figure IV-14): (i) **Level n-2:** Energy & Mining (EM) and Manufacturing & Construction (MC); (ii) **Level n-3:** Energy Sector (ES); Mining & Quarrying (MQ); Iron & Steel (IS); Non-Ferrous Metals (NF); Chemical & Petrochemical (CP); Non-Metallic Minerals (NM); Food & Tobacco (FT); Textil & Leather (TL); Paper, Pulp & Print (PPP); Transport Equipment (TE); Machinery (MA); Wood & Wood Products (WWP); Non-Specified (Industry) (NS); and Construction (CO).

Level n-2	Level n-3
Agriculture, Forestry & Fishing (AF)	Agriculture & Forestry (AFO)
	Fishing (FI)
Energy & Mining (EM)	Energy Sector (ES)
	Mining & Quarrying (MQ)
Manufacturing & Construction (MC)	Iron & Steel (IS)
	Non-Ferrous Metals (NF)
	Chemical & Petrochemical (CP)
	Non-Metallic Minerals (NM)
	Food & Tabacco (FT)
	Textile & Leather (TL)
	Paper, Pulp & Print (PPP)
	Transport Equipment (TE)
	Machinery (MA)
	Wood & Wood Products (WWP)
	Non-Specified (Industry) (NS)
	Construction (CO)

Figure IV-14 Dendrogram of the different levels and compartment analyzed with SBS database

I start the presentation of the results by showing the End Use matrix calculated over the whole EU-22 cluster (at the supranational level) providing a set of average values calculated per sector and subsector. This is shown in Figure IV-15 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n-2 to Level n-3 of EU22 for year 2012

Table IV-13 and Figure IV-15. These values can be used to contextualize the subsequent end use matrices calculated using data referring to the national level.

At level n-2, Energy & Mining (EM) surpasses Manufacturing & Construction (MC) in all EMRs [294 725 22] vs [61 107 12] MJ/h in electricity, heat and fuel. Moreover, EM also presents a higher value of EJP (122 MJ/h) than MC (only 33 MJ/h).

In the same table, we can found also the metabolic rates of the other subsectors at level n-3. Contrary to the previous levels of analysis, I found that the largest electricity and heat EMRs are in the MC. Iron & Steel is the sector with higher EMR heat (1.523 MJ/h) followed distantly by Non-Metallic Minerals (571 MJ/h) due to their intensive use of heat in furnaces smelting and cooking minerals. Non-ferrous Metals (aluminum, copper, lead, nickel, titanium, zinc, etc.) present the largest **EMR** electricity (563 **MJ**/h) due to the use of process like Hall–Heroult for producing aluminum or other electric intensive processes. Regarding **EMR** fuel, I found that the largest value is in the Mining & Quarrying sector (69 **MJ**/h) due to the intensive use of heavy machinery for extracting raw materials, followed by Chemical & Petrochemical sector (47 **MJ**/h). On the other hand, I found again that the largest **EJP** is found in the more intensive sectors: Energy Sector with 133 €/h and Chemical & Petrochemical with 69 €/h. If we add to this group of subsectors Non-Metallic Minerals [122 571 27] and Paper, Pulp & Print [218 391 15] **MJ**/h; we can create a cluster of industrial subsectors characterized by high **EMRs** going from 122 to 563 **MJ**/h in electricity, from 93 to 1.523 **MJ**/h in heat and from 16 to 69 **MJ**/h in fuel. Likewise, these sectors complement this patterns with an **EJP** that goes from 29 to 133 €/h. At this level, it becomes evident that differences among subsectors have nothing to do with the differences in performance of the technologies used. Rather the differences in energy intensity simply reflect differences in the characteristics of the biophysical processes associated to the economic activity of production of goods.

The other group of subsectors presents a pattern of **EMRs** between [4,1-62 7,4-137 2,9-32] **MJ**/h for electricity, heat and fuel respectively and a **EJP** from 16 to 42 €/h. Construction has the lowest electricity (4,1 **MJ**/h) and heat (7,4 **MJ**/h) **EMRs** and Textile & Leather the lowest **EJP** with 16 €/h. Non-specified Industry (formed by rubber and plastic products, furniture, jewelry, toys, brooms and brushes and other minor manufactures) have the highest electricity (62 **MJ**/h) and fuel (32 **MJ**/h) **EMRs** of this subsectors group, whereas Wood & Wood Products have the highest heat **EMR** of 137 **MJ**/h and Transport Equipment the highest **EJP** of 42 €/h. Food & Tobacco is situated in the average of this second group with [53 88 10] **MJ**/h and 29 €/h. From this second group, I must highlight that Machinery and Construction subsectors generate the vast majority of working hours (jobs) in Manufacturing & Construction sector representing 24% and 26% of the total and generating 26% and 23% of the total Value Added respectively.

Finally, looking the Economic Energy Intensity indicator one can say that the most energy *efficient* sector results to be Construction with just 1,1 **MJ**/€ and Iron & Steel the most energy intensive with 80 **MJ**/h. However, knowing the high dependency of Construction from Iron & Steel products (and the big influence of speculation in this sector affecting the value added generated on it), one can realize the fragility of this kind of indicators for measuring energy efficiency. On the other hand, looking this proposal of accounting, one can easily understand that the low EEI of the construction sector depends on (is determined by) the high EEI of the iron & steel sectors. In that sense, this analysis allows us to detect clearly the effect of cost shifting across countries.

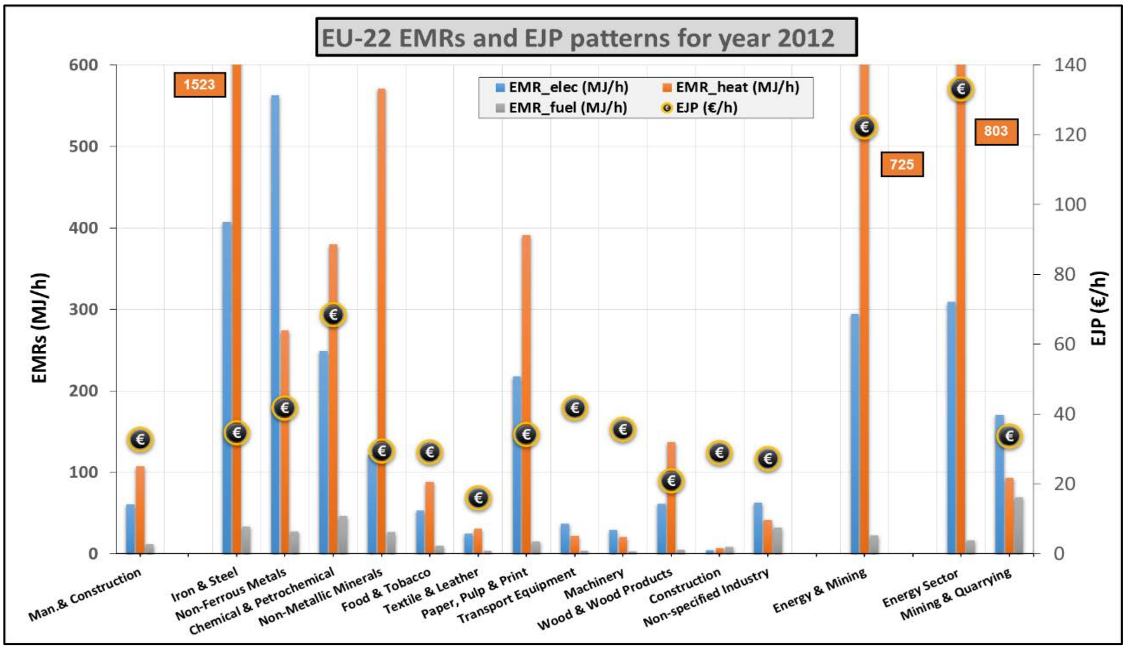


Figure IV-15 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n-2 to Level n-3 of EU22 for year 2012

Table IV-13 Average End use matrix for the region considered (EU-22), all sectors from Level n-2 to Level n-3 for year 2012

EU-22	HA (Mh/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
Manufacturing & Construction	53	x	61	107	12	33	=	3.246	5.735	636	1.752	100%	100%	8,9
Iron and Steel	0,97	X	408	1.523	34	35	=	397	1.484	33	34	1,8%	1,9%	80
Non-Ferrous Metals	0,47		563	274	27	42		264	129	13	20	0,9%	1,1%	43
Chemical and Petrochemical	2,4		249	380	47	69		590	901	111	163	4,4%	9,3%	17
Non-Metallic Minerals	1,8		122	571	27	29		216	1.011	47	52	3,3%	3,0%	33
Food and Tobacco	6,1		53	88	10	29		321	534	60	177	11%	10%	8,5
Textile and Leather	2,9		24	31	4,0	16		71	89	12	47	5,4%	2,7%	6,4
Paper, Pulp and Print	1,9		218	391	15	34		422	757	29	66	3,6%	3,8%	30
Transport Equipment	4,3		37	22	3,6	42		157	95	15	178	8,0%	10%	3,0
Machinery	13		30	20	2,9	36		376	258	37	453	24%	26%	2,9
Wood and Wood Products	1,3		61	137	5,0	21		78	175	6,3	27	2,4%	1,5%	15
Construction	14		4,1	7,4	8,7	29		58	103	122	406	26%	23%	1,1
Non-specified Industry	4,8		62	42	32	27		297	198	153	130	8,9%	7,4%	9,3

EU-22	HA (Mh/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
Energy & Mining	3,1	x	294	725	22	122	=	902	2.222	69	375	100%	100%	13
Energy Sector	2,7	x	310	803	16	133	=	844	2.191	45	363	89%	97%	13
Mining and Quarrying	0,34		170	93	69	34		58	32	24	11	11%	0,7%	19

3.1 Energy & Mining

Opening the Energy & Mining sector for all the EU-22 countries we can see in

Table IV-14 and Figure IV-16, that the Netherlands, Spain, Belgium, Norway and Finland present a heat EMR above 1000 MJ/h. Regarding fuel EMR, just Norway and Ireland exceed the 70 MJ/h. Last but not least, Norway shows the largest EJP with 668 €/h thanks to his important oil industry, distantly followed by the Netherlands with 300 MJ/h due to their gas extraction industry. On the other hand, we can see that Poland concentrate almost 20% of the working hours, followed by Germany (16%) and UK (15%) in this sector. Norway produces 25% of the Value Added using only 4,6% of the working hours, followed by UK (16%) and Germany (15%). One curious point is that, although Energy & Mining sector is one of the most energy intense in terms of machinery and labor (EMRs) nobody would argue that is a dematerialized or an ecofriendly economic activity. However, looking their EEI and using this value as an indicator one may be misled (the value of EEI is just 3,1 MJ/€ for Norway!). One more time, we can see how EEI is a very poor indicator when trying to map the relations between the economy and the environment.

Table IV-14 Energy & Mining End use matrix of EU27+Norway for the year 2012

Energy & Mining	HA (10^6h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	3067	x	310	803	16	133	=	902	2.222	69	375	100%	100%	13
Austria	62		475	651	7,40	103		29	40	0,46	6,3	2,0%	1,7%	18
Belgium	43		562	1.705	2,0	176		24	73	0,085	7,5	1,4%	2,0%	19
Bulgaria	116		221	122	2,4	21		26	14	0,28	2,5	3,8%	0,7%	39
Croatia	36		83	701	18	24		3,0	25	0,64	0,87	1,2%	0,2%	43
Czech Republic	118		298	281	5,8	59		35	33	0,68	6,9	3,9%	1,9%	18
Finland	38		506	1.164	56	103		19	44	2,13	3,9	1,2%	1,0%	26
Germany	502		391	670	6,3	113		196	336	3,2	57	16%	15%	16
Greece	61		527	972	44	69		32	59	2,68	4,2	2,0%	1,1%	38
Hungary	66		201	371	5,1	55		13	25	0,34	3,6	2,2%	1,0%	17
Ireland	25		274	163	73	142		6,8	4,0	1,8	3,5	0,8%	0,9%	5
Italy	236	X	357	918	8,1	154	=	84	217	1,90	36	7,7%	10%	13
Latvia	28		58	37	10	24		1,7	1,05	0,30	0,70	0,9%	0,2%	8,9
Lithuania	30		165	728	5,8	23		4,9	22	0,17	0,69	1,0%	0,2%	58
Netherlands	62		559	2.643	8,3	300		35	164	0,51	19	2,0%	5,0%	14
Norway	140		223	1.270	87	668		31	178	12,1	93	4,6%	25%	3,1
Poland	579		174	252	7,0	35		101	146	4,1	20	19%	5,3%	21
Portugal	47		236	351	28	98		11,1	17	1,3	4,6	1,5%	1,2%	9,4
Romania	184		199	365	17	21		36	67	3,1	3,8	6,0%	1,0%	46
Slovakia	38		330	623	8,8	66		13	24	0,339	2,5	1,3%	0,7%	24
Spain	152		450	2.021	18	178		68	307	2,7	27	5,0%	7,2%	19
Sweden	55		663	790	59	183		36	43	3,22	10,0	1,8%	2,7%	11
United Kingdom	450		210	854	59	136		94	384	27	61	15%	16%	12

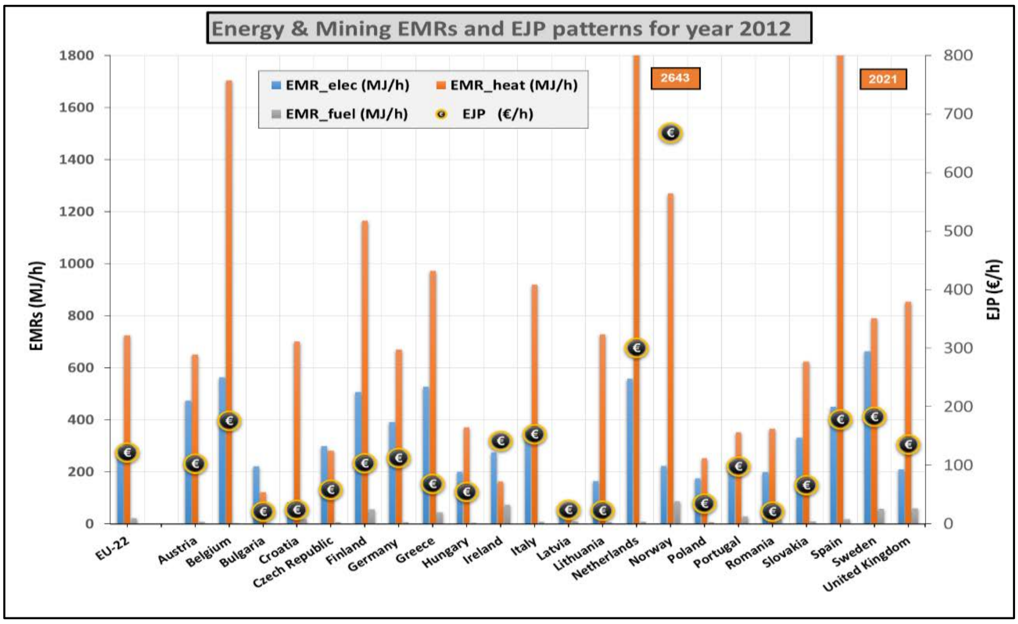


Figure IV-16 Energy & Mining Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

This end use matrix has already been presented in section 2.4.3 (Table IV-7), but the one presented in Table IV-15 and Figure IV-17 has being generated using the SBS database. As we can see, there are some differences in the assessments of HA and VA data, but in general the patterns of gradients in metabolic characteristics are the same.

Table IV-15 Manufacturing & Construction End use matrix of EU27+Norway for the year 2012

Manufacturing & Construction	HA (10^6h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	54730	x	61	108	12	32	=	3.325	5.910	643	1.779	100%	100%	9,0
Austria	1.397		74	189	20	45		104	264	28	63	2,6%	3,5%	10
Belgium	938		144	286	17	65		135	268	16	61	1,7%	3,4%	11
Bulgaria	1.045		26	52	3,1	6		27	55	3,2	5,8	1,9%	0,3%	23
Croatia	601		19	47	10	10		12	28	6,3	5,9	1,1%	0,3%	12
Czech Republic	2.235		37	90	2,1	16		82	201	4,7	36	4,1%	2,0%	12
Finland	761		184	293	44	43		140	223	34	33	1,4%	1,8%	20
Germany	12.892		65	113	11	43		834	1460	137	550	24%	31%	7,2
Greece	606		70	109	28	25		42	66	17	15	1,1%	0,8%	14
Hungary	1.371		24	46	3,5	14		32	63	4,8	19	2,5%	1,1%	8,5
Ireland	407		79	117	34	80		32	48	14	33	0,7%	1,8%	4,7
Italy	6.915	x	64	92	8,5	36	=	442	633	59	248	13%	14%	7,8
Latvia	294		31	127	9,5	10		9,2	37	2,8	2,9	0,5%	0,2%	24
Lithuania	455		25	53	3,4	8,1		11	24	1,6	3,7	0,8%	0,2%	16
Netherlands	1.512		83	194	12	54		125	293	19	82	2,8%	4,6%	8
Norway	658		239	112	24	64		157	74	16	42	1,2%	2,4%	12
Poland	4.821		34	87	4,2	13		162	418	20	63	8,8%	3,6%	14
Portugal	1.653		35	72	8,2	13		57	118	14	22	3,0%	1,2%	14
Romania	2.917		26	65	5,1	6,1		76	191	15	18	5,3%	1,0%	24
Slovakia	774		56	169	6,7	16		43	131	5,2	12	1,4%	0,7%	21
Spain	4.318		60	130	13	31		261	560	55	132	7,9%	7,4%	10
Sweden	1.403		135	184	19	51		190	258	26	72	2,6%	4,1%	11
United Kingdom	6.760		52	73	22	38		352	496	145	260	12%	15%	6,4

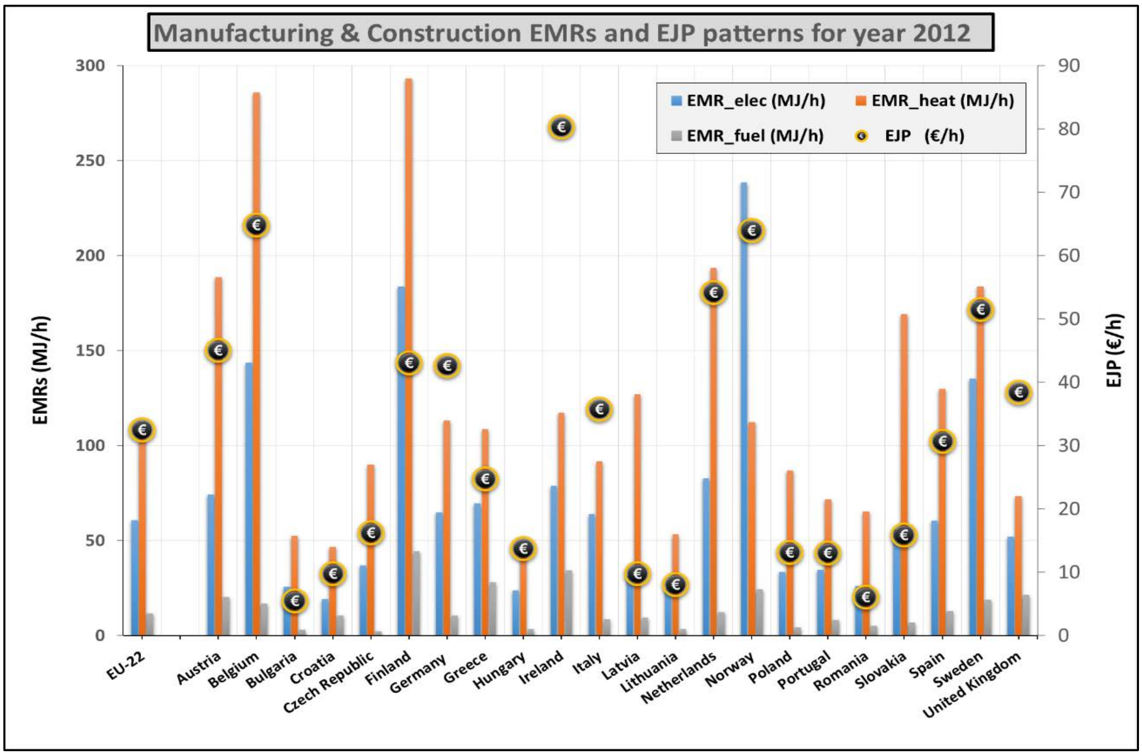


Figure IV-17 Manufacturing & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2 Level n-3 (using the SBS database)

3.2.1 Energy Sector

The energy sector basically coincides with the Energy & Mining sector (it has 89% of HA and 97% of VA), therefore the end use patterns are very similar (see Table IV-16 and Figure IV-18).

Table IV-16 Energy Sector End use matrix of EU27+Norway for the year 2012

Energy Sector	HA (10^6h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	2727	x	310	803	16	133	=	844	2.191	45	363	100%	100%	13
Austria	54		473	707	0,80	110		25	38	0,043	5,9	2,0%	1,6%	18
Belgium	39		580	1.877	2,2	187		23	73	0,085	7,2	1,4%	2,0%	19
Bulgaria	98		227	143	0	19		22	14	0	1,9	3,6%	0,5%	39
Croatia	32		89	780	0	25		2,8	25	0	0,81	1,2%	0,2%	43
Czech Republic	105		322	301	5,7	64		34	32	0,60	6,7	3,9%	1,8%	18
Finland	30		486	1.483	22	113		14	44	0,66	3,4	1,1%	0,9%	26
Germany	456		416	721	5,0	119		190	329	2,3	54	17%	15%	16
Greece	53		608	1.124	3,2	74		32	59	0,17	3,9	1,9%	1,1%	38
Hungary	62		215	399	0	58		13	25	0	3,6	2,3%	1,0%	17
Ireland	23		196	158	0	149		4,4	3,6	0	3,4	0,8%	0,9%	5
Italy	210		389	1.026	4,5	168		82	215	0,94	35	7,7%	9,7%	13
Latvia	23	x	69	42	7,3	26	=	1,6	0,98	0,17	0,62	0,9%	0,2%	8,9
Lithuania	26		185	834	5,0	24		4,8	22	0,13	0,64	1,0%	0,2%	58
Netherlands	59		576	2.722	3,6	313		34	160	0,21	18	2,2%	5,1%	14
Norway	132		221	1.342	70	702		29	177	9,3	93	4,8%	26%	3,1
Poland	531		175	271	3,0	36		93	144	1,6	19	19%	5,3%	21
Portugal	32		279	494	0	136		9,1	16	0	4,4	1,2%	1,2%	9,4
Romania	160		223	412	12	23		36	66	2,0	3,6	5,9%	1,0%	46
Slovakia	35		363	691	2,5	72		13	24	0,085	2,5	1,3%	0,7%	24
Spain	120		528	2.501	0	212		64	301	0	26	4,4%	7,0%	19
Sweden	51		483	765	5,1	192		25	39	0,26	9,8	1,9%	2,7%	11
United Kingdom	398		236	965	67	150		94	384	27	60	15%	16%	12

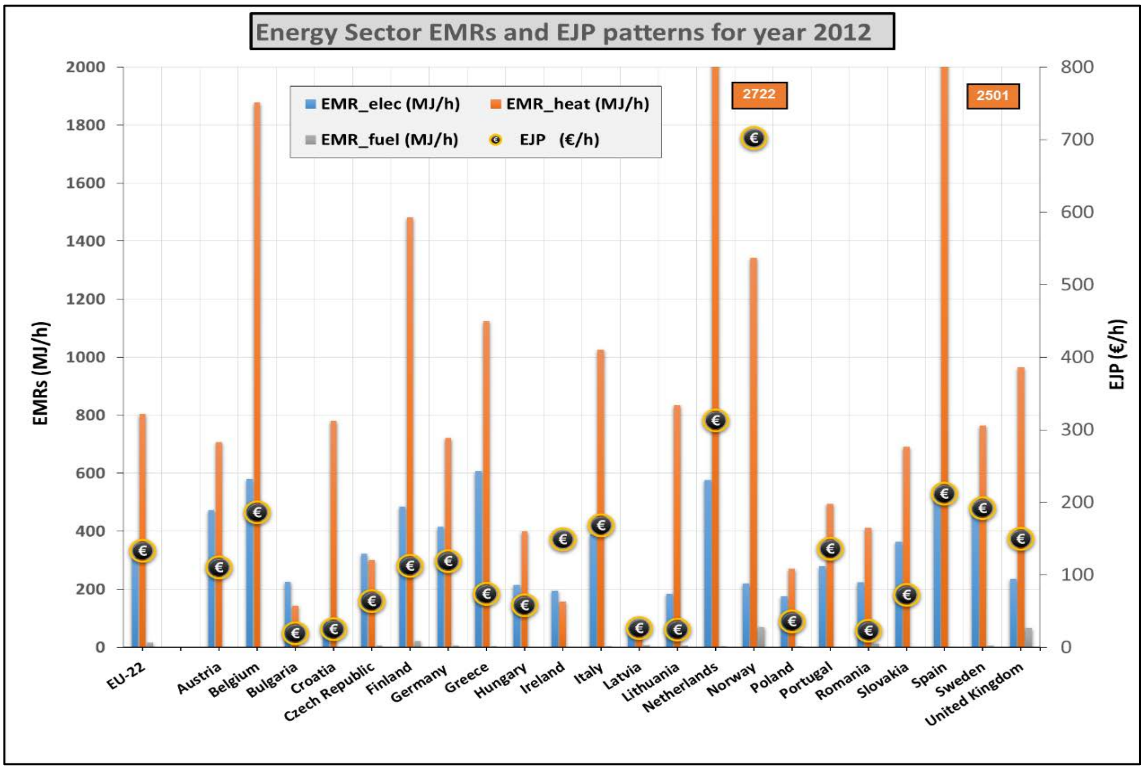


Figure IV-18 Energy Sector Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.2 Mining & Quarrying

In the Table IV-17 and Figure II-1 we can see how Sweden presents really high EMRs [2.889 1.100 723] MJ/h, much higher than the others. This is due to its leading role in EU in ore and metal production. Netherland present also a high heat EMR (1.198 MJ/h) which could be related with the important sand, gravel, peat and limestone extraction industry. Last but not least, Ireland shows the largest fuel EMR (851 MJ/h), which could be explained by the fact that Ireland is the largest zinc producer in Europe and the second largest producer of lead. However, in order to confirm these hypotheses, we should complement the present data with data on production organized on the same definition of subcompartments (an attempt on this direction will be presented in the next chapter).

Table IV-17 Mining & Quarrying End use matrix of EU27+Norway for the year 2012

Mining and Quarrying	HA (10^9h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	339	170	93	69	34	58	32	24	11	100%	100%	19
Austria	7,9	489	266	52	51	3,9	2,1	0,41	0,40	2,3%	3,5%	32
Belgium	3,9	388	0	0	72	1,5	0	0	0,28	1,2%	2,5%	14
Bulgaria	18	190	2,8	16	32	3,4	0,051	0,28	0,57	5,3%	5,0%	17
Croatia	4,0	38	62	160	14	0,15	0,25	0,64	0,058	1,2%	0,5%	27
Czech Republic	13	101	122	6,2	17	1,3	1,6	0,08	0,22	3,8%	1,9%	24
Finland	8,4	576	33	175	69	4,8	0,28	1,5	0,58	2,5%	5,1%	26
Germany	45	143	147	20	53	6,5	6,7	0,90	2,4	13%	21%	11
Greece	8,3	16	5,5	301	34	0,13	0,046	2,5	0,29	2,5%	2,5%	13
Hungary	4,8	19	11	71	12	0,09	0,051	0,34	0,059	1,4%	0,5%	13
Ireland	2,1	1.106	210	851	61	2,4	0,45	1,8	0,1	0,6%	1,1%	70,2
Italy	26	102	59	37	35	2,7	1,5	0,96	0,92	7,7%	8,1%	11
Latvia	5,1	7,9	14	25	15	0,04	0,069	0,13	0,078	1,5%	0,7%	4,6
Lithuania	3,8	24	2,9	11	12	0,09	0,011	0,043	0,048	1,1%	0,4%	6,4
Netherlands	3,2	239	1.198	94	73	0,76	3,8	0,30	0,23	0,9%	2,0%	28
Norway	7,7	269	37	371	83	2,1	0,29	2,8	0,64	2,3%	5,6%	15
Poland	48	164	41	51	17	7,9	2,0	2,5	0,82	14%	7,2%	32
Portugal	15	140	33	90	15	2,0	0,48	1,3	0,21	4,3%	1,9%	36
Romania	24	34	51	46	6,9	0,82	1,2	1,1	0,16	7,0%	1,4%	30
Slovakia	3,9	34	18	66	12	0,13	0,071	0,25	0,047	1,1%	0,4%	16
Spain	32	152	193	86	49	4,8	6,1	2,7	1,6	9,3%	14%	15
Sweden	4,1	2.889	1.100	723	67	12	4,5	3,0	0,28	1,2%	2,4%	145
United Kingdom	52	8,4	0	0	28	0	0	0	1,5	15%	13%	0,8

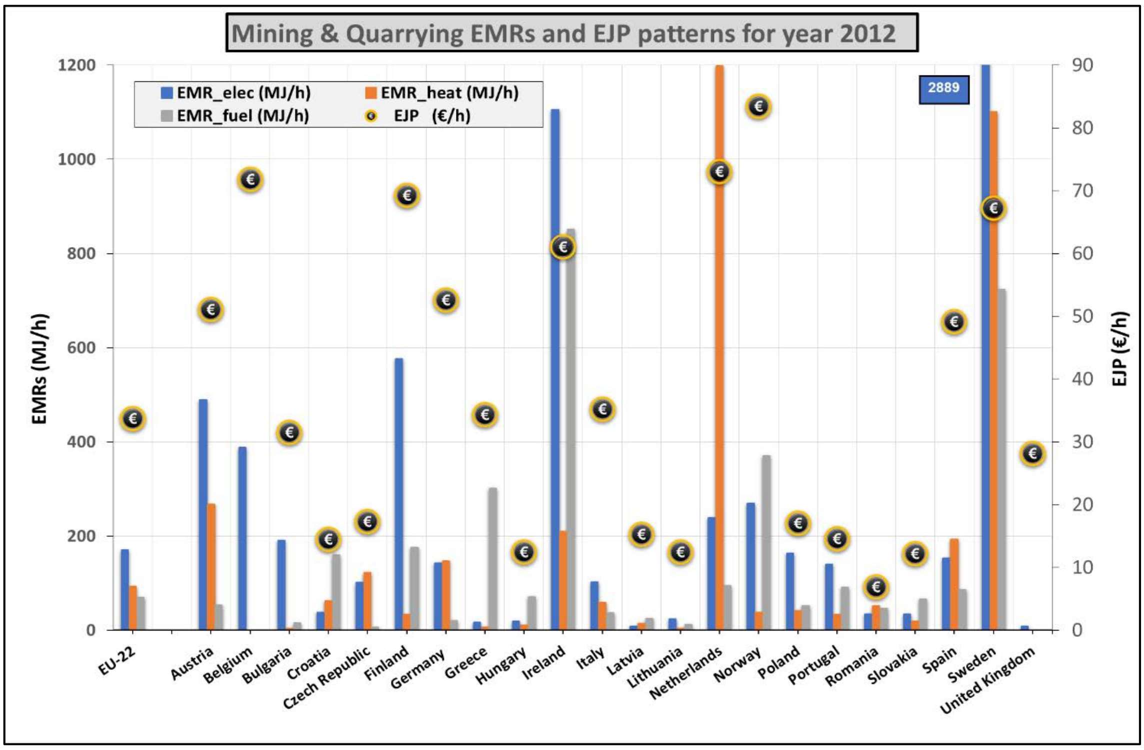


Figure IV-19 Mining & Quarrying Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.3 Iron & steel

Table IV-18 and Figure IV-20 shows among the largest values of EMRs of the entire study. For example, the largest electricity EMR (4.112 MJ/h) in Norway can be explained by the availability of abundant and cheap hydro-electricity used for smelting iron. On the other, the Netherlands seems to take profit of its local natural gas reserves with the largest heat EMR (4.066 MJ/h). Looking at the economic data, Germany is by far the most important Iron & Steel producer with 26% of the HA and 37% of the total VA generated in the EU-22 cluster. Again, this overview show that better understanding of the values expressed in the end use matrices would require complementing this basic information with data about the quality, quantity and type of products.

On the other hand, when comparing the metabolic patterns of Slovakia [308 2650 0] MJ/h and 13 €/h with Austria [391 2157 132] and 69 €/h, one hypothesis could be that they present similar process with comparable technologies, but they have different process of generation of Value Added. This explanation faces with the argument of energy efficiency and the different EEI presented from these two countries: 288 vs 52 MJ/€. One more time, we see how EEI do not map properly technological efficiency. I will propose a more detailed discussion of this topic in the next chapter.

Table IV-18 Iron & Steel End use matrix of EU27+Norway for the year 2012

Iron and Steel	HA (10^6h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	974	x	408	1523	34	35	=	397	1.484	33	34	100%	100%	80
Austria	37		391	2.157	132	69		14	80	4,9	2,5	3,8%	7,5%	52
Belgium	25		803	2.975	27	53		20	76	0,68	1,3	2,6%	4,0%	102
Bulgaria	10		250	204	0,0	5,0		2,6	2,1	0	0,052	1,1%	0,2%	175
Croatia	4,8		61	65	0,0	12		0,30	0,31	0	0,058	0,5%	0,2%	19
Czech Republic	62		149	1.186	4,5	9,8		9,2	73	0,28	0,61	6,3%	1,8%	173
Finland	18		664	1.658	308	33		12	30	5,6	0,60	1,9%	1,8%	120
Germany	254		381	1.796	44	49		97	456	11	12	26%	37%	62
Greece	17		199	171	46	19		3,3	2,8	0,77	0,32	1,7%	0,9%	40
Hungary	15		102	1.386	2,8	7,4		1,5	21	0,042	0,11	1,5%	0,3%	242
Ireland	2,1		0	23	0	35		0	0,047	0	0,072	0,2%	0,2%	0,72
Italy	136		525	1.414	12	39		71	192	1,6	5,3	14%	16%	75
Latvia	5,1	x	342	332	16	14	=	1,75	1,7	0,081	0,074	0,5%	0,2%	89
Lithuania	1,6		55	21	0	7,5		0,086	0,032	0	0,012	0,2%	0,0%	22
Netherlands	22		433	4.066	5,7	49		9,7	91	0,13	1,1	2,3%	3,2%	115
Norway	4,4		4.112	3.327	68	92		18	15	0,30	0,41	0,5%	1,2%	158
Poland	76		298	1.017	0,56	18		23	78	0,043	1,4	7,8%	4,0%	106
Portugal	8,8		553	266	14	22		4,9	2,3	0,13	0,19	0,9%	0,6%	80
Romania	49		464	960	0,85	10		23	47	0,042	0,49	5,1%	1,4%	229
Slovakia	30		308	2.650	0	13		9,3	80	0	0,39	3,1%	1,2%	288
Spain	69		689	1.037	39	35		48	72	2,7	2,4	7,1%	7,1%	86
Sweden	46		351	956	95	40		16	44	4,4	1,8	4,7%	5,4%	53
United Kingdom	80		152	1.495	1,0	27		12	119	0,08	2,2	8,2%	6,4%	76

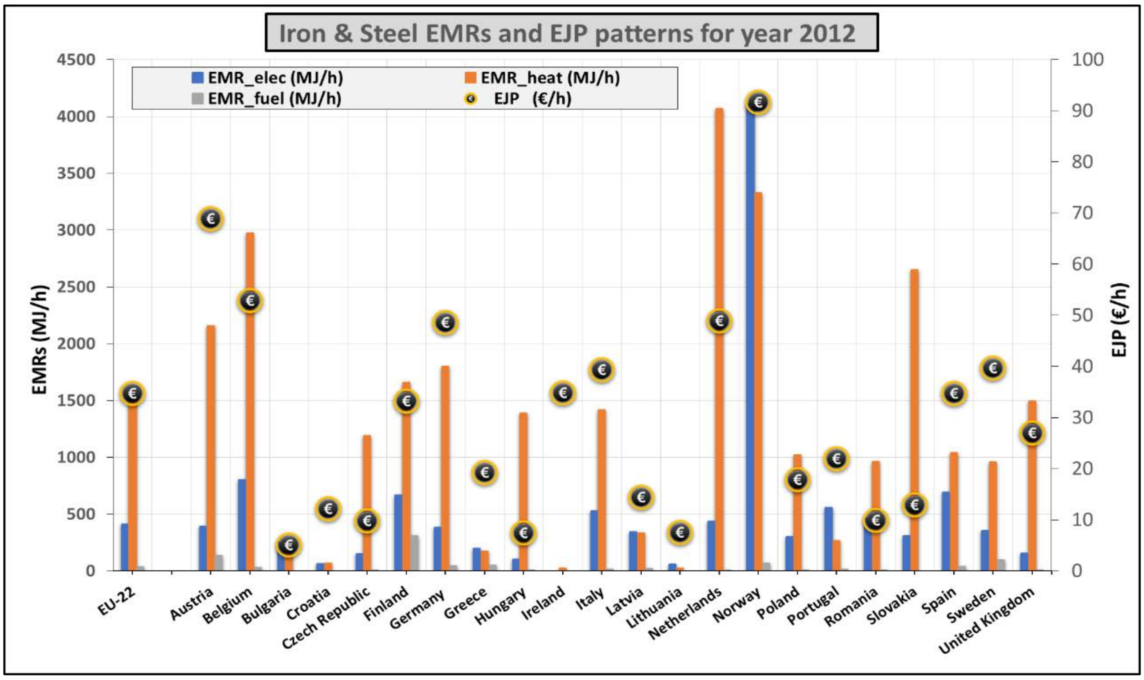


Figure IV-20 Iron & Steel Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.4 Non-Ferrous Metals

Non-ferrous metals sector groups a wide numbers of industrial process in relation to metals and alloys that does not contain iron. In this subsector we can find energy intensive processes as electrolysis for refining purposoes, as well as smelting, casting and manufacturing process of aluminium, copper, lead, zinc or zinc; more rare metals as cobalt, mercury, tungsten, cadmium, indium or lithium; and precious ones as platinium, gold or silver. Table IV-19 and Figure IV-21 shows Ireland with really high heat (9.726 MJ/h) and fuel (3.189) EMRs, and again Norway presents the highst electricity EMR (6.703 MJ/h) and EJP (118). On the other hand, Germany has the largest proportion of HA (31%) and VA (34%) in the cluster studied. Again, better understanding of these metabolic patterns require going to lower scales of analysis and complement the present data arrays with other indicators refering to raw material or output products data.

Table IV-19 Non-Ferrous Metals End use matrix of EU27+Norway for the year 2012

Non-Ferrous Metals	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	470	x	563	274	27	42	=	264	129	13	20	100%	100%	43
Austria	19	x	185	212	13	62	=	3,5	4,0	0,24	1,2	4,1%	6,0%	12
Belgium	13	x	550	462	23	83	=	6,9	5,8	0,29	1,0	2,7%	5,3%	24
Bulgaria	9,0	x	343	118	89	28,5	=	3,1	1,1	0,80	0,26	1,9%	1,3%	40
Croatia	2,6	x	118	105	16	8,0	=	0,31	0,28	0,043	0,021	0,56%	0,11%	56
Czech Republic	12	x	62	110	0	11	=	0,73	1,3	0	0,13	2,5%	0,64%	26
Finland	5,4	x	1.251	313	152	69	=	6,7	1,7	0,82	0,37	1,1%	1,9%	56
Germany	144	x	320	232	11,0	47	=	46	33	1,6	6,8	31%	34%	23
Greece	12	x	1.390	1.342	18	34	=	17	16	0,21	0,41	2,6%	2,1%	151
Hungary	14	x	104	200	2,9	19,0	=	1,5	2,9	0,042	0,27	3,0%	1,4%	26
Ireland	1,4	x	1.889	9.726	3.189	-	=	2,7	14	4,5	-	0,30%	-	-
Italy	58	x	236	301	10,5	36	=	14	18	0,61	2,1	12%	11%	27
Latvia	0,71	x	10	238	0	17	=	0,007	0,17	0	0,012	0,15%	0,06%	17
Lithuania	0,16	x	0	185	0	3,7	=	0	0,03	0	0,0006	0,03%	0,003%	55
Netherlands	11	x	881	237	0,0	51	=	10	2,7	0	0,58	2,4%	3,0%	50
Norway	10	x	6.703	213	25	118	=	69	2,2	0,26	1,2	2,2%	6,1%	151
Poland	30	x	235	274	9,68	15	=	7,1	8,3	0,29	0,47	6,4%	2,4%	60
Portugal	5,9	x	70	64	6,7	15	=	0,41	0,38	0,040	0,089	1,3%	0,45%	18
Romania	15	x	0	0	0	11	=	0	0	0	0,16	3,3%	0,83%	-
Slovakia	7,1	x	1.253	205	0	23	=	8,9	1,5	0	0,16	1,5%	0,84%	151
Spain	30	x	1.283	232	89	51	=	38	6,9	2,7	1,5	6,3%	7,6%	74
Sweden	10	x	1.150	244	29	76	=	12	2,4	0,29	0,76	2,1%	3,9%	44
United Kingdom	59	x	305	112	2,9	36	=	18	6,7	0,17	2,2	13%	11,0%	25

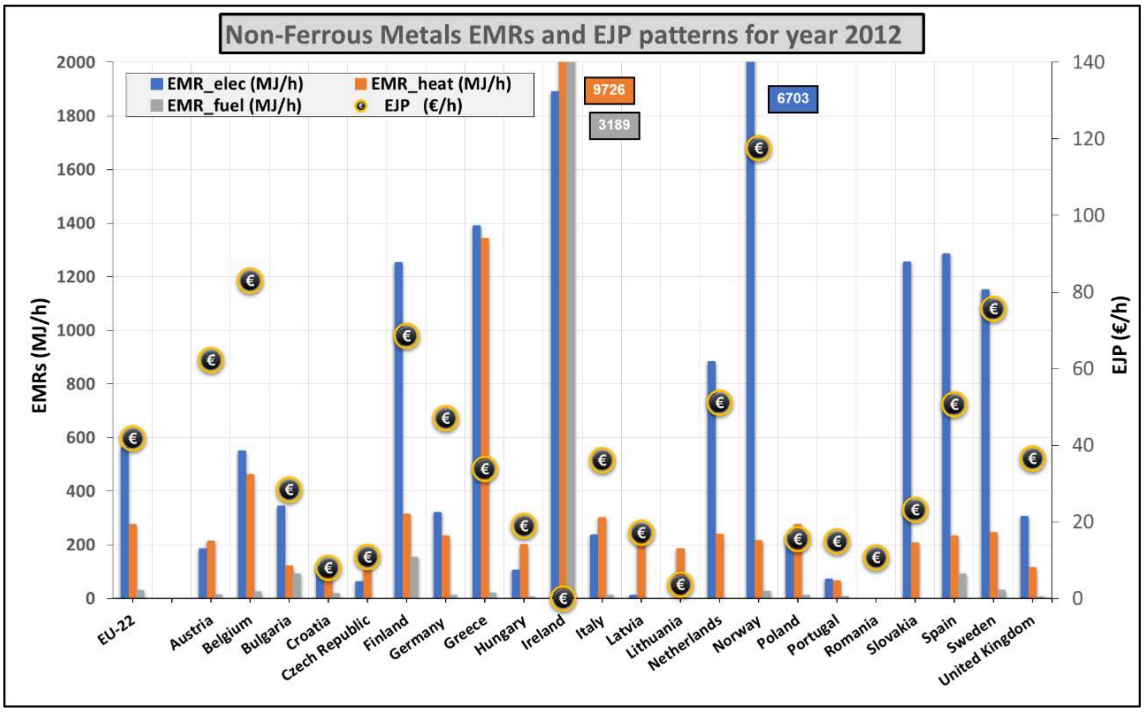


Figure IV-21 Non-Ferrous Metals Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.5 Chemical & Petrochemical

When looking at the end use matrix of the Chemical & Petrochemical sector (Table IV-20 and Figure IV-22), we can find a clear anomaly for Ireland. The country has a really low profile of EMRs values [139 61 24] MJ/h - by far much lower than the average of the EU-22 cluster [249 380 47] MJ/h. But at the same time, Ireland presents a really high EJP (371 MJ/h). Rather than by using biophysical factors to explain this anomaly, we could try to explain this anomaly with the low corporate tax model of Ireland, which make that many companies place their headquarters in the country (declaring there their value added generation) meanwhile they produce elsewhere (consuming energy and human activity). However, this is just a hypothesis that needs to be corroborated with other data. In the Table IV-20 Norway shows the largest electricity (1.302 MJ/h) and heat (1.386 MJ/h) EMRs, whereas Slovakia has the highest fuel EMR (199 MJ/h).

Table IV-20 Chemical & Petrochemical End use matrix of EU27+Norway for the year 2012

Chemical and Petrochemical	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	2371	x	249	380	47	69	=	590	901	111	163	100%	100%	17
Austria	48	x	320	471	23	68	=	15	23	1,1	3,3	2,0%	2,0%	20
Belgium	100		408	507	8,2	119		41	51	0,83	12	4,2%	7,3%	14
Bulgaria	35		118	388	4,7	10		4,2	14	0,17	0,37	1,5%	0,2%	71
Croatia	20		47	219	4,2	19		0,93	4,3	0,083	0,38	0,83%	0,24%	19
Czech Republic	63		213	336	2,6	27		13	21	0,16	1,7	2,6%	1,0%	35
Finland	26		663	402	47	96		17	10	1,2	2,5	1,1%	1,5%	23
Germany	705		266	371	70	72		188	262	50	51	30%	31%	17
Greece	30		75	72	2,2	33		2,3	2,2	0,066	0,99	1,3%	0,61%	8,5
Hungary	53		178	85	0	37		9,4	4,5	0	2,0	2,2%	1,2%	15
Ireland	43		139	61	24	371		6,0	2,6	1,0	16	1,8%	10%	1,2
Italy	276		194	185	107	61		54	51	30	17	12%	10%	14
Latvia	7,4		35	100	12	13		0,26	0,7	0,085	0,093	0,31%	0,06%	17
Lithuania	10		278	376	0	22		2,8	3,8	0	0,22	0,43%	0,14%	52
Netherlands	93		475	843	10	115		44	78	0,94	11	3,9%	6,6%	19
Norway	20		1.302	1.386	121	98		26	28	2,4	2,0	0,85%	1,2%	52
Poland	164		189	477	24	24		31	78	3,9	3,9	6,9%	2,4%	44
Portugal	33		251	236	14	29		8,3	7,8	0,45	0,96	1,4%	0,59%	32
Romania	73		180	832	5,6	11		13	61	0,41	0,83	3,1%	0,51%	123
Slovakia	19		259	398	199	18		5,1	7,8	3,9	0,34	0,82%	0,21%	79
Spain	201		151	667	40	55		30	134	8,1	11	8,5%	6,7%	22
Sweden	50		331	99	37	146		17	5,0	1,8	7,3	2,1%	4,5%	7,0
United Kingdom	300		205	171	16	62		61	51	4,8	19	13%	11%	12

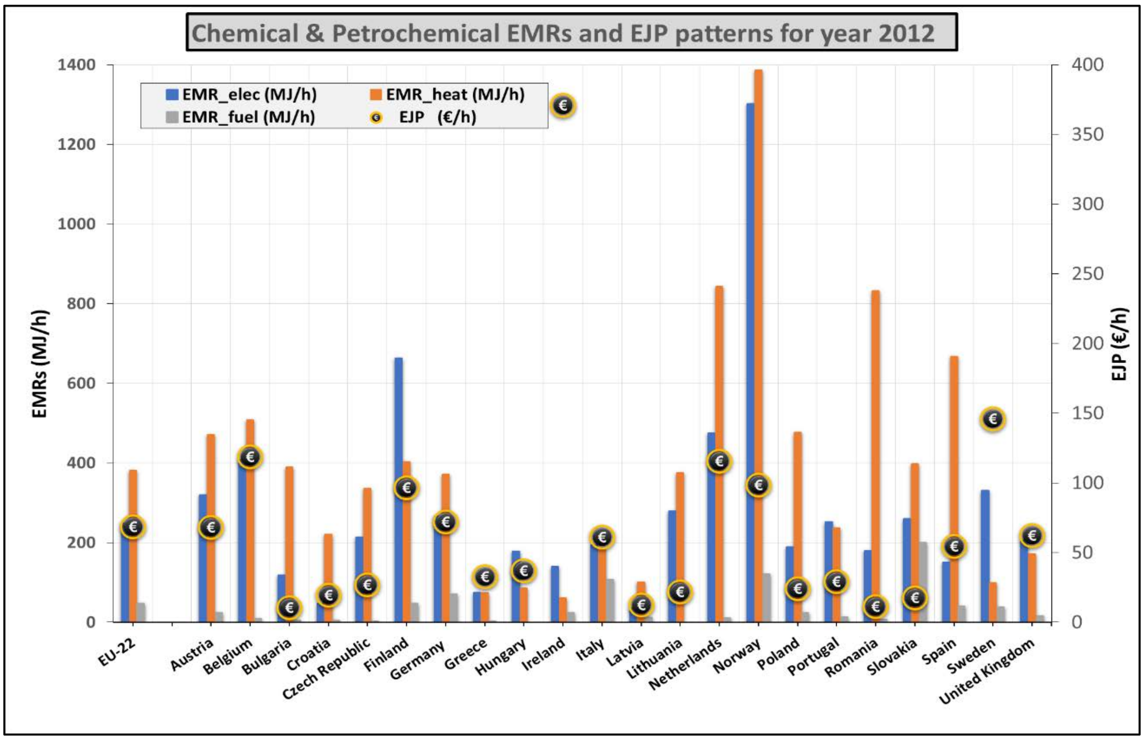


Figure IV-22 Chemical & Petrochemical Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.6 Non-Metallic Minerals

In the case of Non-Metallic Minerals – Table IV-21 and Figure IV-23 - Belgium presents the largest electricity (343 MJ/h) and heat (1.148 MJ/h) EMRs. Italy presents the largest fuel EMR (173 MJ/h) and Norway the largest EJP (64 €/h), nearly followed by Belgium (59 €/h).

Table IV-21 Non-Metallic Minerals End use matrix of EU27+Norway for the year 2012

Non-Metallic Minerals	HA (10^6h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	1770	x	122	571	27	29	=	216	1.011	47	52	100%	100%	33
Austria	51		128	542	26	44		6,6	28	1,3	2,3	2,9%	4,4%	22
Belgium	39		343	1.148	79	59		13	45	3,1	2,3	2,2%	4,4%	39
Bulgaria	34		80	533	9,6	8,4		2,7	18	0,32	0,28	1,9%	0,5%	96
Croatia	20		92	542	14	14		1,9	11	0,29	0,28	1,2%	0,5%	63
Czech Republic	87		90	380	2,8	18		7,9	33	0,24	1,5	4,9%	3,0%	37
Finland	24		117	290	36	45		2,8	7,0	0,87	1,1	1,4%	2,1%	15
Germany	354		125	585	28	40		44	207	9,9	14	20%	27%	25
Greece	28		124	893	23	24		3,4	25	0,62	0,67	1,6%	1,3%	55
Hungary	39		61	287	0	13		2,4	11	0	0,52	2,2%	1,0%	36
Ireland	12		179	800	173	25		2,1	9,3	2,0	0,30	0,7%	0,6%	63
Italy	268	x	134	675	20	33	=	36	181	5,5	8,8	15%	17%	34
Latvia	7,5		117	795	40	16		0,88	5,9	0,30	0,12	0,4%	0,2%	78
Lithuania	13		62	517	19	9,9		0,80	6,6	0,25	0,13	0,7%	0,2%	76
Netherlands	39		113	498	26	43		4,4	19	1,0	1,7	2,2%	3,2%	21
Norway	18		164	500	42	64		3,0	9,2	0,78	1,2	1,0%	2,3%	16
Poland	208		78	441	16	15		16	92	3,3	3,2	12%	6,1%	47
Portugal	72		92	616	13	16		6,6	44	0,93	1,1	4,1%	2,2%	60
Romania	74		92	393	13	10		6,8	29	0,98	0,74	4,2%	1,4%	69
Slovakia	26		90	442	1,6	15		2,4	12	0,04	0,40	1,5%	0,76%	48
Spain	167		139	765	39	29		23	128	6,5	4,9	9,4%	9,4%	43
Sweden	32		114	362	76	53		3,6	12	2,4	1,7	1,8%	3,2%	15
United Kingdom	155		157	500	43	30		24	78	6,6	4,6	8,8%	8,9%	34

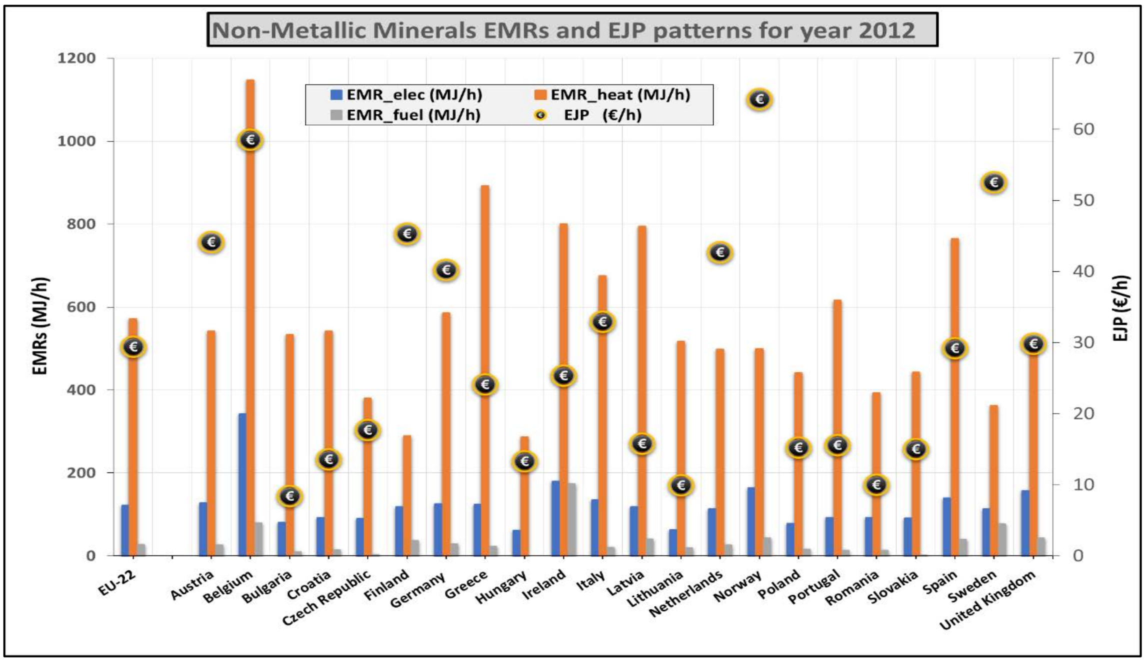


Figure IV-23 Non-Metallic Minerals Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.7 Food & Tobacco

When comparing the average values of the EU clusters for Food & Tobacco [53 88 10] MJ/h and Agriculture & Forestry [8,4 16 25] MJ/h we can see that Food and Tobacco generates much more Value Added per hour than Agriculture and Forestry (43 vs 9,3 €/h) while consuming less energy. In that sense, we can see how we consume energy for saving human time (preparing meals in that case) and how important is to measure this relation as I do with EMRs indicators. Moreover, this fact reinforces the argument of the crucial importance of carrying out an integrated analysis of the end use matrix across levels and dimension of analysis when discussing of efficiency and offshoring effects. Looking at the data in Table IV-22 and Figure IV-24, Belgium shows the largest electricity EMR (153 MJ/h), nearly followed by the Netherlands (130 MJ/h) and Norway (119 MJ/h). The Netherlands have the largest heat EMR (306 MJ/h) followed by Belgium (278 MJ/h). Ireland have the largest fuel EMR (52 MJ/h) and EJP (95 €/h).

Table IV-22 Food & Tobacco End use matrix of EU27+Norway for the year 2012

Food and Tobacco	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	6056	x	53	88	10	29	=	321	534	60	177	100%	100%	8,5
Austria	119		64	120	20	43		7,7	14	2,3	5,1	2,0%	2,9%	7,6
Belgium	116		153	278	4,0	62		18	32	0,46	7,2	1,9%	4,1%	11
Bulgaria	156		25	33	3,1	6,1		3,9	5,1	0,49	0,95	2,6%	0,5%	17
Croatia	106		22	51	9,3	12		2,4	5,4	0,99	1,3	1,8%	0,7%	11
Czech Republic	183		31	76	0,91	15		5,7	14	0,17	2,7	3,0%	1,5%	11
Finland	56		101	50	25	44		5,7	2,8	1,4	2,4	0,9%	1,4%	8,1
Germany	1.262		51	97	9,5	29		65	123	12	36	21%	20%	8,9
Greece	138		57	85	21	27		8,0	12	2,9	3,7	2,3%	2,1%	10
Hungary	172		21	61	1,2	10		3,6	11	0,21	1,8	2,8%	1,0%	12
Ireland	75		93	95	52	95		7,0	7,2	3,9	7,1	1,2%	4,0%	4,4
Italy	568	x	76	91	9,8	39	=	43	51	5,6	22	9,4%	13%	8,0
Latvia	41		22	58	7,9	8,0		0,93	2,4	0,33	0,33	0,7%	0,2%	17
Lithuania	68		32	71	5,4	9,1		2,2	4,8	0,37	0,62	1,1%	0,4%	19
Netherlands	175		130	306	2,4	62		23	54	0,43	11	2,9%	6,1%	11
Norway	76		119	36	36	61		9,1	2,7	2,8	4,6	1,3%	2,6%	6,6
Poland	697		28	74	6,2	13		19	52	4,3	9,3	12%	5,3%	12
Portugal	182		35	37	19	14		6,3	6,8	3,5	2,6	3,0%	1,5%	11
Romania	344		17	45	5,2	5,8		5,9	16	1,8	2,0	5,7%	1,1%	18
Slovakia	65		29	59	0,64	12		1,9	3,9	0,04	0,77	1,1%	0,4%	12
Spain	603		57	72	15	32		34	43	9,2	20	10%	11%	7,6
Sweden	87		102	69	21	45		8,9	6,0	1,8	3,9	1,4%	2,2%	8,3
United Kingdom	764		52	87	6,4	42		40	66	4,9	32	13%	18%	5,8

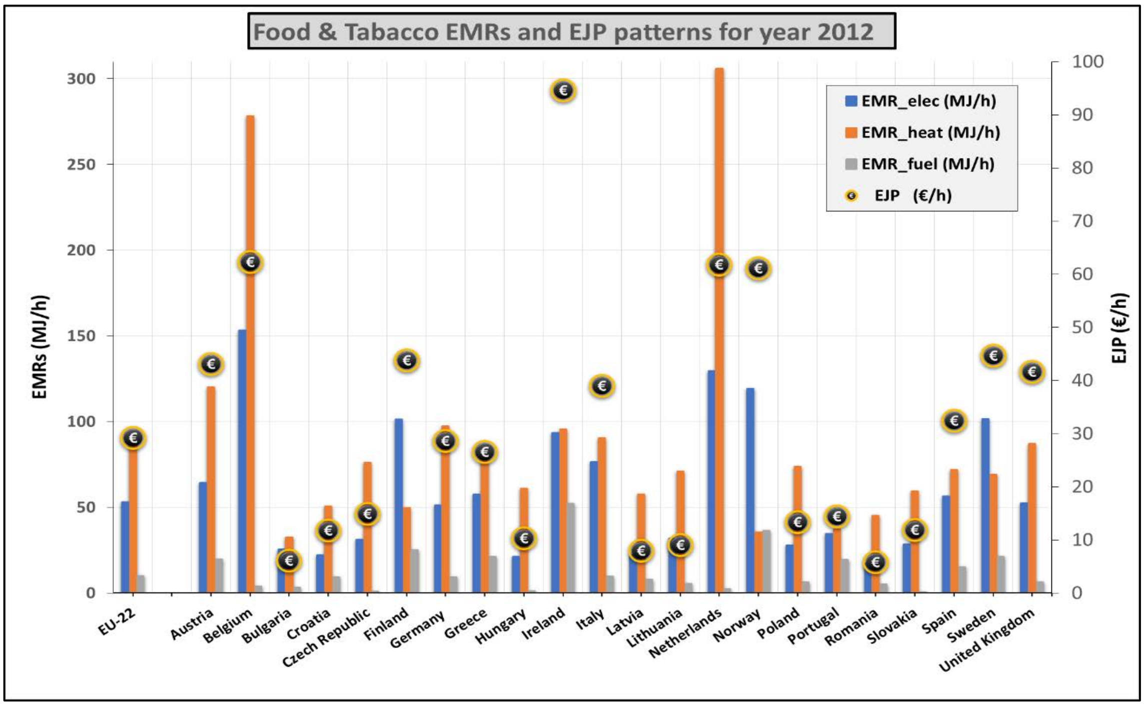


Figure IV-24 Food & Tobacco Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.8 Textile & Leather

Textile & Leather represents a sector with very low values of EJP. Data are presented in Table IV-23 and Figure IV-25. It presents some interesting peculiarities like Germany with a small proportion of HA (7%) but generating 40% of the Value Added. Less fashion textile products seems to be produced in Romania (16% HA and 3,2% VA), Portugal (10% HA and 5% VA), Poland (8% HA and 3,3% VA), and Bulgaria (7,3% HA vs 1,3% VA). Special mention is due for the extremely low value of EJP of Bulgaria (2,8 €/h) and Romania (3,2 €/h).

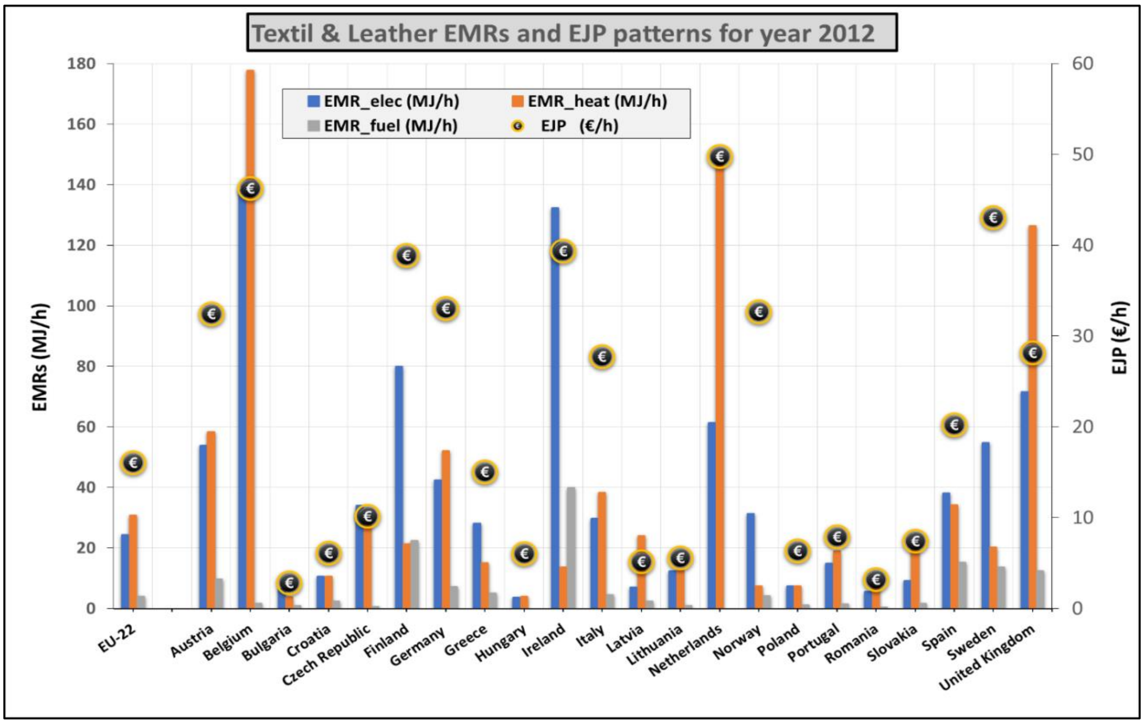


Figure IV-25 Textile & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Table IV-23 Textile & Leather End use matrix of EU27+Norway for the year 2012

Textile and Leather	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	2895	x	24	31	4	16	=	71	89	12	47	100%	100%	6,4
Austria	30		54	58	9,7	32		1,6	1,7	0,29	0,96	1,0%	2,1%	6,7
Belgium	28		138	178	1,6	46		3,8	4,9	0,043	1,3	1,0%	2,8%	12
Bulgaria	211		6,5	3,8	0,97	2,8		1,4	0,81	0,21	0,60	7,3%	1,3%	7,9
Croatia	53		11	11	2,3	6,1		0,56	0,56	0,12	0,32	1,8%	0,7%	7,0
Czech Republic	77		34	30	0,52	10		2,6	2,3	0,040	0,79	2,7%	1,7%	12
Finland	9,5		80	21	22	39		0,76	0,20	0,21	0,37	0,3%	0,8%	6,8
Germany	202		42	52	7,1	33		8,6	11	1,4	6,7	7%	14%	5,4
Greece	41		28	15	4,9	15		1,2	0,62	0,20	0,62	1,4%	1,3%	6,4
Hungary	71		3,6	3,9	0	6,0		0,25	0,28	0	0,43	2,4%	0,9%	2,3
Ireland	3,2		132	14	40	39		0,42	0,043	0,13	0,13	0,1%	0,3%	10,6
Italy	670	X	30	38	4,4	28	=	20	26	3,0	19	23%	40%	4,5
Latvia	18		7,0	24	2,3	5,2		0,13	0,44	0,042	0,10	0,6%	0,2%	9,3
Lithuania	45		12	13	0,95	5,5		0,56	0,57	0,043	0,25	1,6%	0,5%	8,6
Netherlands	21		61	147	0	50		1,3	3,0	0	1,0	0,7%	2,2%	6,5
Norway	10		31	7,4	4,2	33		0,32	0,08	0,043	0,34	0,4%	0,7%	2,9
Poland	244		7,3	7,3	1,1	6,3		1,8	1,8	0,26	1,5	8%	3,3%	4,5
Portugal	292		15	19	1,4	7,9		4,3	5,6	0,40	2,3	10%	5,0%	7,8
Romania	477		5,5	7,9	0,45	3,2		2,6	3,8	0,21	1,5	16%	3,2%	7,5
Slovakia	49		9,1	19	1,62	7,4		0,5	0,96	0,080	0,37	1,7%	0,8%	6,4
Spain	188		38	34	15	20		7,2	6,4	2,9	3,8	6%	8%	7,8
Sweden	10		55	20	14	43		0,52	0,19	0,13	0,41	0,3%	0,9%	4,3
United Kingdom	147		71	126	12	28		10	19	1,8	4,1	5%	9%	12

3.2.9 Paper, Pulp & Print

Paper, Pulp & Print have been already extensively commented in the pilot case study in chapter 3. Nevertheless, we can see again in the values given in Table IV-24 and Figure IV-26, the very high values of EMRs of Scandinavian countries: [1.386 3.095 61] MJ/h for Finland, [1.069 2.023 98] MJ/h for Sweden and [968 527 101] MJ/h for Norway. On the other hand, some other countries like Austria (57 €/h) and Belgium (60 €/h) do have remarkably high EJPs with not so high EMRs (especially in the case of Belgium).

Table IV-24 Paper, Pulp & Print End use matrix of EU27+Norway for the year 2012

Paper, Pulp and Print	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	1937	x	218	391	15	34	=	422	757	29	66	100%	100%	29,7
Austria	48		358	1.040	8,5	57		17	49	0,40	2,7	2,5%	4,1%	37
Belgium	38		279	380	26	60		11	14	0,96	2,3	1,9%	3,4%	20
Bulgaria	29		44	255,9	6,8	6,3		1,29	7,5	0,20	0,19	1,5%	0,3%	64
Croatia	21		48	101	7,5	12		1,03	2,2	0,16	0,25	1,1%	0,4%	21
Czech Republic	63		96	280	3,20	16		6,0	17	0,20	0,99	3,2%	1,5%	36
Finland	50		1.386	3.095	61	67		69	154	3,0	3,3	2,6%	5,0%	106
Germany	445		192	285	5,0	39		85	127	2,2	17	23%	26%	21
Greece	27		72	49,3	30	20		1,9	1,3	0,80	0,54	1,4%	0,8%	14
Hungary	42		47	71	2,8	13		2,0	3,0	0,12	0,53	2,2%	0,8%	16
Ireland	14		55	9,0	6,2	38		0,77	0,13	0,087	0,53	0,7%	0,8%	4,3
Italy	232	x	142	123	8,8	36	=	33	28	2,0	8,3	12%	13%	14
Latvia	7,4		16	23	0	11		0,12	0,17	0	0,08	0,4%	0,1%	6,0
Lithuania	12		38	72	3,6	12		0,46	0,86	0	0,14	0,6%	0,2%	16
Netherlands	64		140	221	0,0	47		9,0	14	0	3,0	3,3%	4,5%	13
Norway	15		968	527	101	56		15	8,1	1,6	0,9	0,8%	1,3%	58
Poland	150		91	245	11	18		14	37	1,7	2,6	7,7%	4,0%	30
Portugal	47		216	896	43	26		10	42	2,0	1,2	2,4%	1,8%	63
Romania	59		25	29	2	6,5		1,5	1,7	0,13	0,4	3,1%	0,6%	16
Slovakia	21		174	538	3,9	19		3,6	11	0,08	0,4	1,1%	0,6%	56
Spain	174		107	313	26	32		19	55	4,5	5,7	9,0%	8,5%	20
Sweden	77		1.069	2.023	98	57		83	157	7,6	4,4	4,0%	6,7%	90
United Kingdom	302		129	88	4	35		39	26	1,1	11	16%	16%	13

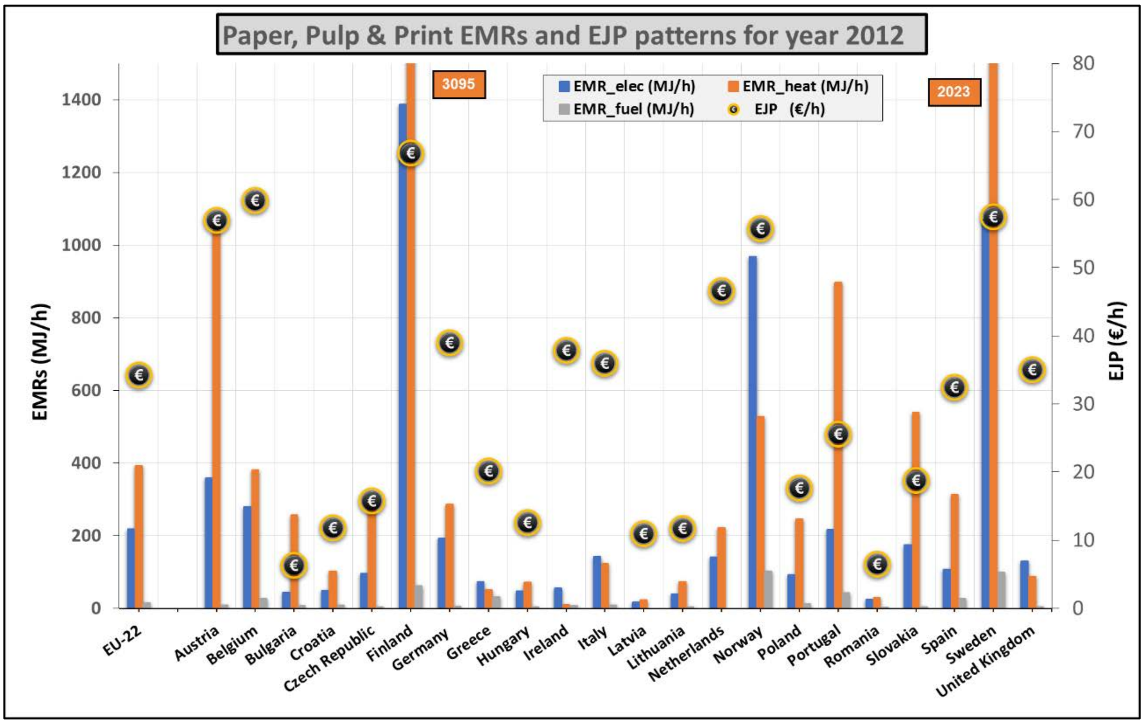


Figure IV-26 Paper, Pulp & Print Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.10 Transport Equipment

Data for this sector are illustrated in Table IV-25 and Figure IV-27. Germany draws attention in the Transport Equipment subsector because it represents 33% of the HA and produce almost 50% of the VA of the EU-22 cluster. Other relevant values are found in Belgium (114 MJ/h in electricity and 146 MJ/h in heat EMRs) and Ireland (130 MJ/h in electricity EMR), representing EMRs values one order of magnitude greater than the others.

Table IV-25 Transport Equipment End use matrix of EU27+Norway for the year 2012

Transport Equipment	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	4264	x	37	22	4	42	=	157	95	15	178	100%	100%	3,0
Austria	62		44	33	2,0	60		2,7	2,1	0,12	3,7	1,5%	2,1%	2,6
Belgium	60		114	146	2,9	56		6,8	8,7	0,17	3,3	1,4%	1,9%	8,3
Bulgaria	29		14	9,9	0	5,9		0,40	0,29	0	0,17	0,7%	0,1%	7,9
Croatia	24		17	10	3,3	7,9		0,40	0,25	0,080	0,19	0,6%	0,1%	7,5
Czech Republic	273		34	28	0,16	22		9,4	7,5	0,043	6,0	6,4%	3,4%	5,4
Finland	24		43	4,0	16	35		1,0	0,094	0,38	0,83	0,6%	0,5%	4,0
Germany	1.408		46	28	1,6	62		65	39	2,2	87	33%	49%	2,5
Greece	12		40	3,7	17	15		0,5	0,046	0,21	0,19	0,3%	0,1%	8,7
Hungary	128		30	16	0,33	21		3,8	2,1	0,042	2,7	3,0%	1,5%	4,6
Ireland	5,4		130	22	16	57		0,70	0,12	0,083	0,31	0,1%	0,2%	6,7
Italy	391		31	0	0,11	35		12	0	0,043	14	9,2%	7,7%	2,3
Latvia	6,3	x	22	16	6,6	9,5	=	0,14	0,10	0,042	0,06	0,1%	0,0%	8,7
Lithuania	5,7		13	10	0	7,8		0,07	0,059	0	0,044	0,1%	0,0%	5,8
Netherlands	59		32	34	4,4	50		1,9	2,0	0,26	2,9	1,4%	1,7%	2,5
Norway	49		37	5,6	5,3	64		1,8	0,28	0,26	3,2	1,2%	1,8%	1,7
Poland	339		21	13	1,7	18		7,3	4,5	0,56	5,9	7,9%	3,3%	4,1
Portugal	58		23	12	1,5	19		1,3	0,68	0,09	1,1	1,4%	0,6%	4,0
Romania	293		12	9,2	0	7,9		3,6	2,7	0	2,3	6,9%	1,3%	5,4
Slovakia	115		29	27	1,9	18		3,4	3,1	0,22	2,0	2,7%	1,1%	6,1
Spain	286		33	20	12	39		9,6	5,8	3,3	11	6,7%	6,2%	3,2
Sweden	126		55	7,9	2,0	51		7,0	1,0	0,25	6,4	3,0%	3,6%	3,1
United Kingdom	511		36	28	13	49		18	14	6,9	25	12%	14%	2,9

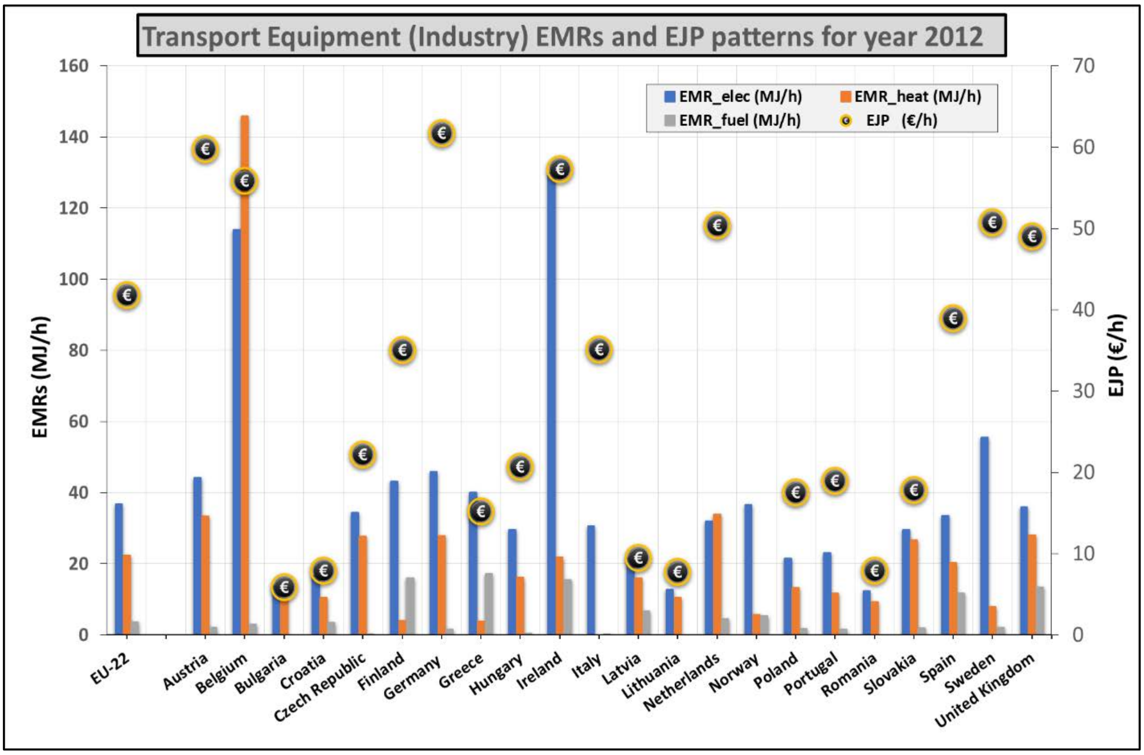


Figure IV-27 Transport Equipment Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.11 Machinery

In this subsector - illustrated in

Machinery	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	12712	x	30	20	3	36	=	376	258	37	453	100%	100%	2,9
Austria	349		39	31	4,1	52		14	11	1,4	18	2,7%	4,0%	2,7
Belgium	159		20	15	5,5	62		3,1	2,5	0,87	9,8	1,3%	2,2%	1,2
Bulgaria	179		18	8,8	0,92	6,1		3,2	1,58	0,17	1,1	1,4%	0,2%	9,6
Croatia	90		13	9,8	0,92	11,4		1,1	0,88	0,083	1,0	0,7%	0,2%	4,0
Czech Republic	659		21	17	0,25	16		14	11	0,17	11	5,2%	2,3%	4,6
Finland	212		36	3,3	3,2	38		7,7	0,69	0,67	8,0	1,7%	1,8%	2,7
Germany	4.102		32	19	3,9	45		131	80	16	185	32%	41%	2,4
Greece	85		8,1	2,5	1,5	22		0,69	0,21	0,12	1,9	0,7%	0,4%	1,2
Hungary	382		11	9,5	0,44	17		4,2	3,6	0,17	6,3	3,0%	1,4%	2,4
Ireland	70		70	70	6,1	58		4,9	4,9	0,43	4,0	0,6%	0,9%	4,6
Italy	1.875	x	39	34	5,0	38	=	73	63	9,4	71	15%	16%	3,8
Latvia	27		14	13	1,5	12		0,40	0,37	0,042	0,32	0,2%	0,1%	4,6
Lithuania	43		15	9,1	0	9,6		0,62	0,39	0	0,41	0,3%	0,1%	5,0
Netherlands	330		31	36	0,91	57		10	12	0,30	19	2,6%	4,1%	2,1
Norway	100		40	3,9	5,2	73		4,0	0,40	0,52	7,4	0,8%	1,6%	1,6
Poland	906		16	11	0,91	13		14	10	0,82	12	7,1%	2,7%	4,1
Portugal	217		21	9,2	0,80	15		4,6	2,0	0,17	3,3	1,7%	0,7%	4,3
Romania	376		19	19	0,92	7,0		7,0	7,1	0,35	2,6	3,0%	0,6%	10
Slovakia	204		20	17	0,21	16		4,0	3,4	0,042	3,3	1,6%	0,7%	4,3
Spain	686		20	21	3,4	30		13	14	2,3	20	5,4%	4,5%	2,6
Sweden	325		40	4,4	7,5	58		13	1,4	2,4	19	2,6%	4,1%	2,1
United Kingdom	1.334		36	21	0,15	37		48	28	0,20	49	10%	11%	3,2

and Figure IV-28- Germany has again a really high percentage of both HA (32%) and VA (41%) over the total of the EU22. Ireland has the greatest electricity and heat EMRs (both 70 MJ/h), whereas Sweden has the highest fuel EMR (7,5 MJ/h) and Norway the largest EJP (73 €/h).

Table IV-26 Machinery End use matrix of EU27+Norway for the year 2012

Machinery	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	12712	x	30	20	3	36	=	376	258	37	453	100%	100%	2,9
Austria	349		39	31	4,1	52		14	11	1,4	18	2,7%	4,0%	2,7
Belgium	159		20	15	5,5	62		3,1	2,5	0,87	9,8	1,3%	2,2%	1,2
Bulgaria	179		18	8,8	0,92	6,1		3,2	1,58	0,17	1,1	1,4%	0,2%	9,6
Croatia	90		13	9,8	0,92	11,4		1,1	0,88	0,083	1,0	0,7%	0,2%	4,0
Czech Republic	659		21	17	0,25	16		14	11	0,17	11	5,2%	2,3%	4,6
Finland	212		36	3,3	3,2	38		7,7	0,69	0,67	8,0	1,7%	1,8%	2,7
Germany	4.102		32	19	3,9	45		131	80	16	185	32%	41%	2,4
Greece	85		8,1	2,5	1,5	22		0,69	0,21	0,12	1,9	0,7%	0,4%	1,2
Hungary	382		11	9,5	0,44	17		4,2	3,6	0,17	6,3	3,0%	1,4%	2,4
Ireland	70		70	70	6,1	58		4,9	4,9	0,43	4,0	0,6%	0,9%	4,6
Italy	1.875	x	39	34	5,0	38	=	73	63	9,4	71	15%	16%	3,8
Latvia	27		14	13	1,5	12		0,40	0,37	0,042	0,32	0,2%	0,1%	4,6
Lithuania	43		15	9,1	0	9,6		0,62	0,39	0	0,41	0,3%	0,1%	5,0
Netherlands	330		31	36	0,91	57		10	12	0,30	19	2,6%	4,1%	2,1
Norway	100		40	3,9	5,2	73		4,0	0,40	0,52	7,4	0,8%	1,6%	1,6
Poland	906		16	11	0,91	13		14	10	0,82	12	7,1%	2,7%	4,1
Portugal	217		21	9,2	0,80	15		4,6	2,0	0,17	3,3	1,7%	0,7%	4,3
Romania	376		19	19	0,92	7,0		7,0	7,1	0,35	2,6	3,0%	0,6%	10
Slovakia	204		20	17	0,21	16		4,0	3,4	0,042	3,3	1,6%	0,7%	4,3
Spain	686		20	21	3,4	30		13	14	2,3	20	5,4%	4,5%	2,6
Sweden	325		40	4,4	7,5	58		13	1,4	2,4	19	2,6%	4,1%	2,1
United Kingdom	1.334		36	21	0,15	37		48	28	0,20	49	10%	11%	3,2

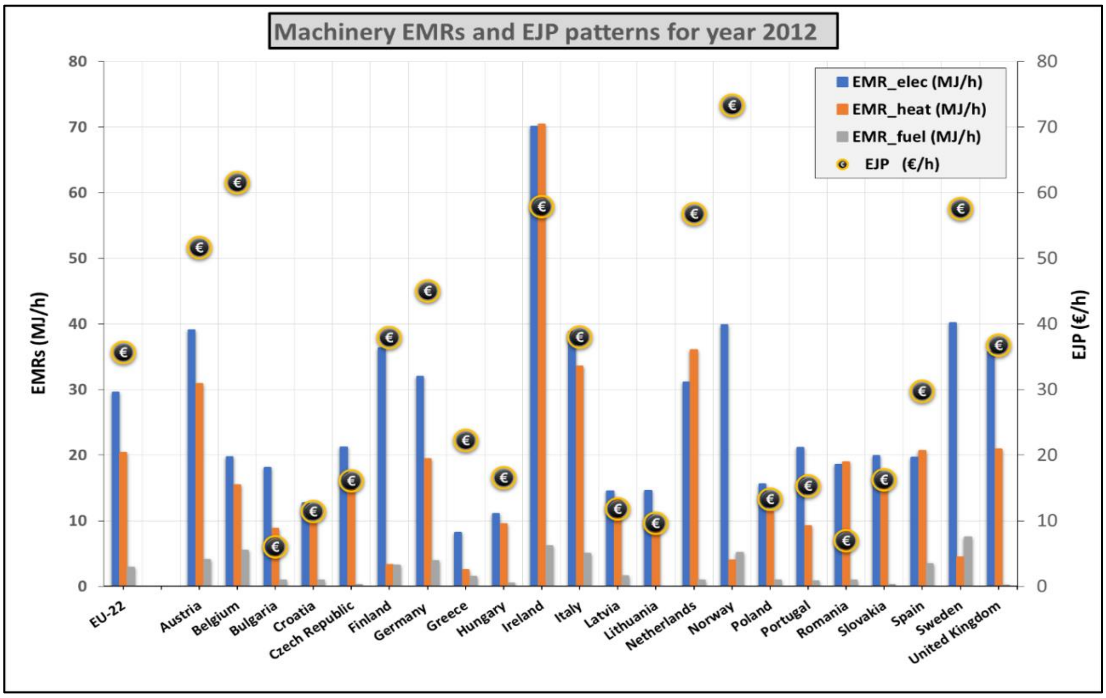


Figure IV-28 Machinery Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.12 Wood & Wood Products

Data for this subsector are illustrated in Table IV-27 and Figure IV-29. Ireland present the largest EMRs in this subsector [288 832 26], even though the resulting value of EJP (17 €/h) is lower than the average EU-22 (21 €/h). Belgium shows the largest EJP (56 €/h).

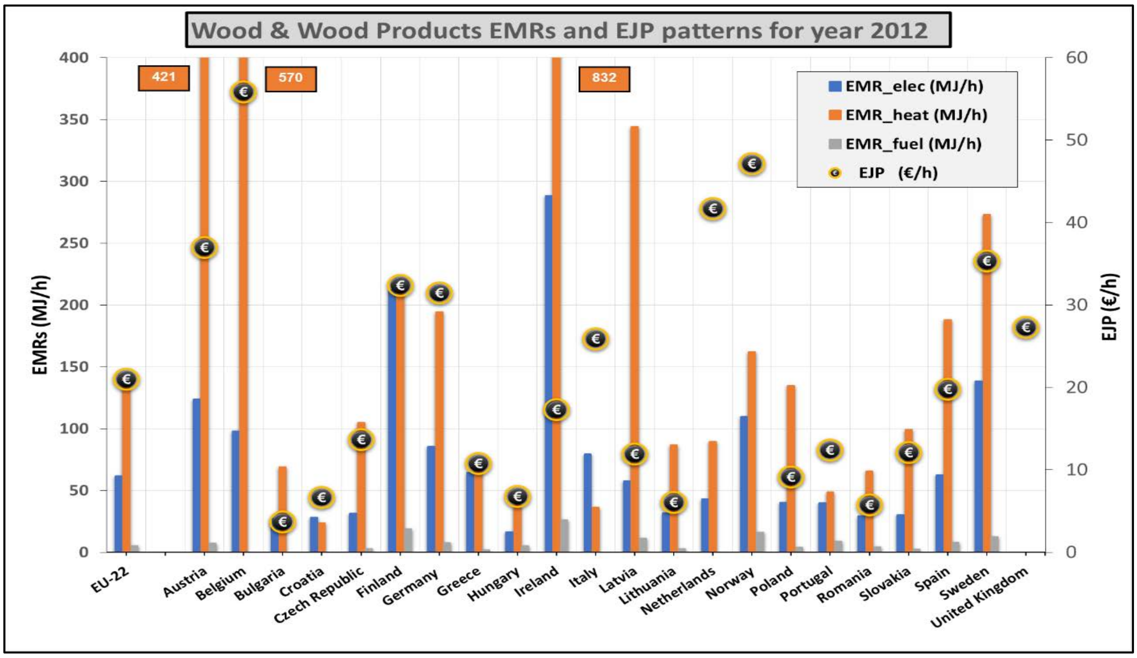


Figure IV-29 Wood & Wood Products Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Table IV-27 Wood & Wood Products End use matrix of EU27+Norway for the year 2012

Wood and Wood Products	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	1276	x	61	137	5	21	=	78	175	6	27	100%	100%	15,1
Austria	52		123	421	7,1	37		6,4	22	0,37	1,9	4,1%	7,2%	21
Belgium	14		98	570	0	56		1,4	7,9	0	0,78	1,1%	2,9%	16
Bulgaria	24		27	69	0	3,7		0,65	1,7	0	0,09	1,9%	0,3%	39
Croatia	25		28	24	0	6,6		0,71	0,60	0	0,17	2,0%	0,6%	15
Czech Republic	60		31	105	2,7	14		1,9	6,3	0,16	0,82	4,7%	3,1%	15
Finland	34		212	222	19	32		7,1	7,5	0,63	1,1	2,6%	4,1%	25
Germany	183		85	194	7,3	31		16	35	1,3	5,7	14%	21%	14
Greece	11		64	76	1,9	11		0,72	0,85	0,022	0,12	0,9%	0,4%	24
Hungary	25		16	38	5,0	6,8		0,41	0,97	0,13	0,17	2,0%	0,6%	13
Ireland	4,9		288	832	26	17		1,4	4,1	0,13	0,1	0,4%	0,3%	99
Italy	145	x	79	36	0	26	=	12	5,2	0	3,8	11%	14%	10
Latvia	35		57	344	11	12		2,0	12	0,38	0,42	2,8%	1,6%	46
Lithuania	31		32	86	2,8	6,1		0,99	2,7	0,088	0,19	2,4%	0,7%	30
Netherlands	20		43	89	0	42		0,86	1,8	0	0,84	1,6%	3,1%	5,0
Norway	22		109	162	16	47		2,4	3,5	0,35	1,0	1,7%	3,8%	10
Poland	169		40	135	3,7	9,2		6,8	23	0,62	1,5	13%	5,8%	28
Portugal	49		40	49	8,5	12		1,9	2,4	0,42	0,60	3,8%	2,3%	14
Romania	105		29	66	4,1	5,7		3,0	6,9	0,43	0,60	8,2%	2,2%	27
Slovakia	19		30	99	2,2	12		0,57	1,9	0,042	0,23	1,5%	0,9%	16
Spain	80		62	188	7,8	20		5,0	15	0,62	1,6	6,3%	5,9%	19
Sweden	50		138	273	12	35		6,9	14	0,61	1,8	3,9%	6,6%	19
United Kingdom	119		-	-	-	27		-	-	-	3,2	9%	12%	-

3.2.13 Non-specified industry

Non-specified Industry is formed by a miscellaneous of activities including: rubber and plastic products, furniture, jewelry, games, toys, brooms and brushes and other minor manufactures. The end use matrix for this sector is illustrated in Table IV-28 and Figure IV-30. Sweden shows the highest electricity EMR (151 MJ/h), Belgium the largest heat EMR (182 MJ/h) and UK the greater fuel EMR (191 MJ/h). Ireland has the largest EJP (63 €/h).

Table IV-28 Non-specified (Industry) End use matrix of EU27+Norway for the year 2012

Non-specified (Industry)	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	4751	x	62	42	32	27	=	297	198	153	130	100%	100%	9,3
Austria	114		52	31	4,6	38		6,0	3,5	0,53	4,3	2,4%	3,3%	4,7
Belgium	58		98	182	103	53		5,7	11	6,0	3,1	1,2%	2,4%	11
Bulgaria	85		22	7,3	0	4,5		1,9	0,62	0	0,39	1,8%	0,3%	15
Croatia	41		20	38	1,0	8,1		0,84	1,6	0,043	0,33	0,9%	0,3%	12
Czech Republic	221		36	18	4,5	16		8,0	4,0	0,99	3,6	4,7%	2,8%	7,5
Finland	38		36	33	81	42		1,4	1,3	3,1	1,6	0,8%	1,2%	5,8
Germany	1.166		54	29	4,9	37		63	34	5,7	44	25%	34%	4,8
Greece	46		62	93	188	20		2,9	4,3	8,7	0,93	1,0%	0,7%	26
Hungary	131		20	14	0,32	13		2,7	1,8	0,042	1,7	2,8%	1,3%	5,3
Ireland	66		67	21	23	63		4,4	1,4	1,5	4,1	1,4%	3,2%	3,7
Italy	602	x	97	6,1	0,54	32	=	58	3,6	0,32	19	13%	15%	8,1
Latvia	16		14	15	2,6	5,8		0,22	0,25	0,042	0,092	0,3%	0,1%	9,7
Lithuania	59		24	15	0,72	8,6		1,4	0,89	0,043	0,51	1,3%	0,4%	9,3
Netherlands	97		84	88	1,8	45		8,1	8,5	0,17	4,3	2,0%	3,4%	7,1
Norway	22		78	14	27	52		1,8	0,30	0,60	1,2	0,5%	0,9%	4,9
Poland	580		20	16	1,1	11		12	9,3	0,65	6,4	12%	5,0%	6,4
Portugal	113		43	4,9	1,1	14		4,8	0,56	0,12	1,6	2,4%	1,3%	8,2
Romania	246		14	10	1,7	5,5		3,5	2,4	0,42	1,4	5,2%	1,1%	9,1
Slovakia	79		37	31	6,1	15		2,9	2,5	0,49	1,2	1,7%	0,9%	9,1
Spain	300		66	102	21	28		20	31	6,3	8,3	6%	6%	11
Sweden	79		151	24	50	45		12	1,9	3,9	3,6	1,7%	2,7%	11
United Kingdom	590		127	125	191	30		75	74	113	18	12%	14%	24

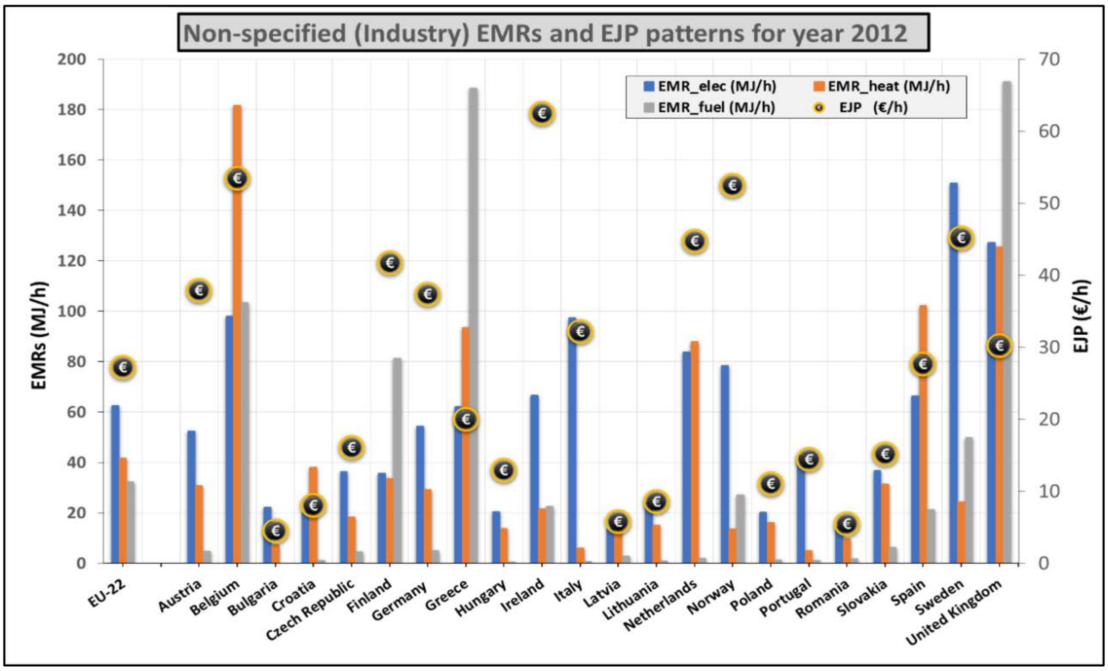


Figure IV-30 Non-specified (Industry) Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

3.2.14 Construction

Construction sector is characterized by an intensive use of human activity – i.e. labor in the paid work. This large use of human labor translates into low values of EMRs [4 7 9] MJ/h for EU-22 average. The end use matrix for this sector is illustrated in Table IV-29 and

Figure IV-31. While Norway have the largest electricity EMR (15 MJ/h), Spain shows the highest heat EMR (24 MJ/h) and Finland the greater fuel EMR (66 MJ/h). Regarding EJP, Norway (62 €/h) and Belgium (57 €/h) do have the largest values.

Table IV-29 Construction End use matrix of EU27+Norway for the year 2012

Construction	HA (10^9h/year)		EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (€/h)		ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	VA (10^9 €)	%HA/ HA_EU-22	%VA/ VA_EU-22	EEI (MJ/€)
EU-22	13976	x	4	7	9	29	=	58	103	122	406	100%	100%	1,1
Austria	416		5,5	8,4	36	36		2,3	3,5	15	15	3,0%	3,7%	2,0
Belgium	275		10	8,9	8,8	57		2,9	2,4	2,4	16	2,0%	3,9%	0,9
Bulgaria	219		4,6	2,9	4,0	5,7		1,0	0,63	0,88	1,2	1,6%	0,3%	3,6
Croatia	166		2,0	0,57	26	8,5		0,33	0,094	4,4	1,4	1,2%	0,3%	4,9
Czech Republic	415		4,0	7,4	5,1	15		1,7	3,1	2,1	6,0	3,0%	1,5%	1,8
Finland	231		5,7	0	66	41		1,3	0	15	9,4	1,7%	2,3%	2,6
Germany	2.483		4,0	7,0	9,0	32		9,9	17	22	79	18%	19%	1,0
Greece	148		0,027	0,93	16	31		0,004	0,14	2,3	4,5	1,1%	1,1%	0,7
Hungary	272		0,54	2,4	14	8,1		0,15	0,66	3,9	2,2	1,9%	0,5%	2,9
Ireland	106		2,5	0	0	-		0,26	0	0	-	0,8%	-	-
Italy	1.550	x	3,4	6,1	0,85	34	=	5,2	9,5	1,3	53	11%	13%	0,5
Latvia	86		3,5	11	12	8,8		0,30	0,91	1,1	0,76	0,6%	0,2%	4,3
Lithuania	135		2,7	5,1	4,8	7,1		0,36	0,69	0,65	0,95	1,0%	0,2%	2,7
Netherlands	560		3,1	7,0	28	45		1,8	3,9	15	25	4,0%	6,2%	1,2
Norway	288		15	3,8	20	62		4,5	1,1	5,7	18	2,1%	4,4%	1,2
Poland	1.087		2,7	2,3	2,7	12		2,9	2,5	3,0	13	7,8%	3,3%	1,1
Portugal	526		3,2	1,8	9,4	11		1,7	0,92	4,9	5,8	3,8%	1,4%	2,1
Romania	700		3,7	9,1	14	5,9		2,6	6,3	9,6	4,2	5,0%	1,0%	6,5
Slovakia	120		1,8	7,8	2,1	21		0,22	0,93	0,25	2,5	0,9%	0,6%	0,8
Spain	1.453		6,1	24	3,5	28		8,9	35	5,1	41	10%	10%	1,7
Sweden	460		8,6	0	0	43		3,9	0,02	0	20	3,3%	4,8%	0,5
United Kingdom	2.281		2,4	6,0	2,7	38		5,4	14	6,1	87	16%	22%	0,4

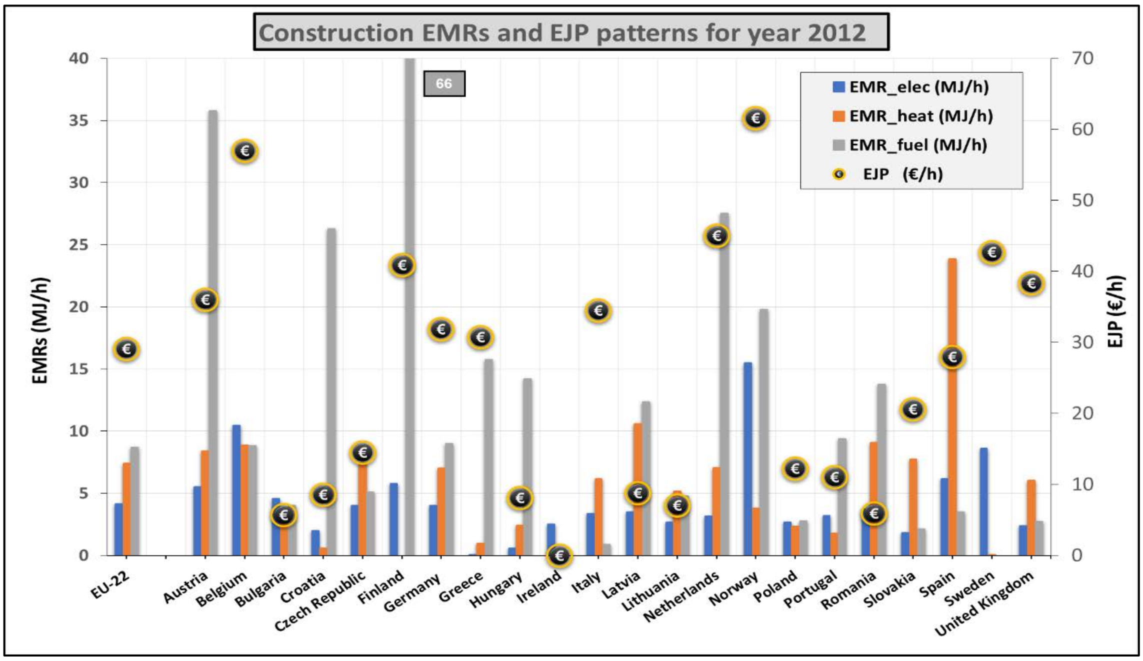


Figure IV-31 Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

4 Mapping metabolic patterns and functional benchmarks

4.1 Comparing EMRs and EJP by NCI and Boxplots.

Metabolic indicators as EMRs and EJP give systemic information about the characteristics of the various processes taking place in the various sectors and subsectors making up a societal metabolic entity. These indicators refer to intensity values out of scale. Because of this fact they can be used to compare qualitative characteristics of sub-sectors, sectors and countries independently from their relative size. This section, illustrates the possible use of four tables organizing these metabolic indicators to illustrate their patterns. The benchmarks for the European countries are represented by using boxplots (explained below). Moreover, I have colored the tables in two different ways using Normalized Chromatic Intensity method (see section 3.3.3 in chapter 3). In this way, we can compare: (i) different sectors in the same country (Iron & steel vs Machinery of Spain); (ii) different countries in relation to the same sector (Iron & steel of Spain vs Italy); and (iii) different countries and sectors (Iron & Steel of Norway vs Paper, Pulp & Print of Finland). Additionally, we can identify metabolic patterns across countries and across sectors and subsectors.

Tables and figures illustrating levels n, n-1, n-2 and n-3 (section 2 of this chapter) are illustrated in Appendix B. Here I illustrate as example the analysis of the method proposed here Manufacturing and Construction and their subsectors (section 3 of this chapter).

By showing all electricity EMRs in Table IV-30, and by applying the Normalized Chromatic Intensity (NCI) we can see which country has the highest level of capitalization (of electric power capacity) per each subsector of the Manufacturing and Construction sector. As we can see, Norway presents the highest value for the average MC, as well as for IS, NFM, CP and the Co sectors. On the other hand, Belgium presents the highest one for NMM, FT and TL subsectors; Finland for PPP; Ireland for TE, Ma and WWP; and Sweden for NSI. If we apply NCI per country instead of per sector, we obtain the result illustrated in Table IV-31. This time we can see clearly the sectors with the highest values of EMRs. In this case, we obtain a clear pattern where IS, NFM, CP, NMM and PPP are the sectors consuming more electricity per hour of labor. On the other hand, we can see that some of the subsectors - FT, TL, TE, Ma, WWP and NSI – belong to another cluster expressing values lower than the previous one by 1 or 2 orders of magnitude. Finally, we can see how Construction represents a particular pattern with one of the lowest values.

Table IV-30 Electricity EMRs for Manufacturing and Construction sector and subsectors for EU-22 countries -year 2012

EMR_elec (MJ/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	61	408	563	249	122	53	24	218	37	30	61	4	62
Austria	75	391	185	320	128	64	54	358	44	39	123	5	52
Belgium	145	803	550	408	343	153	138	279	114	20	98	10	98
Bulgaria	29	250	343	118	80	25	6	44	14	18	27	5	22
Croatia	19	61	118	47	92	22	11	48	17	13	28	2	20
Czech Republic	37	149	62	213	90	31	34	96	34	21	31	4	36
Finland	187	664	1.251	663	117	101	80	1.386	43	36	212	6	36
Germany	65	381	320	266	125	51	42	192	46	32	85	4	54
Greece	69	199	1.390	75	124	57	28	72	40	8	64	0	62
Hungary	24	102	104	178	61	21	4	47	30	11	16	1	20
Ireland	82	-	1.889	139	179	93	132	55	130	70	288	2	67
Italy	64	525	236	194	134	76	30	142	31	39	79	3	97
Latvia	27	342	10	35	117	22	7	16	22	14	57	3	14
Lithuania	24	55	-	278	62	32	12	38	13	15	32	3	24
Netherlands	84	433	881	475	113	130	61	140	32	31	43	3	84
Norway	243	4.112	6.703	1.302	164	119	31	968	37	40	109	15	78
Poland	35	298	235	189	78	28	7	91	21	16	40	3	20
Portugal	35	553	70	251	92	35	15	216	23	21	40	3	43
Romania	26	464	-	180	92	17	6	25	12	19	29	4	14
Slovakia	56	308	1.253	259	90	29	9	174	29	20	30	2	37
Spain	61	689	1.283	151	139	57	38	107	33	20	62	6	66
Sweden	143	351	1.150	331	114	102	55	1.069	55	40	138	9	151
United Kingdom	53	152	305	205	157	52	71	129	36	36	-	2	127

Table IV-31 Electricity EMRs compilation for Manufacturing and Construction sector and subsectors for EU-22 countries and year 2012. Comparing sectors by NCI.

EMR_elec (MJ/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	61	408	563	249	122	53	24	218	37	30	61	4	62
Austria	75	391	185	320	128	64	54	358	44	39	123	5	52
Belgium	145	803	550	408	343	153	138	279	114	20	98	10	98
Bulgaria	29	250	343	118	80	25	6	44	14	18	27	5	22
Croatia	19	61	118	47	92	22	11	48	17	13	28	2	20
Czech Republic	37	149	62	213	90	31	34	96	34	21	31	4	36
Finland	187	664	1.251	663	117	101	80	1.386	43	36	212	6	36
Germany	65	381	320	266	125	51	42	192	46	32	85	4	54
Greece	69	199	1.390	75	124	57	28	72	40	8	64	0	62
Hungary	24	102	104	178	61	21	4	47	30	11	16	1	20
Ireland	82	0	1.889	139	179	93	132	55	130	70	288	2	67
Italy	64	525	236	194	134	76	30	142	31	39	79	3	97
Latvia	27	342	10	35	117	22	7	16	22	14	57	3	14
Lithuania	24	55	0	278	62	32	12	38	13	15	32	3	24
Netherlands	84	433	881	475	113	130	61	140	32	31	43	3	84
Norway	243	4.112	6.703	1.302	164	119	31	968	37	40	109	15	78
Poland	35	298	235	189	78	28	7	91	21	16	40	3	20
Portugal	35	553	70	251	92	35	15	216	23	21	40	3	43
Romania	26	464	0	180	92	17	6	25	12	19	29	4	14
Slovakia	56	308	1.253	259	90	29	9	174	29	20	30	2	37
Spain	61	689	1.283	151	139	57	38	107	33	20	62	6	66
Sweden	143	351	1.150	331	114	102	55	1.069	55	40	138	9	151
United Kingdom	53	152	305	205	157	52	71	129	36	36	0	2	127

As have been already said, the analysis of the values of the EU22 and EU27+N cluster could be used to individuate benchmarks for the European context. The values found in the different countries can then be used study the distribution and variability of this benchmark inside the clusters. Doing so, we can build one boxplot for each one of the sectors and subsectors considered by representing these values as illustrated in the Figure IV-32 Boxplot of electricity EMR of Manufacturing and Construction sector and subsectors for EU-22 countries in 2012.. In this way, we can summarize all the information in the tables and have an idea of: (i) the robustness of the benchmarks for each subsector; and (ii) variability of the metabolic assessment in each category. A high variability in a subsector tends to indicate that there are different technical processes grouped in the same category by the statistical accounting (this will be discussed in detail in the next chapter). A high variability in the values of a given subsector indicates that the categorization done by the statistical office is making difficult our pattern recognition definition.

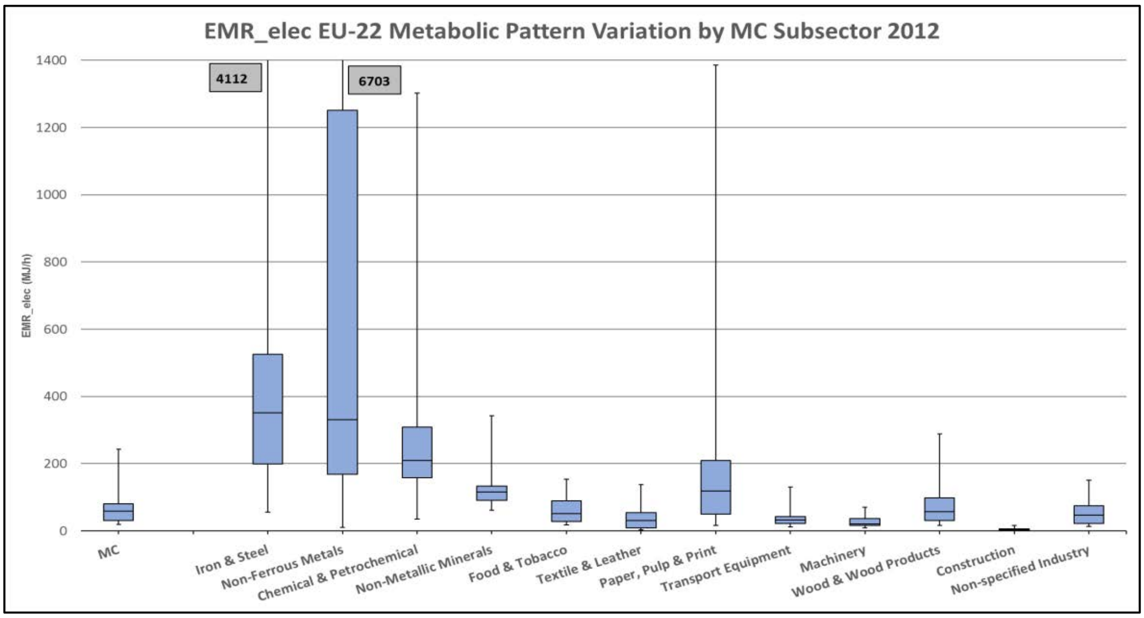


Figure IV-32 Boxplot of electricity EMR of Manufacturing and Construction sector and subsectors for EU-22 countries in 2012.

Doing the same exercise with heat EMRs I obtain

Table IV-32 and Table IV-33 and Figure IV-33. In Table IV-33 we can see similar patterns to those shown in Table IV-31 Electricity EMRs compilation for Manufacturing and

Construction sector and subsectors for EU-22 countries and year 2012. Comparing sectors by NCI., which means that electricity and heat energy carriers are consumed per hour of labor with similar patterns of intensity in the subsectors. In this integrated analysis, the Iron & Steel sector becomes clearly as the most energy demanding subsector per hour of labor. When looking Figure IV-33, we can appreciate that the variability of heat EMR in Iron and Steel is much higher than for electricity EMR, just the contrary of what is found in the Non-Ferrous Metals subsector.

Table IV-32 Heat EMRs compilation for Manufacturing and Construction sector and subsectors for EU-22 countries - year 2012

EMR_heat (MJ/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	107	1.523	274	380	571	88	31	391	22	20	137	7	42
Austria	180	2.157	212	471	542	120	58	1.040	33	31	421	8	31
Belgium	280	2.975	462	507	1.148	278	178	380	146	15	570	9	182
Bulgaria	51	204	118	388	533	33	4	256	10	9	69	3	7
Croatia	48	65	105	219	542	51	11	101	10	10	24	1	38
Czech Republic	90	1.186	110	336	380	76	30	280	28	17	105	7	18
Finland	294	1.658	313	402	290	50	21	3.095	4	3	222	0	33
Germany	112	1.796	232	371	585	97	52	285	28	19	194	7	29
Greece	108	171	1.342	72	893	85	15	49	4	2	76	1	93
Hungary	46	1.386	200	85	287	61	4	71	16	10	38	2	14
Ireland	109	23	9.726	61	800	95	14	9	22	70	832	0	21
Italy	93	1.414	301	185	675	91	38	123	0	34	36	6	6
Latvia	96	332	238	100	795	58	24	23	16	13	344	11	15
Lithuania	50	21	185	376	517	71	13	72	10	9	86	5	15
Netherlands	197	4.066	237	843	498	306	147	221	34	36	89	7	88
Norway	110	3.327	213	1.386	500	36	7	527	6	4	162	4	14
Poland	85	1.017	274	477	441	74	7	245	13	11	135	2	16
Portugal	72	266	64	236	616	37	19	896	12	9	49	2	5
Romania	65	960	-	832	393	45	8	29	9	19	66	9	10
Slovakia	170	2.650	205	398	442	59	19	538	27	17	99	8	31
Spain	129	1.037	232	667	765	72	34	313	20	21	188	24	102
Sweden	183	956	244	99	362	69	20	2.023	8	4	273	0	24
United Kingdom	74	1.495	112	171	500	87	126	88	28	21	-	6	125

Table IV-33 Electricity EMRs for Manufacturing and Construction sector and subsectors for EU-22 countries - year 2012

EMR_heat (MJ/h) 2012	MC	Iron and Steel	Non-Ferrous Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, Pulp and Print	Transport Equipment	Machinery	Wood and Wood Products	Construction	Non-specified Industry
Europe (EU-22)	107	1.523	274	380	571	88	31	391	22	20	137	7	42
Austria	180	2.157	212	471	542	120	58	1.040	33	31	421	8	31
Belgium	280	2.975	462	507	1.148	278	178	380	146	15	570	9	182
Bulgaria	51	204	118	388	533	33	4	256	10	9	69	3	7
Croatia	48	65	105	219	542	51	11	101	10	10	24	1	38
Czech Republic	90	1.186	110	336	380	76	30	280	28	17	105	7	18
Finland	294	1.658	313	402	290	50	21	3.095	4	3	222	0	33
Germany	112	1.796	232	371	585	97	52	285	28	19	194	7	29
Greece	108	171	1.342	72	893	85	15	49	4	2	76	1	93
Hungary	46	1.386	200	85	287	61	4	71	16	10	38	2	14
Ireland	109	23	9.726	61	800	95	14	9	22	70	832	0	21
Italy	93	1.414	301	185	675	91	38	123	0	34	36	6	6
Latvia	96	332	238	100	795	58	24	23	16	13	344	11	15
Lithuania	50	21	185	376	517	71	13	72	10	9	86	5	15
Netherlands	197	4.066	237	843	498	306	147	221	34	36	89	7	88
Norway	110	3.327	213	1.386	500	36	7	527	6	4	162	4	14
Poland	85	1.017	274	477	441	74	7	245	13	11	135	2	16
Portugal	72	266	64	236	616	37	19	896	12	9	49	2	5
Romania	65	960	0	832	393	45	8	29	9	19	66	9	10
Slovakia	170	2.650	205	398	442	59	19	538	27	17	99	8	31
Spain	129	1.037	232	667	765	72	34	313	20	21	188	24	102
Sweden	183	956	244	99	362	69	20	2.023	8	4	273	0	24
United Kingdom	74	1.495	112	171	500	87	126	88	28	21	0	6	125

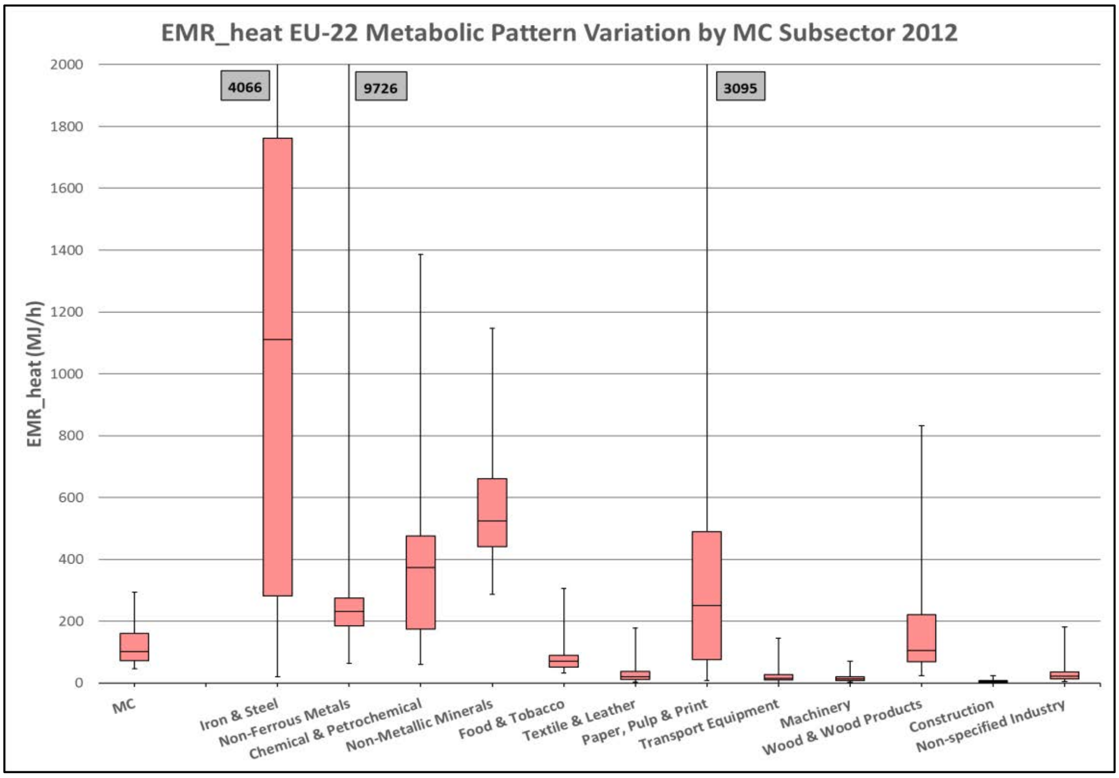


Figure IV-33 Boxplot of heat EMR of Manufacturing and Construction sector and subsectors for EU-22 countries in 2012.

Fuel EMRs are shown in Table IV-34 and Table IV-35. In the first one we can see that Finland and Ireland present quite high values for many of the subsectors. When comparing subsectors, we can see that CP, IS, NFM, NMM and NSI present the highest values, followed by PPP and Co.

Table IV-34 Fuel EMRs compilation for Manufacturing and Construction sector and subsectors for EU-22 countries - year 2012

EMR_fuel (MJ/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	12	34	27	47	27	10	4	15	4	3	5	9	32
Austria	21	132	13	23	26	20	10	8	2	4	7	36	5
Belgium	17	27	23	8	79	4	2	26	3	5	0	9	103
Bulgaria	3	0	89	5	10	3	1	7	0	1	0	4	0
Croatia	12	0	16	4	14	9	2	7	3	1	0	26	1
Czech Republic	2	4	0	3	3	1	1	3	0	0	3	5	4
Finland	47	308	152	47	36	25	22	61	16	3	19	66	81
Germany	11	44	11	70	28	9	7	5	2	4	7	9	5
Greece	32	46	18	2	23	21	5	30	17	1	2	16	188
Hungary	4	3	3	0	0	1	0	3	0	0	5	14	0
Ireland	39	0	3.189	24	173	52	40	6	16	6	26	0	23
Italy	9	12	11	107	20	10	4	9	0	5	0	1	1
Latvia	10	16	0	12	40	8	2	0	7	2	11	12	3
Lithuania	4	0	0	0	19	5	1	4	0	0	3	5	1
Netherlands	13	6	0	10	26	2	0	0	4	1	0	28	2
Norway	29	68	25	121	42	36	4	101	5	5	16	20	27
Poland	5	1	10	24	16	6	1	11	2	1	4	3	1
Portugal	9	14	7	14	13	19	1	43	1	1	9	9	1
Romania	5	1	0	6	13	5	0	2	0	1	4	14	2
Slovakia	7	0	0	199	2	1	2	4	2	0	2	2	6
Spain	13	39	89	40	39	15	15	26	12	3	8	3	21
Sweden	21	95	29	37	76	21	14	98	2	7	12	0	50
United Kingdom	22	1	3	16	43	6	12	4	13	0	0	3	191

Table IV-35 Fuel EMRs compilation for Manufacturing and Construction sector and subsectors for EU-22 countries -year 2012

EMR_fuel (MJ/h) 2012	MC	Iron and Steel	Non-Ferrous Metals	Chemical and Petrochemical	Non-Metallic Minerals	Food and Tobacco	Textile and Leather	Paper, Pulp and Print	Transport Equipment	Machinery	Wood and Wood Products	Construction	Non-specified Industry
Europe (EU-22)	12	34	27	47	27	10	4	15	4	3	5	9	32
Austria	21	132	13	23	26	20	10	8	2	4	7	36	5
Belgium	17	27	23	8	79	4	2	26	3	5	0	9	103
Bulgaria	3	0	89	5	10	3	1	7	0	1	0	4	0
Croatia	12	0	16	4	14	9	2	7	3	1	0	26	1
Czech Republic	2	4	0	3	3	1	1	3	0	0	3	5	4
Finland	47	308	152	47	36	25	22	61	16	3	19	66	81
Germany	11	44	11	70	28	9	7	5	2	4	7	9	5
Greece	32	46	18	2	23	21	5	30	17	1	2	16	188
Hungary	4	3	3	0	0	1	0	3	0	0	5	14	0
Ireland	39	0	3.189	24	173	52	40	6	16	6	26	0	23
Italy	9	12	11	107	20	10	4	9	0	5	0	1	1
Latvia	10	16	0	12	40	8	2	0	7	2	11	12	3
Lithuania	4	0	0	0	19	5	1	4	0	0	3	5	1
Netherlands	13	6	0	10	26	2	0	0	4	1	0	28	2
Norway	29	68	25	121	42	36	4	101	5	5	16	20	27
Poland	5	1	10	24	16	6	1	11	2	1	4	3	1
Portugal	9	14	7	14	13	19	1	43	1	1	9	9	1
Romania	5	1	0	6	13	5	0	2	0	1	4	14	2
Slovakia	7	0	0	199	2	1	2	4	2	0	2	2	6
Spain	13	39	89	40	39	15	15	26	12	3	8	3	21
Sweden	21	95	29	37	76	21	14	98	2	7	12	0	50
United Kingdom	22	1	3	16	43	6	12	4	13	0	0	3	191

When looking at the fuel EMR boxplot, one can see how there are important outliers for IS, NFM, CP, NMM and NSI (see Figure IV-34).

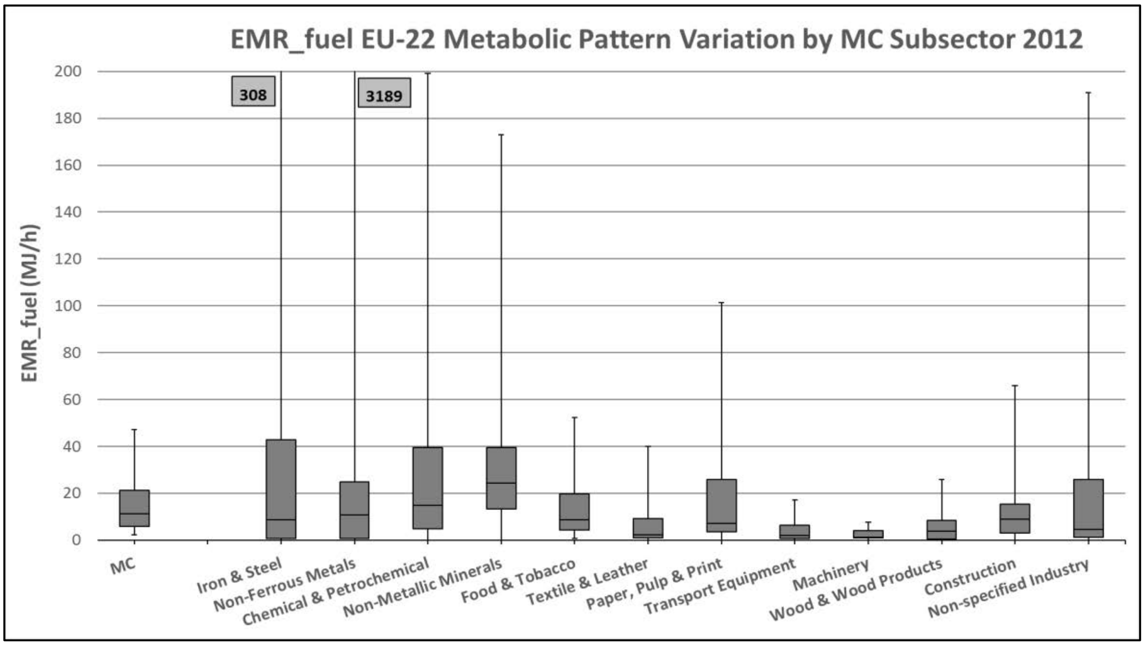


Figure IV-34 Boxplot of fuel EMR of Manufacturing and Construction sector and subsectors for EU-22 countries in 2012

Finally, I present tables and boxplots referring to EJP values. In Table IV-36 we can see how Norway presents the highest EJP for many of the subsectors. Ireland also shows very high values for all the subsectors and the greatest one for the Chemical and Petrochemical. Austria and Belgium present also high EJP. On the other hand, Rumania, Bulgaria and Lithuania have the lowest EJP values for most of the subsectors. When looking Table IV-37, one can easily appreciate that Chemical and Petrochemical is clearly the subsector with the highest EJP for all the countries, except for Bulgaria, Greece, Latvia, Norway and Slovakia, where the highest is the Non-Ferrous Metals subsector. The Textile & Leather subsector is clearly the subsector with the lowest EJP for all the countries but in Greece where Food & Tabaco has a slightly lower value.

Table IV-36 EJP for Manufacturing and Construction sector and subsectors for EU-22 countries -year 2012

EJP (€/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	33	35	42	69	29	29	16	34	42	36	21	29	27
Austria	45	69	62	68	44	43	32	57	60	52	37	36	38
Belgium	65	53	83	119	59	62	46	60	56	62	56	57	53
Bulgaria	6	5	28	10	8	6	3	6	6	6	4	6	5
Croatia	10	12	8	19	14	12	6	12	8	11	7	9	8
Czech Republic	16	10	11	27	18	15	10	16	22	16	14	15	16
Finland	44	33	69	96	45	44	39	67	35	38	32	41	42
Germany	43	49	47	72	40	29	33	39	62	45	31	32	37
Greece	25	19	34	33	24	27	15	20	15	22	11	31	20
Hungary	14	7	19	37	13	10	6	13	21	17	7	8	13
Ireland	81	35	-	371	25	95	39	38	57	58	17	-	63
Italy	36	39	36	61	33	39	28	36	35	38	26	34	32
Latvia	10	14	17	13	16	8	5	11	9	12	12	9	6
Lithuania	8	8	4	22	10	9	6	12	8	10	6	7	9
Netherlands	54	49	51	115	43	62	50	47	50	57	42	45	45
Norway	65	92	118	98	64	61	33	56	64	73	47	62	52
Poland	13	18	15	24	15	13	6	18	18	13	9	12	11
Portugal	13	22	15	29	16	14	8	26	19	15	12	11	14
Romania	6	10	11	11	10	6	3	6	8	7	6	6	6
Slovakia	16	13	23	18	15	12	7	19	18	16	12	21	15
Spain	31	35	51	55	29	32	20	32	39	30	20	28	28
Sweden	52	40	76	146	53	45	43	57	51	58	35	43	45
United Kingdom	39	27	36	62	30	42	28	35	49	37	27	38	30

Finally, when looking the Figure IV-35 we can see that the variability of EJP is similar for all the subsector, although one can appreciate higher values in the subsectors that require more capitalization (highest values of EMRs). This fact seems to justify the assumption that if the subsectors with higher EMRs (more technical capital and more energy consumption per worker) have also higher EJP richer countries tend to have a larger share of their working HA in high EMRs subsectors. On the other hand, are these rich countries the one that present higher EMRs in the subsectors? Put it in another way, do they have more capital and then, more capitalization? For answering these questions, I introduce in the next section the Metabolic Structural tables.

Table IV-37 EJP for Manufacturing and Construction sector and subsectors for EU-22 countries - year 2012

EJP (€/h) 2012	MC	Iron & Steel	Non-Ferrous Metals	Chemical & Petrochemical	Non-Metallic Minerals	Food & Tobacco	Textile & Leather	Paper, Pulp & Print	Transport Equipment	Machinery	Wood & Wood Products	Construction	Non-specified Industry
Europe (EU-22)	33	35	42	69	29	29	16	34	42	36	21	29	27
Austria	45	69	62	68	44	43	32	57	60	52	37	36	38
Belgium	65	53	83	119	59	62	46	60	56	62	56	57	53
Bulgaria	6	5	28	10	8	6	3	6	6	6	4	6	5
Croatia	10	12	8	19	14	12	6	12	8	11	7	9	8
Czech Republic	16	10	11	27	18	15	10	16	22	16	14	15	16
Finland	44	33	69	96	45	44	39	67	35	38	32	41	42
Germany	43	49	47	72	40	29	33	39	62	45	31	32	37
Greece	25	19	34	33	24	27	15	20	15	22	11	31	20
Hungary	14	7	19	37	13	10	6	13	21	17	7	8	13
Ireland	81	35	-	371	25	95	39	38	57	58	17	-	63
Italy	36	39	36	61	33	39	28	36	35	38	26	34	32
Latvia	10	14	17	13	16	8	5	11	9	12	12	9	6
Lithuania	8	8	4	22	10	9	6	12	8	10	6	7	9
Netherlands	54	49	51	115	43	62	50	47	50	57	42	45	45
Norway	65	92	118	98	64	61	33	56	64	73	47	62	52
Poland	13	18	15	24	15	13	6	18	18	13	9	12	11
Portugal	13	22	15	29	16	14	8	26	19	15	12	11	14
Romania	6	10	11	11	10	6	3	6	8	7	6	6	6
Slovakia	16	13	23	18	15	12	7	19	18	16	12	21	15
Spain	31	35	51	55	29	32	20	32	39	30	20	28	28
Sweden	52	40	76	146	53	45	43	57	51	58	35	43	45
United Kingdom	39	27	36	62	30	42	28	35	49	37	27	38	30

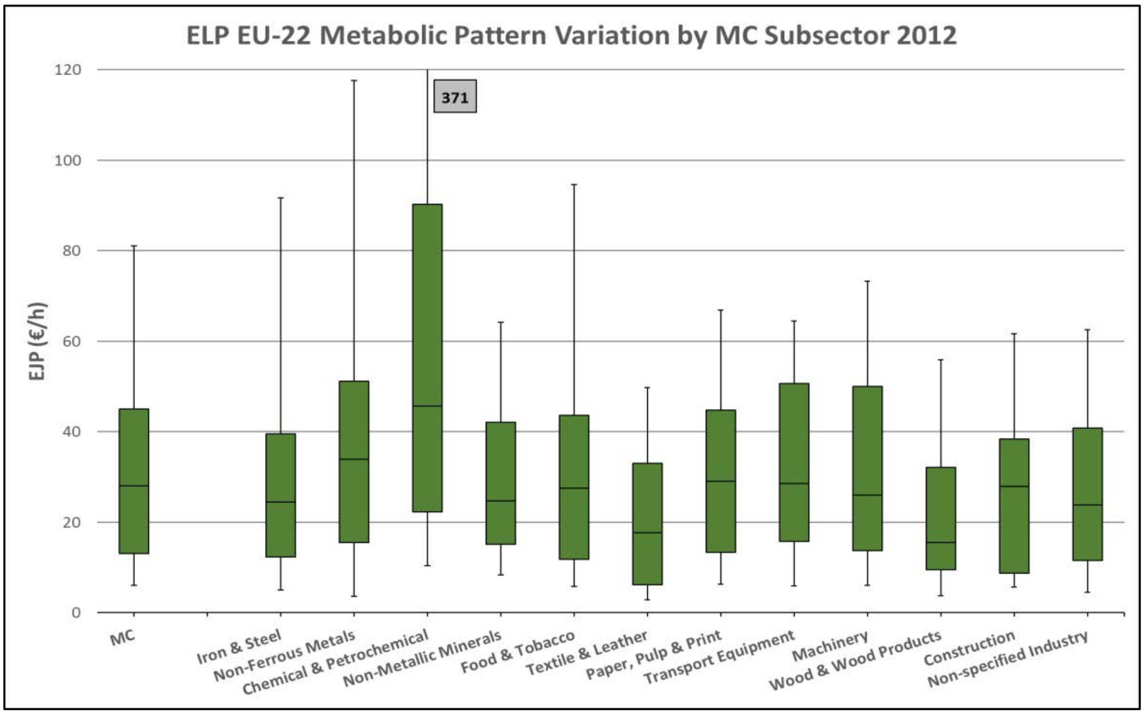


Figure IV-35 Boxplot of EJP of Manufacturing and Construction sector and subsectors for EU-22 countries in 2012.

4.2 HA distribution analysis through the Metabolic Structural tables

As we have seen throughout this chapter, even when using a small number of indicators, the multi-scale integrated approach become easily a source of an excessive amount of information difficult to handle. Namely, when we open one sector to analyze its parts, the new parts present differences that in order to be explained require an additional opening of the sub-parts into sub-sub-parts. By doing additional splitting to lower level sub-sectors, we get a better understanding of the structural characteristics of the systems we are analyzing, their functional similarities and their structural differences. Unfortunately, this implies increasing the complexity of the information space we have to handle. For this reason, we need strategies to organize and visualize the massive flow of information to avoid being overwhelmed by an overflow of information. In relation to this task, I propose here the Metabolic Structural table. The idea of these tables is to map the different metabolic characteristics at different levels of analysis showing the distribution (proportion) of the scaling factor - human activity – transforming the EMR into extensive quantities of energy consumed by the various subsectors according to the relation: Hai x EMRi = ETi.

Tracking quantities of human activity across the different functional sectors of a society, one can relate the analysis to demographic variables and to the profile of allocation of human activity distribution across the economic sectors (how the work force is distributed across the various sectors and subsectors). This information complements the one regarding technological aspects of processes. Therefore, this type of integrated accounting can be used to: (i) study the profile of skills and educational levels required in one society translating into a requirement of work, infrastructures and technical capital in the education system; and (ii) the implication of the demographic structure and the geographic distribution of population.

4.3 Metabolic structural table of level n vs n-1

The first metabolic structural Table IV-38 refers to the level of analysis of whole society (Average Society - AS) which is split into two sub-levels - Household (HH) and Paid Work

(PW). In the first column, we can see the EU27+N human activity distribution across EU countries (hours are expressed in 10^9 hours) at the level of AS. The second and third columns show the percentage of the hours in AS allocated in HH and PW. The NCI is applied vertically, showing the countries with higher proportion of HA allocated in HH having more intense colors (same for PW). The proportion of the HA of each country vs the European cluster is showed in the last column (size of the country in terms of HA), while in the last row we can see the proportion of HA distributed between HH and the PW for the EU27+N cluster. These data are complemented by information about the metabolic patterns in terms of EMRs and EJP for each country. Values referring to the upper level of analysis (AS) are in the rows (the first row refers to EU27+N), while in the columns we find the same set of indicators for AS, HH and PW referring to the EU27+N.

In this way, we can summarize the intensive variables (EMRs and EJP) giving information about qualitative characteristics (per unit of size) and extensive variables (HA) determining the size of the various sectors and subsectors and the distribution of labor and energy carriers' consumption across sectors and countries.

The combination of both types of information allows us to go through the different levels of the analysis and understand how the metabolic characteristics of different "wholes" (whole countries at the level AS and the whole macro-economic entity at the level of EU27+N) are determined by the metabolic characteristics of the functional and structural parts, and vice versa: this analysis in fact establishes a set of impredicative relations in which the characteristics of the parts are affected and are affecting the characteristics of the whole..

These representations are very useful to better frame the discussion of sustainability issues since they make it possible to integrate different factors studied in different dimensions: population (HA_{AS}); demographic structure (HA_{HH} VS HA_{PW}), employment policies (HA distribution across the different economic sectors), energy consumption associated with the functional compartments divided per type of energy carrier (ETs), level of capitalization of the various sectors (EMRs), value added generation per hour of labor in the various activities (EJP) or the role of different regions (and existence/implications/causes of inequalities). An integrated comparison of all these factors is essential when discussing international policies.

As we can see in the Table IV-38, most of the countries allocate more than 90% of their total human activity (population x 8760 hours per year) outside the paid work sector. The exception of Luxemburg (89%) is probably due to the fact that many people resident elsewhere commute to work there. This effect creates a distortion in the expected metabolic pattern of the country because of its small dimensions.

Also, we can see from the different metabolic patterns of the HH vs PW sectors, the relative size of these two sectors do gaffect in an important manner the overall metabolic pattern of the Average society. In the same way, at the level of the EU27 the distribution of people among different countries operating at different metabolic rates do affect the value of the metabolic rate of the whole Europe: more people expressing activities associated with a high EMRs will increase the overall EMR. Thus, this method of accounting could be used to analyses social inequalities (differences of EMRs between households or between countries) and the displacement (externalization) of environmental impacts associated with the various economic sectors.

Table IV-38 Metabolic structural table for Average Society split in Household and Paid Word sectors of EU27+N, year 2012

2012	Average Society (10^9 hours)	Household (10^9 hours)	Paid Work (10^9 hours)	EMR_ELEC (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)	HA_i/HA_PW (%)
EU27+N	4.422	4.167	255	2,6	4,3	3,9	2,6	100%
Norway	44	91%	8,7%	9,8	6,6	6,1	7,0	1,0%
Finland	47	91%	8,8%	6,4	7,4	5,6	3,5	1,1%
Sweden	83	91%	8,8%	5,8	4,6	4,4	4,3	1,9%
Luxembou	4,6	89%	11%	5,3	6,8	26	7,2	0,1%
Austria	74	91%	9,4%	3,4	6,4	5,6	3,8	1,7%
Belgium	97	97%	3,3%	3,2	6,2	5,9	3,4	2,2%
France	572	96%	3,5%	3,0	3,6	4,4	3,2	13%
Germany	704	96%	3,9%	3,0	5,0	4,8	3,3	16%
Netherlan	147	91%	8,5%	2,8	7,5	4,4	3,7	3,3%
Slovenia	18	91%	8,5%	2,8	3,0	5,3	1,7	0,4%
Estonia	12	90%	9,6%	2,7	3,1	3,5	1,3	0,3%
Czech	92	90%	9,8%	2,5	5,0	2,8	1,5	2,1%
Denmark	49	92%	8,0%	2,5	3,6	5,0	4,3	1,1%
Ireland	40	92%	7,9%	2,3	3,0	6,0	3,5	0,9%
Greece	97	91%	8,6%	2,3	2,3	3,5	1,8	2,2%
Spain	410	93%	7,4%	2,2	3,2	3,9	2,3	9,3%
United	556	96%	4%	2,2	4,3	4,3	2,9	13%
Italy	520	97%	3,3%	2,2	4,6	3,3	2,7	12%
Cyprus	7,6	91%	8,8%	2,1	1,4	6,2	2,1	0,2%
Slovakia	47	92%	8,3%	2,1	5,3	1,9	1,4	1,1%
Malta	3,7	92%	8,0%	2,0	0,5	3,4	1,6	0,1%
Bulgaria	64	96%	3,7%	1,9	2,4	1,7	0,5	1,5%
Portugal	92	91%	9,0%	1,9	2,4	3,1	1,6	2,1%
Poland	333	91%	9,4%	1,6	4,2	2,2	1,0	7,5%
Hungary	87	92%	8,0%	1,5	3,6	2,0	0,9	2,0%
Latvia	18	97%	2,7%	1,5	4,0	2,9	0,9	0,4%
Lithuania	26	96%	3,9%	1,4	3,5	2,3	1,1	0,6%
Romania	176	91%	8,9%	1,1	3,1	1,4	0,7	4,0%

Average Society	Household	Paid Work
2,6	0,7	33
4,3	1,7	47
3,9	1,9	37
2,6	0	46
100%	94%	6%

4.4 Metabolic structural table of level n-1 vs n-2

In the Table IV-39 I continue the analysis of metabolic characteristics to lower levels of analysis. To do this I split the Paid Work sector into Agriculture, Forestry & Fishing; Energy & Mining; Manufacturing & Consumption; and Service & Government. By doing so, we can appreciate how the economic sector concentrating more proportion of human activity is the service & government for all the European countries studied. The percentage goes from 46% in Romania to 83% in Luxemburg. Only Romania presents a $\%HA_{SG}$ lower than 50%, while Poland and Bulgaria have a percentage lower than 60%. As there are many countries with more than 70% of HA_{SG}, the EU27+N average is 68%. Manufacturing & Construction is the second sector with more HA allocated, going from 13% Greece to 40% Bulgaria, and with and EU27+N average around 25%. Agriculture, Forestry and Fishing remains quite high for countries like Latvia (44%), Bulgaria (32%), Lithuania (31%) and Romania (26%); while residual for a country like Luxemburg (0,6%), the average of Europe is 8,4%. Last but not least, Energy and Mining sector represent just a 1,5% of HA allocated in Paid Work in Europe. It varies from 0,5% of Portugal and Luxemburg, to 6,1 of Latvia. There are important differences in the values of EMRs and EJP across the different economic sectors (up to 3 orders of magnitude), the different distribution of HA among them is a crucial issue affecting the overall benchmarks the upper sector that should be added to the technical aspects of the sectors (EMRs).

4.5 Metabolic structural table of level n-2 vs n-3

The third metabolic structural table I present here (Table IV-40) refers to the second part of the analysis in depth of the Manufacturing and Construction sector looking at its subsectors. In this table, we can see how each country present different profiles of distribution of their labor force across their MC subsectors. Again, I have ordered the countries and the subsector from higher to lower electricity EMR. In this way, we can study the relation between the values of EMRs and EJP both by country and by subsector. In particular, we can observer that: (i) the countries with higher values of EMRs present also higher values EJP (we already have seen this in the chapter 2 at the level of paid work, see Figure II-7 a) Evolution of EMR_{PW} and ELP_{PW} of China between 1975 and 2009. b) EMR_{PW}

vs. ELPPW of China between 1975 and 2009. Sources: IEA (2010), ILO (2012), NBSC (2011), OECD (2012) and World bank (2012).); (ii) the sectors with higher EMRs present also higher EJP (this correlation with less intensity that the previous one); (iii) the countries presenting higher values of EMRs and higher values of EJP in the MC sector allocate more HA in the subsectors with higher EMRs and EJP.

Table IV-39 Metabolic structural table for Paid Work sector and subsectors of EU27+N, year 2012

2012	Paid Work (10^9 hours)	EM (10^9 hours, %)	MC (10^9 hours, %)	SG (10^9 hours, %)	AF (10^9 hours, %)	EMR_ELEC (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)	HA_i/HA_PW (%)
EU27+N	255	3,9	65	172	21	33	47	37	46	100%
Norway	3,8	3,3%	17%	76%	3,2%	76	68	51	7,0	1,5%
Belgium	3,2	1,3%	26%	72%	3,9%	76	133	94	3,4	1,3%
Germany	27	1,9%	33%	65%	4,2%	58	85	53	3,3	11%
France	20	1,2%	25%	74%	8,5%	58	59	72	3,2	7,9%
Finland	4,2	0,9%	22%	70%	6,3%	54	70	33	3,5	1,6%
Italy	17	1,4%	38%	61%	14%	52	76	39	2,7	6,8%
Sweden	7,3	1,0%	21%	75%	3,1%	47	45	26	4,3	2,9%
Luxembourg	0,5	0,5%	16%	83%	0,6%	43	45	212	7,2	0,2%
Latvia	0,5	6,1%	24%	69%	44%	40	78	62	0,92	0,2%
United	23	1,9%	25%	73%	2,9%	36	54	62	2,9	9,0%
Bulgaria	2,4	4,2%	40%	56%	32%	35	45	37	0,53	0,9%
Austria	6,9	0,9%	21%	71%	6,5%	27	49	33	3,8	2,7%
Lithuania	1,0	3,0%	35%	62%	31%	27	58	25	1,1	0,4%
Netherlands	12	0,5%	17%	80%	2,9%	26	62	30	3,7	4,9%
Slovenia	1,5	1,2%	27%	62%	9,9%	25	17	36	1,7	0,6%
Estonia	1,1	2,5%	26%	66%	4,8%	22	15	21	1,3	0,4%
Denmark	3,9	0,7%	18%	79%	2,8%	22	29	35	4,3	1,5%
Spain	30	0,6%	19%	76%	4,8%	21	33	36	2,3	12%
Slovakia	4,0	1,2%	29%	67%	3,4%	21	51	10	1,4	1,6%
Czech	9,0	1,3%	34%	62%	3,6%	20	33	20	1,5	3,5%
Ireland	3,2	1,0%	18%	75%	5,8%	20	23	42	3,5	1,2%
Greece	8,3	0,8%	13%	74%	12%	18	20	14	1,8	3,3%
Malta	0,3	-	15%	79%	4,3%	17	2,6	32	1,6	0,1%
Portugal	8,3	0,5%	22%	68%	9,2%	16	19	22	1,6	3,3%
Cyprus	0,7	0,6%	18%	73%	8,1%	15	9,2	48	2,1	0,3%
Poland	32	2,9%	27%	58%	12%	14	26	13	0,98	12%
Hungary	7,0	1,3%	26%	65%	7,6%	13	23	17	0,93	2,7%
Romania	16	2,3%	26%	46%	26%	9,3	19	11	0,65	6,1%
	33	280	57	19	8,0					
	47	612	103	15	15					
	37	17	7,1	48	26					
	46	122	36	50	9,2					
	100%	1,5%	25%	68%	8,4%					

As I have already mention, construction sector is special due to: (i) the impossibility to outsource the activities carried out in it; (ii) the highly manual intensity it needs despite the introduction of prefabricated modules; and (iii) the important effects of speculation over real estate market (more in relation with the location than with the type of construction).

On the other hand, Non-Ferrous Metals, Irion & Steal, Chemical & Petrochemical and Paper, Pulp & Print are clear example of subsector with high EMRs and EJP and where the countries with higher EMRs and EJP in the upper level (MC sector) allocate more proportion of their HA. Textile & Leather subsector represent the opposite of these with the lower allocation of HA in a subsector with low values of EMRs and EJP. This different allocation of HA gets us a clear idea of the specialization and division of work inside the MC in the Eurozone, as well as the different tradeoffs in relation to environmental, social and economic dimensions. However, in order to get a better idea of these relations we need to open more the subsectors for getting closer to characteristics of the production processes where the characteristics of technology play a clear role. It is essential to arrive to a level of disaggregation at which the benchmarks reflect the technical coefficients used in the processes of production in order to be able to compare oranges with oranges, avoiding to use benchmarks describing subsectors in which data reflect the co-existence of mix of clearly different processes. Moreover, we need to analyze the other factors presented in Figure III-1 The metabolic pattern of social-ecological systems and the different factors affecting the energy and carbon intensity of an economy. Abbreviations: PES = primary energy sources; EC = energy carriers; GDP = gross domestic product to get an appropriate understanding of the issues affecting the energy and carbon intensity of an economy. Additional metabolic structural tables could be found in the Appendix B.

Table IV-40 Metabolic structural table for Manufacturing and Construction sector and subsectors of EU22, year 2012

2012	MC	Non-Ferrous Metals	Iron & Steel	Chemical & Petrochemical	Paper, Pulp & Print	Mining & Quarrying	Non-Metallic Minerals	Non-specified Industry	Wood & Wood Products	Food & Tobacco	Transport Equipment	Machinery	Textile & Leather	Construction	EMR_ELEC (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)	
EU-22	54	0,47	0,97	2,4	1,9	0,34	1,8	4,8	1,3	6,1	4,3	13	2,9	14	61	107	12	33	100%
Norway	0,64	1,6%	0,7%	3,1%	2,4%	1,2%	2,9%	3,5%	3,4%	12%	7,6%	16%	1,6%	45%	243	110	29	65	1,2%
Finland	0,74	0,7%	2,5%	3,5%	6,8%	1,1%	3,3%	5,2%	4,6%	7,6%	3,2%	29%	1,3%	31%	187	294	47	44	1,4%
Belgium	0,93	1,3%	2,7%	11%	4,1%	0,4%	4,2%	6,3%	1,5%	12%	6,5%	17%	3,0%	30%	145	280	17	65	1,7%
Sweden	1,4	0,7%	3,4%	3,7%	5,7%	0,3%	2,4%	5,8%	3,7%	6,4%	9,3%	24%	0,7%	34%	143	183	21	52	2,5%
Netherlands	1,5	0,8%	1,5%	6,2%	4,3%	0,2%	2,6%	6,5%	1,3%	12%	3,9%	22%	1,4%	37%	84	197	13	54	2,8%
Ireland	0,40	0,4%	0,5%	11%	3,5%	0,5%	2,9%	16%	1,2%	19%	1,3%	17%	0,8%	26%	82	109	39	81	0,8%
Austria	1,4	1,4%	2,7%	3,6%	3,5%	0,6%	3,8%	8,4%	3,9%	8,8%	4,6%	26%	2,2%	31%	75	180	21	45	2,5%
Greece	0,60	2,0%	2,8%	5,0%	4,4%	1,4%	4,6%	7,7%	1,9%	23%	2,1%	14%	6,8%	25%	69	108	32	25	1,1%
Germany	13	1,1%	2,0%	5,5%	3,5%	0,4%	2,8%	9,1%	1,4%	9,9%	11%	32%	1,6%	19%	65	112	11	43	24%
Italy	6,8	0,9%	2,0%	4,1%	3,4%	0,4%	3,9%	8,9%	2,1%	8,4%	5,7%	28%	9,9%	23%	64	93	8,8	36	13%
Spain	4,3	0,7%	1,6%	4,7%	4,1%	0,7%	3,9%	7,0%	1,9%	14%	6,7%	16%	4,4%	34%	61	129	13	31	7,9%
Slovakia	0,76	0,9%	4,0%	2,6%	2,7%	0,5%	3,5%	10%	2,5%	8,6%	15%	27%	6,5%	16%	56	170	7,1	16	1,4%
United Kingdom	6,7	0,9%	1,2%	4,5%	4,5%	0,8%	2,3%	8,8%	1,8%	11%	7,6%	20%	2,2%	34%	53	74	22	39	12%
Czech Republic	2,2	0,5%	2,8%	2,9%	2,9%	0,6%	4,0%	10%	2,7%	8,4%	12%	30%	3,5%	19%	37	90	2,1	16	4,1%
Portugal	1,6	0,4%	0,5%	2,0%	2,9%	0,9%	4,4%	7,0%	3,0%	11%	3,6%	13%	18%	32%	35	72	9,0	13	3,0%
Poland	4,7	0,6%	1,6%	3,5%	3,2%	1,0%	4,4%	12%	3,6%	15%	7,2%	19%	5,2%	23%	35	85	4,7	13	8,7%
Bulgaria	1,0	0,9%	1,0%	3,4%	2,8%	1,7%	3,2%	8,2%	2,3%	15%	2,8%	17%	20%	21%	29	51	3,4	6,0	1,9%
Latvia	0,26	0,3%	1,9%	2,8%	2,8%	1,9%	2,8%	6,0%	13%	16%	2,4%	10%	7,0%	33%	27	96	10	9,6	0,5%
Romania	2,8	0,5%	1,7%	2,6%	2,1%	0,8%	2,6%	8,7%	3,7%	12%	10%	13%	17%	25%	26	65	5,5	6,1	5,3%
Lithuania	0,43	0,0%	0,4%	2,4%	2,8%	0,9%	3,0%	14%	7,3%	16%	1,3%	10%	11%	31%	24	50	3,6	8,2	0,8%
Hungary	1,4	1,1%	1,1%	3,9%	3,1%	0,4%	2,9%	9,7%	1,9%	13%	9,5%	28%	5,2%	20%	24	46	3,7	14	2,5%
Croatia	0,58	0,5%	0,8%	3,4%	3,7%	0,7%	3,5%	7,1%	4,4%	18%	4,1%	16%	9,1%	29%	19	48	12	10	1,1%
	61	563	408	249	218	170	122	62	61	53	37	30	24	4,1					
	107	274	1.523	380	391	93	571	42	137	88	22	20	31	7,4					
	12	27	34	47	15	69	27	32	5,0	9,9	3,6	2,9	4,0	8,7					
	33	42	35	69	34	34	29	27	21	29	42	36	16	29					
	100%	0,9%	1,8%	4,4%	3,6%	0,6%	3,3%	8,8%	2,4%	11%	7,9%	24%	5,4%	26%					

5 Conclusions

5.1 In relation to the usefulness of the methodology

In this chapter, I have presented results based on the application of the accounting method explained in chapter 3 to characterizing the metabolic pattern of European countries in the year 2012. As we have seen, the scaling approach is based in the use of redundancy – assessing the consumption of energy carriers in two non-equivalent ways: (i) using the values of energy consumption (extensive variables – quantities per year – ETs) from statistical sources; (ii) expressing the overall energy consumption of economic sectors as determined by a combination of quantities of labor (HAs) and the levels of energy consumption per hours (EMRs) determined by the technical coefficients of the processes taking place in the sector.

Moreover, quantities of human activity could be analyzed at the level of subsector as job requirement for reproducing some industrial process or as employment opportunities. In relation to this possible line of analysis it is possible to refine this analysis including different categories for accounting hours of HA (as done for accounting different types of energy carriers). It is possible to characterize job requirement using categories reflecting relevant attributes – e.g. level of skill required, type of contract, salary, expected worker characteristics as man-woman, young-old, etc.). At the level of average society where the quantitative assessment of the size of the work force can be related to demographic structure, the size of THA (population size) and the profile of allocation of HA between PW and HH (dependency ratios) can be associated with the analysis of the overall metabolic pattern of the economy. These important advances in quantitative analysis are breaking the boundaries of traditional disciplines, however they require the ability of handling and integrating the meaning of a huge amount of data mapping onto different relevant issues. Although we are dealing with just 5 extensive indicators (HA, ETs, VA) and their relation expressed in 4 intensive ones (EMRs, EJP), then we have to analyze using these indicators (i) multiple levels of organization (they can be a lot of levels! In fact, we can move from Average society at level n to Iron & Steel subsector at level n-3); and (ii) multiple geographic entities (from Europe to country level with 28 entities); which multiply the meaning of these and their relations.

The meaning of the distribution of HA and the metabolic rates across levels for Europe is discussed in Table IV-1 and Table IV-13, the same for all the functional sectors at the different levels (Table IV-2 to Table IV-12 and Table IV-14 to Table IV-29) and across levels and countries in the Metabolic structural tables (Table IV-38, Table IV-39 and Table IV-40). Additionally, I have also used the popular indicator of Economic Energy Intensity just to show the misunderstandings that it could create when dealing with the complex relation between energy and value added.

The goal of this approach is not to generate simple quantitative assessment. In these two chapters, the effort has been to give meaning to individual numbers by showing their relation to other numbers both in functional comparison and in relation to structural constraints. To do this, I have introduced the concept of data arrays, which is used to give meaning to indicators and benchmarks in relation to the necessity of expressing a metabolic pattern capable of reproducing the expected functions of the society.

The Normalized Chromatic Intensity (NCI) approach has been introduced in order to make it possible to compare the characteristics of the different elements expressing the metabolic patterns in the context of a cluster of reference (e.g., European cluster, one upper sector of analysis as Paid Work sector, etc.).

Last but not least, I have try to get also some metabolic benchmarks for the European context and used different boxplot charts to better understand the meaning of the European energy data arrays.

Metabolic characteristics of countries and sectors are expressed as determined by a combination of the characteristics of lower level compartments (EMR, EJP) and the relative size of these lower level compartments (the profile of allocation of HA). This method makes it possible to explain the existence of outliers – e.g. Luxemburg or Malta – that because of their small size do not include in their metabolic pattern the ability to express all the functions that are required for the reproduction of a modern economy.

The characteristics of subsectors can be studied using a top-down approach (looking at the available statistical data) and using a bottom-up approach (looking at the expected characteristics of specific process depending on technological coefficients).

An important problem faced when going for this integration is represented by the very high level of opened of the European economy that is heavy dependent on imports for the supply of many products it consumes, especially for energetic ones as crude oil (just check the benchmarks of the energy sector of Norway, the only important oil producer analyzed). The variability of the benchmark values of many economic sectors and subsectors, indicated by the boxplot diagrams clearly indicates the need to understand better the role that externalization (the ability of importing inputs without the need of producing them) plays in determining the final metabolic pattern.

In conclusion, we have to work to better understand these variabilities in relation to the following factors: (i) differences in technology (ii) differences in the organization of the production, or (iii) differences in the mix of different products that are categorize by statistical offices in the same category (e.g. pulp production vs paper products production). Additional socio-economic factors that have to be considered are: (i) cost of labor, (ii) subsidies by local governments, (iii) financial conditions, (iv) environmental conditions and availability of resources; (v) institutional settings and regulations.

5.2 In relation to the multi-level integrated quantitative assessment

When looking at the benchmarks for Europe at the level of n-1, we see that Paid Work present EMRs one order of magnitude higher than Households. However, when looking extensive values, we see that the differences are not that big: the Households, because of its much larger size in terms of HA, consumed around 3100, 7100 and 7900 PJ of electricity, heat and fuel energy carriers in 2012, while the Paid Work sector consumed around 8300, 12000 and 9300 PJ respectively.

When opening the Paid Work sector at the level of n-2, one can see that Energy & Mining sector present the highest electricity and heat EMRs [280 612] MJ/h and EJP (122 €/h), while Service & Government the highest fuel EMR [48] MJ/h. Nevertheless, SG and MC consume almost the same amount of electricity (ET_{elec}), MC consume almost 3 times more ET_{heat} than SG, while SG consume 20 times more ET_{fuel} and generate almost 4 times more GVA than MC. In that sense, SG allocate 68% of the HA_{PW} and produce 74% of the GVA, while MC 25% of the HA_{PW} and 20% of the GVA. When looking at the Energy & Mining sector, we see that with just 1,5% of the HA_{PW} it consumes almost the same amount of heat than SG, one third of the electricity (when taking into account distribution losses, it becomes more than two thirds) and almost insignificant amount of fuel (70 vs 8300 PJ). Nonetheless, it is clearly the sector generating most value added per hour: 2,5 times the one of SG, 3,4 times the one of MC and 13 times more than the subsidized European agriculture. Seeing that, one understands the high social tensions and conflicts that Energy & Mining companies generate in agriculture areas around the world. Just in Europe, the AF sector allocate 8,4% of HA_{PW} and just generate 1,7% of the GVA. Then, if we look inside the AF sector, Fishing sector consumes much more fuel than Agriculture & Forestry (260 vs 25 MJ/h), while presents higher EJP (36 vs 9,3 €/h).

When looking inside SG sector we see that the Transport Service sector is the responsible of the great amount of fuel consumption (almost 45% of the total fuel consumption in all Europe) and a huge fuel EMR of 1200 MJ/h. When analyzing the other part of the service sector (SGnT), we found a serious problem if we want to do scaling because the data from the energy balance database do not make possible to split the assessment of the consumption of energy carriers in the service in more in details (even though it represents almost 30% of the electricity consumption, 68% of the HA_{PW} and almost 60% of the GVA). In this sector, we found aggregated in the same assessment of energy carriers consumption quite different economic activities as Education, Human Health, Public Administration, Defense, Real Estate activities, Financial and Insurance activities, Accommodation and Food service activities, Wholesale and Retail trade or Reparation activities. In order to analyze the energy metabolic patterns of this sectors using the same approach presented so far, we should get better data from the statistical offices. That is, the statistical offices should split the Energy Balances in the services sector according to different sub-sectors of activities in order to make possible an analysis of the energy carriers profile of consumption. Then we could carry out the same type of analysis carried out for the manufacturing and construction sector.

From the analysis of Energy & Mining and Manufacturing & Construction sector and its subsector presented in the second part of the chapter, we can identify the most energy intensive subsectors per each energy carrier: Iron & Steel for heat, Non-Ferrous Metals for electricity and Mining and Quarrying for fuels. The ones with higher EJP: Energy Sector and Chemical & Petrochemical; or the ones that generate more jobs: Machinery and Construction. Moreover, we see that we can create clusters from EMRs patterns. The most intensive subsectors cluster would be: Iron & Steel, Non-Ferrous Metals, Chemical & Petrochemical, Non-Metallic Minerals and Paper, Pulp & Print; and the lowest ones: Food & Tabaco, Textile & Leather, Transport Equipment, Machinery, Wood & Wood Products, Construction and Non-Specified Industry. Textile & Leather presents the lowest EJP, which clearly explains the important outsourcing taking place in it. Finally, the Construction sector has a peculiar status in the sense that it presents the lowest EMRs but a value of EJP in the average of MC. Moreover, it represents the 26% of the HA_{MC} and 23% of VA_{MC} (nearly followed by Machinery with 24% HA_{MC} and 26% VA_{MC}).

When comparing the energy data arrays among countries instead than among functional compartments we found another type of information which is quite difficult to generalize because it reflects special features of countries. For example, the high electricity EMRs values of Norway in many of the sectors (due to the abundant supply of hydroelectricity), or the heat EMRs for the Netherlands (due to the abundant supply of natural gas). The important allocation of HA_{MC} of Finland and Sweden in Paper, Pulp & Print industry; (due to the abundant availability of forests), Belgium and Ireland in Chemical & Petrochemical. The case of Ireland is interesting because the co-existence of a high level of EJP coupled to a low level of EMRs suggest a clear anomaly that could be explained not by adoption of "miraculous technologies" but rather by the fact that for fiscal reasons there are products produced elsewhere that are accounted as produced there.

If we look at the Paid Work sector EMRs can individuate 3 clusters: (i) Norway, Belgium, Germany, France, Finland and Italy [EMRelec EMRheat EMRfuel] = [52-76 133-76 33-94] MJ/h; (ii) Sweden, Luxembourg, Latvia, UK, Bulgaria, Austria, Lithuania and the Netherlands [26-47 45-78 25-212] MJ/h; and (iii) Slovenia, Estonia, Denmark, Spain, Slovakia, Czech Republic, Ireland, Greece, Malta, Portugal, Cyprus, Poland, Hungary and Romania [9-25 2-51 10-48] MJ/h.

If we look at Household EMRs – a value that can be used as a proxy of material standard of living - we can distinguish two groups: (i) Norway, Finland, Luxembourg, Sweden, Austria, Belgium, Germany, Ireland, Netherlands, France, Slovenia, Denmark, UK and Italy above the European average; and (ii) Greece, Estonia, Cyprus, Czech Republic, Latvia, Spain, Poland, Lithuania, Hungary, Portugal, Slovakia, Malta, Romania and Bulgaria below it.

From the analysis carried out in this chapter I can conclude that the MuSIASEM methods presents a lot of potentialities when applied to the analysis of the energetics of societies. However, the multiscale approach represents a huge challenge of transdisciplinarity requiring the handling of information referring to non-equivalent descriptive domains. This challenge translates into the need of working simultaneously with relevant questions coming from different disciplines. In that sense, I found that the problem of knowledge fragmentation is reproduced in statistics, where important efforts to improve the integration are needed. For example, ISIC classification at international level and NACE at European one, represents an important attempt of carrying an integration of databases. However, more efforts in this direction are needed, especially when building basic energy databases as Energy Balances or when going to lower levels of analysis.

Concluding these remarks on quantitative assessment of the characteristics of the metabolic pattern of EU economies the crucial challenge of this approach is determined by the need of not aggregating data categories of accounting that imply the loss of valuable information. In fact, some of the quantitative attributes that seem not to be relevant in relation to a given goal - e.g. assessing the profile of energy intensities in the end uses of energy carriers in the service sector is not relevant when assessing the importance of the amount of energy consumed in service sector in the national energy balances – can become important when constructing an integrated analysis - e.g. defining benchmarks for the various activities taking place in the service sector. In the definition of a multi-level end use matrix matching the assessments of the different types of energy carriers with assessments of human activity and value added, we need that all the relevant categories required for such an accounting must be disaggregated across the various levels of analysis.

In this chapter, I have shown that quantitative integrated analysis has a lot of potentialities for enlightening sustainability discussion, but more efforts are needed if we want to take advantage of these potentialities. In the next chapter, I will present preliminary results illustrating the possibility of going a step forward in the direction of multi-level integrated assessment that imply considering the different material products coming out (or imported) when characterizing the metabolic characteristics of the different sectors and subsectors.

Chapter V

"Since matter and energy cannot be reduced to a common denominator, one of the popular illusions has to go by the wayside. We cannot decide on purely technical grounds which of the two process producing the same product is more efficient -that which uses more energy and less matter or that which uses less energy and more matter. This decision requires considerations of the relative supplies; hence it belongs to the economics science, but to one that would not take into consideration only the present generation. "

Nicholas Georgescu-Roegen

Material products matter, too

1 Introduction

In previous chapters, I have analyzed the combined processes of production and consumption of goods and services within metabolic patterns of socio-economic systems adopting different approaches.

In the first comparison of China and India (Chapter 2), at the beginning of my PhD the approach was based on a simple definition of metabolic rate that was obtained by summing energy forms of different qualities using a quality conversion factor. By using this approach, one can see that the increase of the capitalization (EMR) in the paid work sector is associated with an increase in the productivity of labor (EJP).

A more detailed analysis has been used in the analysis of the EU27 + Norway metabolic pattern, based on a characterization based on end use matrices (Chapter 3 and 4). With this more advanced method we can study changes associated with economic growth by considering four different societal metabolic effects: (i) an average improvement of the overall material standard or living at the household sector (increase in the value of EMR_{HH}); (ii) an increase in the dependency ratio (ageing) reflected by a change in the HA_{HH}/THA ratio due to demographic trends; (iii) a change in the distribution of labor within HA_{PW} determined by a continuous increase in HA_{SG} and a continuous decrease of HA_{AF}, HA_{EM}, HA_{MC}; (iv) an increase in the volume of trade in the economy increasing the volume of exports and imports of products to and from international markets.

The results presented in Chapter 3 and 4 clearly show that the approach developed so far can be used to generate biophysical indicators capable of describing the first three effects (changes in EMR_{HH}, HA_{HH}/THA and HA_i/HA_{PW}). However, this analysis based on end use matrices of energy and labor does not cover the assessment of the level of openness (export/import of products) of the sectors and subsectors analyzed. To assess the level of openness of modern economies we have to develop a biophysical accounting of material flows, making the distinction between: (i) raw materials; (ii) semi-finished products; (iii) final products. For each one of these flows of materials we have to be able to define the quantities that are domestically produced and consumed in the investigated economy and the quantities that are going to and coming from international markets. This information is essential to understand the performance of the economy, because favorable terms of trade can be used to externalize environmental impact, depletion of resources and requirement of cheap labor to other economies.

For this reason, an accounting of material flows would be relevant for discussing responsibilities of environmental and social damages – e.g. international negotiations regarding emissions, international working rules regarding child work, etc. - associated with the production of commodities exchanged in the international trade. An analysis of the level of externalization of modern economies would make it possible to have a better idea of who gets the benefits of the biophysical outputs of production in relation to the consumption.

But there is another important reason making it important to assess the level of openness of the different sectors and sub-sectors included in the end use matrices. As illustrated in chapters 3 and 4, when looking at the data-arrays characterizing the subsectors of the economy, we can find quite important differences in the benchmarks associated to the use of labor and energy carriers across countries even when looking at the same subsector. As discussed then these differences do not depend only on differences in the technologies used in the different countries, but also (and often mainly) by the fact that subsectors can operate at a completely different level of openness and mode (net importers versus net exporters) when considering trade. More specifically, I have studied in detail the case of Paper, Pulp & Print, which shows clearly how the international trade and the specialization of some countries (e.g. Finland and Sweden) in some specific process could create important metabolic pattern differences between countries when considering the effect of trade.

In this chapter, I explore the possibility of extending the approach of end use matrix to the analysis of material flows. This attempt has never been made in MuSIASEM and the findings of this chapter are more relevant for the development of the methodology in this direction than to provide a characterization of the situation. After a short discussion of the importance of material accounting, I provide an overview of the problems faced in material accounting and then present an example of how the protocol of accounting of the end-use matrix can be adapted to study the metabolic pattern of material flows. In this way, it becomes possible to include in the analysis of the metabolic pattern also the effect of imports and exports of material (raw materials, semi-finished products and final products) across sectors and countries. This information is crucial for understanding the cost shifting (or internalization) of different production factors as energy carriers and labor (and the impacts associated with them) to third countries through trade. This information is essential to have an informed discussion about the "biophysical performance" (often called improperly efficiency) of the various sectors and of the whole economy.

In conclusion, with this chapter I want to illustrate the importance of a multiscale and multidimensional approach of the performance of the economy in relation to the analysis of material flow.

2 The take of Georgescu-Roegen on the importance of material flows

The title of this chapter is inspired by the title of a famous paper by Georgescu-Roegen *Matter Matters, Too* (Georgescu-Roegen, 1977), where he introduce the fourth law of thermodynamics (or the first of dirty thermodynamics as he suggests). By proposing this fourth law he wanted to make the point that not only is energy quality degraded by the economic process due to the entropy law, but matter is also subject to the same fate. He defines the perpetual motion of the third kind as "*a closed system that can perform forever work between its subsystems*" and states that this is impossible due to the dispersion of material provoked by friction. In other words, 100% of recycling is impossible. The inclusion in the analysis of the role of matter in the metabolic pattern of societies was used by him to reinforce his arguments against cornucopians – i.e. the stereotype of neoclassical economists focusing only on monetary flows without much concern for the environment (Giampietro and Mayumi, 2009) – proposing the idea of a perpetual economic growth. According to Georgescu the analysis of the metabolism of matter could be used to disprove the belief that perpetual growth is possible.

What I tried to do by introducing material accounting into MuSIASEM is less ambitious. I do not want to get into an entropic discussion, rather I am using his idea that in order to better understand the sustainability predicament one has to construct a general flow matrix checking the feasibility, viability and desirability of the circulation of matter and energy. This general flow matrix is essential if we want to have an informed discussion of the relations of the economic process with the environment.

The call of Georgescu-Roegen for a biophysical analysis of the economic process builds on previous work on the same topic developed within the field of energetics. For example, Fred Cottrell already in the 50s proposed that it is not "energy" but "net energy" that powers the activity of human societies (Cottrell, 2009). H. T. Odum, moving into this discussion from the field of theoretical ecology, supported Cotrell's idea and elaborated on another concept proposed by Lotka (Lotka, 1922a, 1922b, 1925): biological and human systems define their energetic performance in terms of maximization of power: the more net energy is obtained by a metabolic process the more energy can be used to express functional behaviors supporting the identity of the biological system. Within this framework the more "*efficient*" a system is, the more power it generates to express its behavior (Odum, 1973). As a matter of fact, Odum proposed the maximum power principle as the driver of the evolution of ecological systems (Odum and Pinkerton, 1955). Here one can see the problem with the use of the term "efficiency". In fact, taking a different view Prigogine, when discussing the evolution of dissipative systems, proposed an opposite principle – the minimum entropy generation principle (Prigogine, 1961, 1987) saying that metabolic systems evolve by minimizing the requirement of inputs to generate a given output. This second principle associates the concept of performance to the ability of generating more output by using less input. This definition of maximization of the output/input ratio resonates better with the classical definition of efficiency used in technical analysis. In relation to this bifurcation in the definition of the meaning of efficiency, Kawamiya (1983) notes the co-existence of two contrasting definitions of "efficiency" when coming to the analysis of the evolution of living systems: "Type 1 efficiency" refers to the maximization of the throughput of energy metabolized (max power), and "Type 2 efficiency" refers to the maximization of the output/input ratio (min entropy generation). The coexistence of these two principles operating simultaneously but at different scales is generating what is called the "Jevons' Paradox": any increase of efficiency (output/input ratio) in a metabolic system, perceived at a local scale, will result in an increase of its ability of expressing new functions – i.e. the use of more energy (higher level of metabolic pace), perceived at a large scale – (Polimeni *et al.*, 2008).

Because of the unsatisfactory indications obtained when trying to define energy improvements, Georgescu-Roegen gave a critical appraisal of the energetic dogma. I strongly oppose the scientific work of those trying to reduce every process to just energy. Within this criticism G-R raised the question *"why not relate efficiency to net matter?"*: "*we use copper in the process of producing copper*" (Georgescu-Roegen, 1979). In that sense, he pointed out that there was no practical procedure at a macro-scale for converting energy into matter or matter of whatever form into energy.

This discussion is important because the ideas of G-R were at the basis of the development of the MuSIASEM approach by Giampietro and Mayumi – as presented in a special issue of *Population and Environment* (Giampietro and Mayumi, 2000a, 2000b; Pastore, Giampietro and Mayumi, 2000). In these papers, Giampietro and Mayumi used the concept of self-organizing systems, generated by informed autocatalytic loops (as proposed by Odum) in theoretical ecology. These systems belong to the class of dissipative systems (as proposed by Prigogine) and this makes it possible to extend the analyses also to the metabolic pattern of societies.

However, the tracking of material flows in modern economies is extremely challenging. For this reason, it was indicated in very generic terms by Georgescu-Roegen in his theoretical description of the approach and it was not done in the first applications of MuSIASEM. Moreover, as indicated by G-R this type of analysis requires explicitly a multiscale focus: "*at the macro-level no practical procedure exist for converting energy into matter or matter of whatever form into energy*" (Georgescu-Roegen, 1979). In his theoretical discussion

Georgescu-Roegen considers for this matrix five fundamental categories: (i) energy inputs (primary sources in the jargon of MuSIASEM); (ii) material inputs (primary sources in the jargon of MuSIASEM); (iii) dissipated energy (end uses); (iv) dissipated matter (products in use); and (v) waste (post-use products). In relation to the users of these flows he contemplates seven basic sectors: two processes transforming environmental energy and matter into controlled energy and matter (what in MuSIASEM jargon we call the Primary Sectors identified in Agriculture, Forestry, Fishing, Energy and Mining sectors); two sectors producing capital goods and consumer goods (Manufacturing and Construction); and the consumption sectors (Service & Government and Households) called Dissipative Sectors in MuSIASEM (Giampietro, Mayumi and Sorman, 2013).

In relation to this challenge, in the rest of this chapter I will present an extended version of the data array presented in chapter 3 including an accounting of the material products coming out from each subsector. When grouping the data arrays by the various sectors composing society, we can generate a matrix with some similarities to the one proposed by Georgescu-Roegen in his paper *Matters matter, too* (Georgescu-Roegen, 1977) and developed with more detail in the latter paper Energy Analysis and Economic Valuation (Georgescu-Roegen, 1979). Nonetheless, the matrix of end use proposed below still misses a few elements included in the original one: (i) the assessment of funds as Ricardian land and Capital equipment (here assessed only indirectly by EMRs); (ii) the distinction of the recycling and waste sector; and (iii) the accounting of material inputs (a specific accounting of the raw materials).

However, this represent a first attempt to associate specific material flows to the existence and operation of structural and functional compartments of the economy. The inclusion of matter flows in the big picture generates a richer understanding of the set of forced biophysical relations determined by the metabolic pattern that can be used to study the feasibility, viability and desirability of the economic process.

3 The conceptual problems with the existing accounting of material flows in the metabolic pattern of societies

In section 2 of chapter 3 I provide a critical appraisal of the indicator Economic Energy Intensity (EEI). There, I explained why EEI is not a good indicator to study dematerialization or decarbonization of the economy of a country, because the amount of energy equivalent consumed by a society in a year and the GDP generated in a country in the same year are correlated, therefore we look at white noise when analyzing variation over their ratios at the aggregated level of the whole country (Fiorito, 2013). But even when analyzing the performance of individual sectors and subsectors one can still find a set of standard problems:

(i) the mix of different typologies of production in the different sectors does affect the overall intensity.

(ii) massive flows of imports (externalization) and exports can affect the overall ratio and therefore imply a total loss of the relation between technical performance of the various sectors and their output/input ratio;

(iii) printing of money and credit leverage can generate a "free-ride" of imports, altering the level of openness of individual sectors. Externalization then can be read by the indicator as "an improvement" in the performance of the economy.

A similar criticism can be applied to the Material Intensity of the Economy (MI) indicator. The Material Intensity indicator has been used as a proxy for productivity efficiency long ago (Street *et al.*, 1988). Nowadays this indicator is still used in the field of Material Flow Accounting (MFA) – e.g. Wuppertal Institute in Germany, Institute for Social Ecology in Austria and National Institute for Environmental Studies in Japan (Fischer-Kowalski *et al.*, 2011).

Still, it is not clear why a very generic analysis of material intensity not related to the characteristics of the metabolic pattern should be considered as a relevant piece of information. In fact, countries specialized in mining of raw materials present a greater material intensity, while post-industrial economies present the lowest levels of material intensity. Put in another way, material intensity is affected by the level of tertiarization of the economy, the availability of raw material and the outsourcing of mining and industry. Differences in the level of domestic exploitation of natural resources and externalization to other economies through imports can create an illusion of dematerialization or decoupling or that the economy is increasing its resource productivity. But in most of the cases, we are just in the presence of poor choices of biophysical accounting. Even more surprising is that even those who seem to be aware of the problems of assessment generated by externalization still interpret material intensity as a proxy of material productivity.

In this chapter, I will explore the possibility of generating an alternative accounting method capable of better dealing with the relation between value added generation and material productivity across subsectors.

As done in chapter 3, the strategy is to use a more complex approach taking into account the multiscale aspects (the relation between the performance of sectors and subsectors) and the existence of expected flow-fund relations over structural and functional elements. This requires going back to the discussion of the different factors affecting the relations between CO_2, energy and GDP (Figure III-1) discussed there. In chapter 3 and 4 I have only analyzed the role of the mix of energy carriers used and the role of the mix of economic activities carried out in society (factor 2, 3 in Figure III-1). In this chapter, I introduce a tentative protocol of accounting having the goal of dealing with effect of import-export goods (factor 4 in Figure III-1). The protocol is illustrated using practical examples.

The logic of Figure III-1 (used to study the factors affecting energy metabolism) has been used in Figure V-1 to study the factors affecting the use of materials in the different sectors and sub-sectors. In Figure V-1 we can see that the different factors affecting the relation between material consumption and GDP are:

1. the degree of openness of Primary Sectors;
2. the mix of Raw Material and Final Products used in society;
3. the mix of economic activities carried out in society;
4. selective externalization of secondary activities (import-export of final products);
5. credit leverage and quantitative easing ('virtual money') boosting the GDP not requiring the production of an equivalent volume of products and services.

In this case, I use the requirement of raw materials as the general category of environmental impacts (rather than CO_2 in Figure III-1).

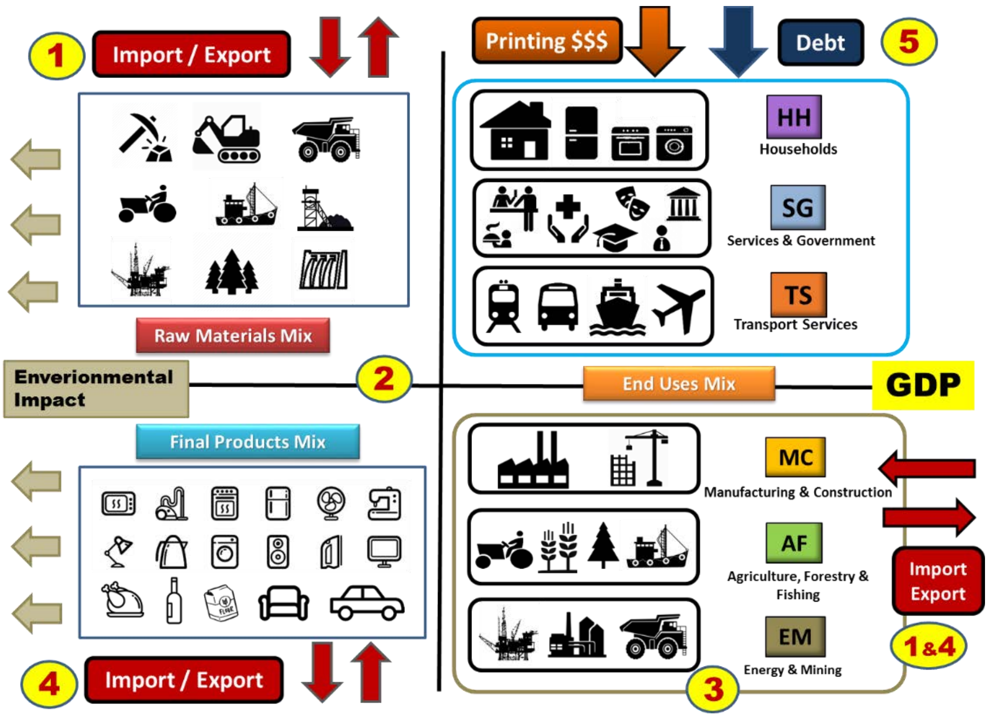


Figure V-1 The metabolic pattern of social-ecological systems and the different factors affecting the material and environmental impact intensity of an economy.

On the left of this figure there are the flows of material products: (i) on the top raw material coming from primary sectors (Agriculture, Forestry, Fishing, Mining and Quarrying); and (ii) on the bottom final products coming from secondary sectors (Manufacturing and Construction). As we can see, if we want to assess the different materials that one country needs to consume in its metabolism and the environmental impact associated with it we have to consider different types of material flows. This distinction is crucial as the consumption of quantities of the same material (iron) in the form of raw materials (iron ore) or in the form of final product (fridge made of iron in an alloy as steel) cannot be summed. The problem of the impossibility of summing quantities of different "matter forms" is exactly the same as the one faced when trying to sum quantities of different "energy forms". The quantity of 1 Joule of coal (a Primary Energy Sources) cannot be summed to 1 Joule of electricity (a special type of Energy Carrier). The same problem is faced when trying to sum quantities of different "food forms". When accounting quantities of nutrient carriers – 1 Joule of potato – we cannot sum them as such to quantities of nutrient end uses – 1 Joule of proteins.

For sustainability analysis, it is essential to be able to establish a relation between Raw Material, Carriers and End Uses, and for this reason the accounting has to be based on the development of grammars – e.g. for water, food and energy – making it possible to establish an effective accounting across different categories (Giampietro *et al.*, 2014).

Looking at one of the basic traditional indicators used in MFA analysis, we see that there is no theoretical discussion of the key importance of discussing the implication of the pre-analytical choice of categories of accounting. Domestic Material Consumption (DMC) is defined as: "*measures the total amount of materials directly used by an economy and is defined as the annual quantity of* ***raw materials*** *extracted from the domestic territory, plus all* ***physical imports minus all physical exports***" (Eurostat, 2015f). These material indicators follow a semantic choice that maps in the flows coming from the biosphere (the ones produced or extracted by primary sectors): biomass, fossil fuels, industrial minerals and metal ores. But then, when coming to the traded products: "*each traded product is assigned to one material category only*" (Eurostat, 2017d) - this implies the summing of kgs of refrigerator to kgs of iron.

The explanation for not accounting for liquid or gaseous materials in the material flow is even more baffling. Water and air are not considered because they *"in general, exceed all other physical flows by an order of magnitude*" (Fischer-Kowalski *et al.*, 2011).

The ratio between DMC and GDP is used as a proxy for measuring resource productivity, eco-efficiency or for analyzing decoupling trends (OECD, 2008). However, MFA analysists do not take into account, when using the DMC as a proxy of environmental impact, that the overall assessment is mixing together raw material and imported final products (Krausmann *et al.*, 2009). Consequently, all material intensity (kg/€) or resource productivity (€/kg) indicators are not doing that either.

It has to be noted that the European Commission takes this ratio (GDP/DMC) to focus on resource productivity and qualify it as "*the lead indicator*" and "*the most appropriate indicator available*" (Comission, 2017).

It also has to be noted that the analysts carrying out these assessments and the statistical offices such as Eurostat are aware of this problem and have introduced recently the Raw Material Equivalent (RME) indicator. This indicator is an attempt to estimate how DMC underestimates the material consumption of services economies. The approach of the RME is illustrated in Figure V-2. RME is a virtual material equivalent determined by a factor of equivalence: the actual weight of the traded goods is increased by a factor reflecting the weight of materials extracted to produce them. However, the protocols used to establish the equivalence factors are still under development and at the moment they present high statistical uncertainty, and for this reason they are not produced as official statistics yet (Eurostat, 2017d).

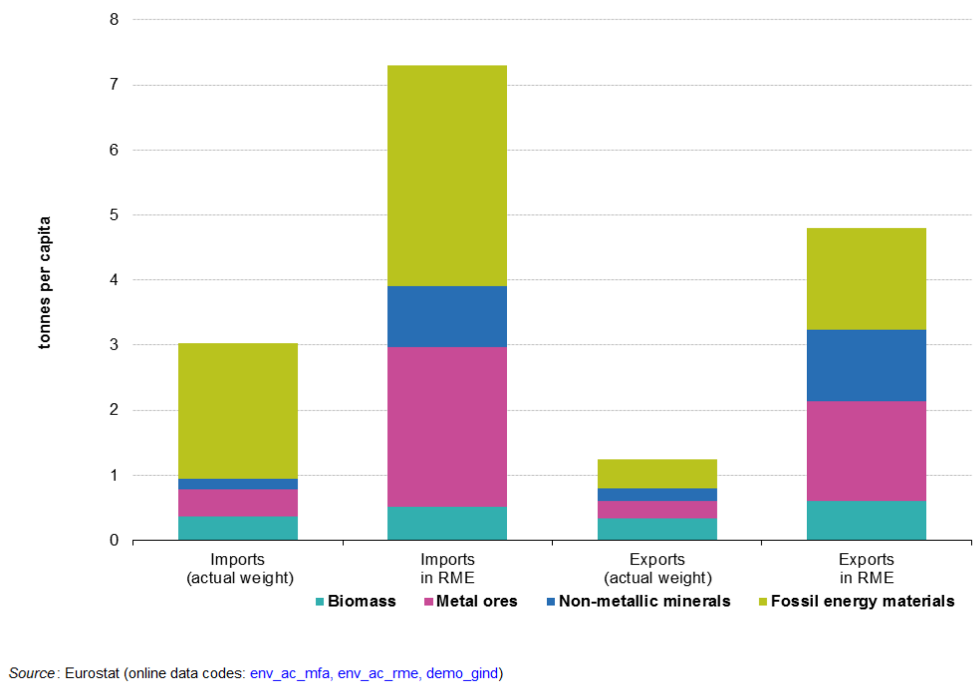


Figure V-2 : Comparison of the actual weight of traded goods with trade in raw material equivalents (RME), EU28, 2014. Source: Eurostat.

Giampietro and Sorman (2012) in relation to energy accounting and Giampietro and Saltelli (2014a, 2014b) in relation to footprint accounting have discussed important conceptual problems when trying to generate aggregated indicators on the basis of quality factors and "embodied assessments". The calculation of aggregated indicators based on the summing of quantities that can only be defined and measured on the basis of perceptions referring to different scales and narratives implies that any protocol used to aggregate into a single number quantities of different material forms will result useful only in relation to the chosen scale and the chosen criteria of aggregation. Moreover, as illustrated by the problems faced when trying to develop energy balances, statistical offices very often do not provide enough information to carry out a proper aggregation protocol (Giampietro and Sorman, 2012). Obviously, these problems will be exactly the same when creating Raw Material Equivalent data.

4 Exploring a material product protocol for assessing Societal Metabolism

In the characterization of the subsectors of the economy in Chapter 4, I arrived to a point of disaggregation where one could detect a relation between the different metabolic benchmarks of the sub-sub-sectors and the technical characteristics of the different production processes taking place within them. However, an important limitation of this approach was determined by the choice of categories of accounting done by statistical offices, using the same category of accounting to characterize different types of production processes. This mixing of different typologies of technical processes prevents the use of data included in the end use matrix (HA, ETs and VA) for assessing the technical characteristics of the processes.

By complementing the assessments of energy, human activity and value added with assessments about the material inputs and outputs of the various subsectors, we can adopt another strategy to differentiate what is happening inside these "black boxes" and improve the interpretation of the differences in metabolic rates among subsectors. I will use an example of characterization of an industrial sector and subsectors in order to illustrate the idea. Obviously, the approach can be applied to all economic sectors and subsectors.

4.1 Starting from a pre-analytical definition of typologies of material flows

Four general categories of material inputs and outputs are illustrated in Figure V-3:

(i) Raw material (RM) entering the subsector;

(ii) Semi Finished Products In (SFPI) entering the subsector;

(iii) Semi Finished Products Out (SFPO) coming out of the subsector;

(iv) Finished Products (FP) coming out of the subsector.

These categories can be used in order to detect differences among countries allocating more of their inputs (energy carriers and labor) to more intensive processes – i.e. production of raw material and semi-finished products. For example, following the example of the analysis of the Paper, Pulp & Print subsector (in Chapter 4), the countries producing Pulp – handling the flows (i) and (ii) - are the ones that present the higher EMRs. We can detect the peculiarity of this subsector without looking at the individual technical processes taking place in it by indirectly analyzing the type of inputs (raw material) and outputs (semi-finished and finished material products).

More in general we can say that: (i) raw materials are material inputs not produced by the subsector (timber for doing pulp); (ii) semi-finished products are products that can be produced by the subsector, or that can be imported (pulp for making paper, paper for making paper products); and (iii) finished products are products going outside the subsector (paper products). By making this distinction it becomes possible to distinguish between 4 typologies of productive sectors and subsectors in manufacturing:

1. Primary subsector industry: a subsector industry consuming more Raw Materials (materials coming from outside the subsector) than Semi Finished Products (materials coming from the subsector) - RM > SFPI;
2. Intermediate subsector industry: a subsector industry consuming less Raw Materials (RM) than Semi Finished Products (SFPI) and producing more Semi Finished Products (SFPO) than Finished Products (FP) - RM < SFPI & SFPO > FP;
3. Final subsector industry: a subsector industry consuming less Raw Materials (RM) than Semi Finished Products (SFPI) and producing more Finished Products (FP) than Semi Finished Products (SFPO) - RM < SFPI & SFPO < FP;
4. Vertically Integrated industry: a subsector industry consuming only Raw Materials (materials coming from outside the subsector) and producing only Finished Products (material products going outside the subsector) - SFPI=SFPO=0

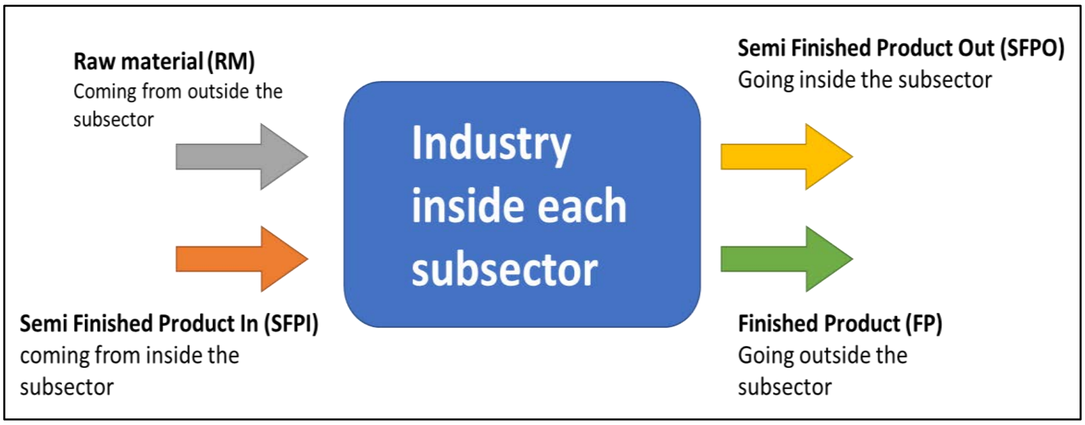


Figure V-3 Type of material products coming in and out characterizing the subsectors

The use of these 4 categories for material accounting will help us to understand the differences of metabolic patterns (EMRs and EJP) found when analyzing different subsectors when adopting material flow accounting. In this way, we can also better understand the implications of shifting biophysical processes of production to third countries in terms of social, environmental and economic impact. In relation to the analysis of the metabolic pattern of the investigated countries, we can identify economies where the subsector studied is just residual – i.e. the production of the subsector is not covering the domestic consumption. In alternative, we can identify countries with competitive subsectors - due to comparative advantages - exporting a large amount of their production.

This analysis will require a material balance sheet – assessing the level of consumption of the country in relation to the production of the subsector studied - according to the standard equation: production + imports – exports – Δstocks (applied to each one of the selected products).

The same system of classification can be generalized at the level of whole sectors, in this way one can classify countries that produce mainly raw materials and process them into semi-finished products inside the industrial sector (iron & steel) from those that are only assembling (machinery or transport equipment). This type of classification would be useful in order to synthetize the metabolic characteristics of each country when comparing them at the national level. Unfortunately, I could not apply properly these classifications in the example developed here due to lack of data. The rest of the chapter presents the lessons learned in this exercise.

4.2 Material products data sources

When looking at the statistics of material and products of European countries, there are two big databases that could be useful for the purpose of this analysis:

(i) Material flows and resource productivity (env_mrp) (Eurostat, 2017b); and

(ii) PRODuction COMmunautaire (PRODCOM) (prom) (Eurostat, 2017c).

The first database comes from the Economy-wide material flow accounts (EW-MFA); account materials reflecting the semantics of "raw materials" (top left corner in Figure V-1). The logic of this choice is to use this assessment for checking environmental impacts. The problem with the first database is that it does not match the Statistical Classification of Economy Activity in the European Union (NACE 2).

The second database - PRODCOM - presents data allocated according to NACE categories, but it only provides information of material products produced. We do not know anything about domestic consumption. The second database comes from the production of manufactured goods statistics: account mining, quarrying and manufacturing products. The semantics is the economic one referring to volume of products having economic significance. It includes both raw materials and final products as described in Figure V-4. This information is useful for monitoring the inputs and outputs of industry and to evaluate market opportunities.

Due to the compatibility of PRODCOM with the NACE classification and with the previous analysis in chapter 3 and 4, I did not use the EW-MFA database and used PRODCOM. However, this choice limits the analysis only to the outputs and with this database it is not possible to classify the subsectors according to the method proposed earlier.

On the basis of this data limitation, I propose to characterize each subsector using the same approach of the end use matrix (as done in Chapter 3 and 4) by adding the biophysical information of the material quantities of products coming out. In this way, I complement the monetary information quantifying the output of the compartment studied as Value Added, with biophysical data accounting the final products generated (Figure V-4).

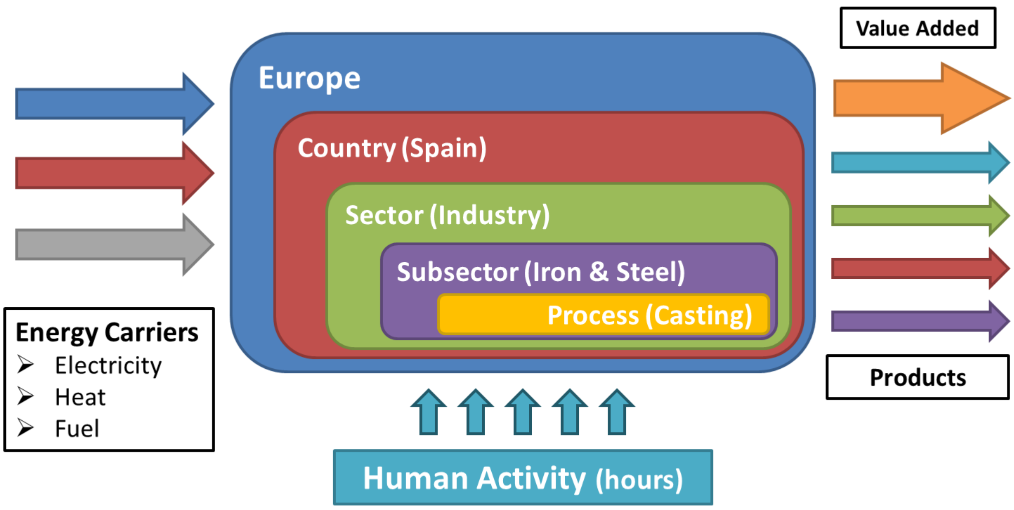
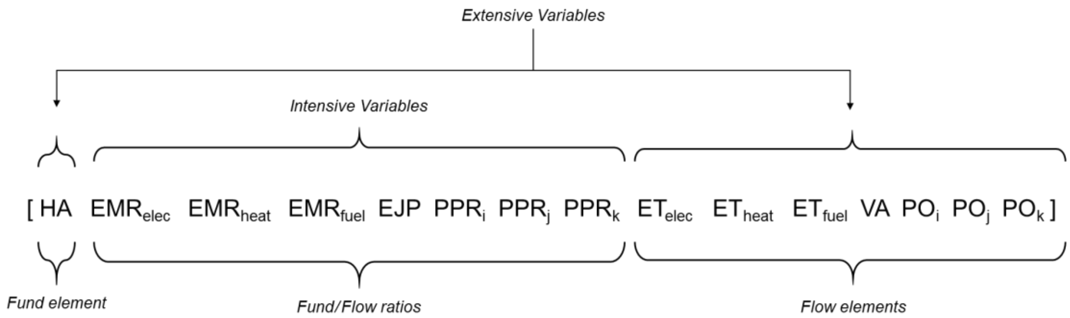


Figure V-4 Flows and funds characterizing our analysis across scales.

Our data array can therefore be complemented with quantitative assessments of material flows. This addition makes it possible to introduce two new metabolic indicators characterizing the system: (i) flows of product output (PO); and (ii) Product Production Rate (PPR), i.e. quantity of mass of product per hour of labor (the flow of product divided by the fund of human activity used to control the process). These new indicators present a lot of new possibilities for characterizing the metabolic pattern of the economic process, however, as explained below, at this moment they are used here simply to illustrate the new protocol of analysis. When extending the analysis to include material flows, the data array presented in chapter 3 would take the following form for each subsector analyzed:



Where:

- HA: Human Activity measured in hours
- ET_i: Energy Throughput measured in MJ of electricity, heat and fuel
- VA: Value Added (at factor cost) measured in €
- PO_i: Product Output type *i* produced in the sector measured in biophysical units (could change depending on the product)
- EMR_i: Energy Metabolic Rate, measured in MJ of carrier i per hour of HA
- EJP: Economic Job Productivity, measured in € per hour of HA
- PPR_i: Product Production Rate, measured in biophysical units of product output *i* per hour of HA

4.3 Material products data sources: problems and assumptions

PRODCOM provides statistics on the production of manufactured goods, from sections B (Mining & Quarring) to C (Manufacturing) of the Statistical Classification of Economy Activity in the European Union (NACE Rev. 2). PRODCOM contains about 3900 different types of manufactured products listed with codes of 8 digits. The first 4 digits correspond to the producing enterprise given by the Statistical Classification of Economic Activities in the European Community (NACE) and the first six correspond to the CPA classification, the remaining digits specifying the product in more detail. Handling this amount of data accordingly for all the subsectors represents a tremendous challenge, so I focused only on the Paper, Pulp and Print sector that I have already briefly outlined in chapter 3 to illustrate the procedure.

If we focus on the Paper, Pulp and Print sector (NACE codes 17 and 18), we find that the PRODCOM database considers more than 140 categories of products for this subsector. In order to handle this huge amount of data I have chosen 5 categories of products:

1. Pulp (codes beginning in 1711) measured in kg of substance 90 % dry (kg 90% sdt) Table V-1

   Paper & Paperboard (codes beginning in 1712) measured in kg,
2. Table *V-2*
3. Articles of paper and paperboard (codes beginning in 172) measured in kg, Table V-3
4. Printing and related services (codes beginning in 181), Table V-4 and
5. Reproduction and recorded material (codes beginning in 182). Table V-5

The variety of products inside these categories varies from 4 items for Pulp (see Table V-1), to almost 50 items for the Paper & Paperboard (see

Table *V-2*). As we can see, at this level of analysis the loss of information due to aggregation of different types of products is important. Nonetheless, their conscious and transparent aggregation help us to be aware of the current challenges of carrying this type of analysis and understand the missing availability of methods able to carry out them. Additionally, the large amount of missing and confidential data that we find in the PRODCOM database makes the attempt to get relevant information even more difficult.

Table V-1 Products inside the Pulp category

PRCCODE	PRODUCTS
1711	**Pulp**
17111100	Chemical wood pulp, dissolving grades
17111200	Chemical wood pulp, soda or sulphate, other than dissolving grades
17111300	Chemical wood pulp, sulphite, other than dissolving grades
17111400	Mechanical wood pulp; semi-chemical wood pulp; pulps of fibrous cellulosic material other than wood

Table V-2 Products inside the Paper & Paperboard category

PRCCODE	PRODUCTS
1712	**Paper & paperboard**
17121100	Newsprint in rolls or sheets
17121200	Hand-made paper and paperboard in rolls or sheets (excluding newsprint)
17121300	Paper and paperboard used as a base for photo-sensitive, heat-sensitive or electro-sensitive paper; carbonising base paper; wallpaper base
17121410	Graphic paper, paperboard : mechanical fibres <= 10%, weight < 40 g/m^2
17121435	Graphic paper, paperboard : mechanical fibres <= 10%, weight <= 40 g/m^2 but <= 150 g/m^2, in rolls
17121439	Graphic paper, paperboard : mechanical fibres <= 10%, weight <= 40 g/m^2 but <= 150 g/m^2, sheets
17121450	Graphic paper, paperboard : mechanical fibres <= 10%, weight > 150 g/m^2
17121470	Graphic paper, paperboard : mechanical fibres > 10%
17122030	Cellulose wadding for household or sanitary purposes, in rolls of a width > 36 cm or in rectangular (including square sheets) with at least one side > 36 cm in an unfolded state
17122055	Creped paper and webs of cellulose fibres for household/ sanitary purposes, in rolls, width > 36 cm, rectangular sheets min. one side > 36cm in unfolded state, weight <= 25 g/m^2/ply
17122057	Creped paper and webs of cellulose fibres for household/sanitary purposes, in rolls, width > 36 cm, rectangular sheets min. one side > 36 cm in unfolded state, weight > 25 g/m^2/ply
17122090	Paper stock for household : others
17123100	Uncoated, unbleached kraftliner in rolls or sheets (excluding for writing, printing or other graphic purposes, punch card stock and punch card tape paper)
17123200	Uncoated kraftliner in rolls or sheets (excluding unbleached, for writing; printing or other graphic purposes, punch card stock and punch card tape paper
17123300	Semi-chemical fluting
17123400	Recycled fluting and other fluting
17123520	Uncoated testliner (recycled liner board), weight <= 150 g/m^2, in rolls or sheets
17123540	Uncoated testliner (recycled liner board), weight > 150 g/m^2, in rolls or sheets
17124120	Uncoated, unbleached sack kraft paper (excluding for writing, printing or other graphic purposes, punch card stock and punch card tape paper)
17124140	Uncoated sack kraft paper (excluding unbleached, for writing, printing or other graphic purposes, punch card stock and punch card tape paper)
17124160	Uncoated kraft paper and paperboard weighing <= 150 g/m^2 (excluding kraftliner, sack kraft paper, for writing, printing and other graphic purposes, etc)
17124180	Creped or crinkled sack kraft paper; creped or crinkled; in rolls or sheets
17124220	Sulphite wrapping paper in rolls or sheets
17124240	Other uncoated paper and paperboard, in rolls or sheets, weight <= 150 g/m^2 (excluding products of HS 4802, fluting paper, testliner, sulphite wrapping paper, filter or felt paper and paperboard)
17124260	Other uncoated paper and paperboard, in rolls or sheets, weight > 150 g/m^2 and < 225 g/m^2 (excluding products of HS 4802, fluting paper, testliner, sulphite wrapping paper, filter or felt paper and paperboard)
17124280	Other uncoated paper and paperboard, in rolls or sheets, weight <= 225 g/m^2 (excluding products of HS 4802, fluting paper, testliner, sulphite wrapping paper, filter or felt paper and paperboard)
17124330	Uncoated filter paper and paperboard in rolls or sheets
17124360	Uncoated felt paper and paperboard in rolls or sheets
17124400	Cigarette paper (excluding in the form of booklets or tubes), in rolls > 5 cm wide
17125100	Uncoated, inside grey paperboard
17125110	Uncoated, inside grey paperboard
17125900	Other uncoated paperboard
17125910	Other uncoated paperboard
17126000	Vegetable parchment, greaseproof papers, tracing papers and glassine and other glazed transparent or translucent papers
17127100	Composite paper and paperboard in rolls or sheets (including strawpaper and paperboard) (excluding surface coated or impregnated)
17127200	Paper and paperboard, creped, crinkled, embossed or perforated
17127335	Coated base for paper..., for photo-, heat-, electro-sensitive paper, weight <= 150 g/m^2, m.f. <= 10%
17127336	Coated bases for paper and paperboard of a kind used for: photo-, heat- and electro-sensitive paper and having 10 % or less of mechanical and chemi-mechanical fibres, and paper and paperboard of a kind used for writing, printing or other graphic purposes, which weight less than or equal to 150g/m^2
17127337	Coated paper, for writing, printing, graphic purposes (excluding coated base, weight <= 150 g/m^2)
17127360	Light-weight coated paper for writing, printing, graphic purposes, m.f. > 10%
17127375	Other coated mech. graphic paper for writing, printing, graphic purposes, m.f. > 10%, rolls
17127379	Other coated mech. graphic paper for writing, printing, graphic purposes, m.f. > 10%, sheets
17127400	Kraft paper (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances
17127500	Kraft paperboard (other than that of a kind used for writing, printing or other graphic purposes), coated with kaolin or with other inorganic substances
17127600	Carbon paper, self-copy paper and other copying or transfer paper, in rolls or sheets
17127710	Tarred, bituminized or asphalted paper and paperboard in rolls or sheets
17127733	Self-adhesive paper and paperboard in rolls or sheets
17127735	Gummed paper and paperboard in rolls or sheets (excluding self-adhesives)
17127755	Bleached paper and paperboard in rolls or sheets, coated, impregnated or covered with plastics weighing > 150 g/m^2 (excluding adhesives)
17127759	Paper and paperboard in rolls or sheets, coated, impregnated or covered with plastics (excluding adhesives, bleached and weighing > 150 g/m^2)
17127770	Paper and paperboard in rolls or sheets, coated, impregnated or covered with wax, paraffin wax, stearin, oil or glycerol
17127780	Other paper, paperboard, coated..., n.e.c.
17127820	Kraft paper and paperboard, coated on one or both sides with kaolin or other inorganic substances, in rolls or in square or rectangular sheets, of any size (excluding that for writing, printing or other graphic purposes; paper and paperboard bleached uniformly in the mass and containing > 95% chemically processed wood fibres by weight in relation to the total fibre content)
17127850	Multi-ply paper and paperboard, coated, others
17127953	Multi-ply paper and paperboard, coated, of which each layer in bleached
17127955	Multi-ply paper and paperboard, coated, with 1 bleached outer layer
17127970	Paper/paperboard in rolls or sheets, coated on one/both sides with kaolin or other inorganic substances excluding of a kind used for any graphic purposes, multi-ply paper/paperboard

Table V-3 Products inside the Articles of paper and paperboard category

PRCCODE	PRODUCTS
172	**Articles of paper and paperboard**
17211100	Corrugated paper and paperboard in rolls or sheets
17211230	Sacks and bags, with a base width <= 40 cm, of paper, paperboard, cellulose wadding or webs of cellulose fibres
17211250	Sacks and bags of paper, paperboard, cellulose wadding or webs of cellulose fibres (excluding those with a base width <= 40 cm)
17211300	Cartons, boxes and cases, of corrugated paper or paperboard
17211400	Folding cartons, boxes and cases of non-corrugated paper or paperboard
17211530	Other packaging containers, including record sleeves, n.e.c.
17211550	Box files, letter trays, storage boxes and similar articles of paper or paperboard of a kind used in offices, shops or the like
17221120	Toilet paper
17221140	Handkerchiefs and cleansing or facial tissues of paper pulp, paper, cellulose wadding or webs of cellulose fibres
17221160	Hand towels of paper pulp, paper, cellulose wadding or webs of cellulose fibres
17221180	Tablecloths and serviettes of paper pulp, paper, cellulose wadding or webs of cellulose fibres
17221210	Sanitary towels and tampons, napkins and napkin liners for babies and similar sanitary articles, of wadding
17221220	Sanitary towels, tampons and similar articles of paper pulp, paper, cellulose wadding or webs of cellulose fibres
17221230	Napkins and napkin liners for babies and similar sanitary articles of paper pulp, paper, cellulose wadding or webs of excluding toilet paper, sanitary towels, tampons and similar articles
17221240	Wadding; other articles of wadding
17221250	Articles of apparel and clothing accessories of paper pulp; paper; cellulose wadding or webs of cellulose fibres (excluding handkerchiefs, headgear)
17221290	Household, sanitary or hospital articles of paper, etc, n.e.c.
17221300	Trays, dishes, plates, cups and the like of paper or paperboard
17231100	Carbon paper, self-copy paper and other copying or transfer papers; duplicator stencil and offset plates of paper; gummed or adhesive paper
17231230	Envelopes of paper or paperboard
17231250	Letter cards, plain postcards and correspondence cards of paper or paperboard
17231270	Boxes, pouches, wallets and writing compendiums of paper or paperboard, containing an assortment of paper stationery
17231313	Registers, account books, order books and receipt books, of paper or paperboard
17231315	Note books, letter pads, memorandum pads, of paper or paperboard
17231317	Diaries, of paper or paperboard
17231319	Engagement books, address books, telephone number books and copy books, of paper or paperboard (excluding diaries)
17231330	Exercise books, of paper or paperboard
17231350	Binders, folders and file covers, of paper or paperboard (excluding book covers)
17231370	Manifold business forms and interleaved carbon sets, of paper or paperboard
17231375	Continuous multi-part business forms, including interleaved carbon sets, carbonless paper and books
17231379	Multi-part business forms, including single leaf forms, interleaved carbon sets, carbonless paper and books (excluding continuous forms)
17231380	Albums for samples, collections, stamps or photographs, of paper or paperboard
17231390	Blotting pads and book covers, of paper or paperboard
17231400	Other paper and paperboard, of a kind used for writing or printing or other graphic purposes, printed, embossed or perforated
17241100	Wallpaper and similar wall coverings; window transparencies of paper
17241200	Textile wall coverings in coverings 45 cm or more
17291120	Self-adhesive printed labels of paper or paperboard
17291140	Printed labels of paper or paperboard (excluding self-adhesive)
17291160	Self-adhesive labels of paper or paperboard (excluding printed)
17291180	Labels of paper or paperboard (excluding printed, self-adhesive)
17291200	Filter blocks, slabs and plates of paper pulp
17291910	Cigarette paper in rolls of a width <= 5 cm or in the form of booklets or tubes
17291920	Bobbins, spools, cops and similar supports of paper pulp, paper or paperboard used for winding textile yarn
17291930	Bobbins, spools, cops and similar supports of paper pulp, paper or paperboard (excluding of a kind used for winding textile yarn)
17291951	Filter paper and paperboard cut to shape
17291955	Rolls, sheets and dials of paper or paperboard, printed for self-recording apparatus
17291957	Moulded or pressed articles of paper pulp
17291985	Other articles of paper and paperboard n.e.c.

Table V-4 Products inside the Printing and related services category

PRCCODE	PRODUCTS
181	**Printing and related services**
18111000	Printed newspapers, journals and periodicals, appearing at least four times a week
18121100	Printed new stamps, stamp-impressed paper, cheque forms, banknotes, etc
18121230	Printed commercial catalogues
18121250	Printed trade advertising material (excluding commercial catalogues)
18121300	Printed newspapers, journals and periodicals, appearing less than four times a week
18121407	Printed books, brochures, leaflets and similar printed matter, in single sheets
18121414	Printed books, brochures, leaflets and similar printed matter (excluding in single sheets)
18121421	Printed children's picture, drawing or colouring books
18121428	Printed dictionaries and encyclopaedias, and serial instalments thereof
18121435	Printed maps, hydrographic or similar charts, in book-form
18121442	Printed maps, hydrographic or similar charts (excluding in book-form)
18121449	Printed postcards, whether or not illustrated
18121456	Printed cards bearing personal greetings, messages or announcements, whether or not illustrated, with or without envelopes or trimmings
18121463	Printed pictures, designs and photographs
18121910	Printed calendars of any kind, including calendar blocks
18121920	Printed music (including braille music)
18121930	Printed transfers (decalcomanias)
18121990	Other printed matter, n.e.c.
18131000	Composition, plate-making services, typesetting and phototypesetting
18132000	Printing components
18133000	Other graphic services
18141010	Bookbinding and finishing of books and similar articles (folding, assembling, stitching, glue, cutting, cover laying)
18141030	Binding and finishing of brochures, magazines, catalogues, samples and advertising literature including folding, assembling, stitching, gluing, cutting cover laying
18141050	Binding and finishing including finishing of printed paper/cardboard excluding finishing of books, brochures, magazines, catalogues, samples, advertising literature

Table V-5 Products inside the Reproduction and recorded material category

PRCCODE	PRODUCTS
182	**Reproduction and recorded material**
18201010	Reproduction of sound on gramophone records
18201030	Reproduction of sound on magnetic tapes of a width <= 4 mm
18201050	Reproduction of sound on magnetic tapes of a width > 4 mm but <= 6.5 mm
18201070	Reproduction of sound on compact discs
18202050	Reproduction of sound and vision video recording on magnetic tapes of a width > 6.5 mm
18202070	Reproduction of sound and vision on video discs and other supports (excluding magnetic tapes)
18203030	Reproduction of magnetic tapes bearing data or instructions of a kind used in automatic data-processing machines; of a width <= 4 mm (excluding sound or vision recordings)
18203050	Reproduction of magnetic tapes bearing data or instructions of a kind used in automatic data-processing machines; of a width > 4 mm (excluding sound or vision recordings)
18203070	Reproduction of computer supports bearing data or instructions of a kind used in automatic data-processing machines (excluding magnetic tapes, sound or vision recordings)

Unfortunately, the PRODCOM database refers to products and not to activities, therefore it is not strictly comparable with the NACE codes of Structural Business Statistics. A second problem is represented by the fact that PRODCOM presents data both in monetary values (sold production, exports and imports) and in biophysical volumes (total production, sold production, exports and imports). Here I will focus on the biophysical volumes in order to analyze the biophysical relations between energy, labor and products. However, the two assessments do not refer to the same quantity and this generates obvious problems of accounting. The method still counts with the assessment of VA generation and EJP indicators for checking the relations between biophysical and monetary information. But it should be made extremely clear that this analysis no longer guarantees the congruence between qualitative (intensive/benchmarks) variables and quantitative (extensive/volumes) assessments, achieved in the tables presented in Chapter 3 and Chapter 4.

Data regarding Human Activity (HA), Value Added (VA) and Energy Throughputs (ETs) came from the analysis of Manufacturing & Construction sector and subsectors in chapters 3 and 4.

To be consistent with the biophysical accounting, we should use in the assessment **total production data** (the energy and human labor refer to the total production and not to the sold ones). On the other hand, the VA refers to the sold and not to the production.

4.4 Energy and products data arrays, results and discussion

Looking at the example of the Paper, Pulp and Print subsector, PRODCOM only offers data regarding total production for Pulp categories. The category of sold pulp, however, has a much smaller quantity. Then, aggregating the material products data as explained in the previous section I obtain Table V-6:

Table V-6 Total and sold production coming out from Paper, Pulp and Print subsector, year 2012

2012	Total Production	Sold Production				
Paper, Pulp and Print	PO_pulp (kg 90% sdt)	PO_pulp (kg 90% sdt)	PO_paper (kg)	PO_papap (kg)	PO_print (-)	PO_Rep (-)
EU-22	3,2E+10	1,3E+10	5,1E+10	4,7E+10	-	-
Austria	8,9E+08	-	2,4E+9	8,5E+8	-	-
Belgium	-	-	3,2E+8	1,5E+9	-	-
Bulgaria	-	-	3,2E+7	2,6E+8	-	-
Croatia	7,3E+07	3,0E+07	1,6E+8	2,2E+8	-	-
Czech Republic	-	-	2,1E+8	8,6E+8	-	-
Finland	1,0E+10	4,6E+09	1,1E+10	4,6E+8	-	-
Germany	3,0E+09	7,6E+07	1,5E+10	1,2E+10	-	-
Greece	0,0E+00	-	1,5E+8	3,2E+8	-	-
Hungary	-	-	-	5,6E+8	-	-
Ireland	0,0E+00	-	3,7E+6	2,7E+8	-	-
Italy	8,9E+07	8,7E+07	6,5E+9	1,1E+10	-	-
Latvia	0,0E+00	-	-	4,3E+7	-	-
Lithuania	1,5E+06	1,5E+06	1,1E+8	1,9E+8	-	-
Netherlands	-	-	4,7E+8	2,0E+9	-	-
Norway	-	1,3E+08	-	1,1E+8	-	-
Poland	1,3E+09	-	8,9E+8	3,7E+9	-	-
Portugal	2,4E+09	2,1E+09	2,0E+9	1,0E+9	-	-
Romania	0,0E+00	-	1,2E+8	4,9E+8	-	-
Slovakia	-	-	3,8E+7	1,7E+8	-	-
Spain	2,9E+09	1,4E+09	3,6E+9	5,0E+9	-	-
Sweden	1,1E+10	4,6E+09	5,5E+9	7,8E+8	-	-
United Kingdom	-	0,0E+00	2,7E+9	5,4E+9	-	-

From Table V-6 we can observe that the PRODCOM database does not offer any data regarding Print & Related services, neither for Reproduction & Recorded materials. This implies that not only does this database not provide coverage of the entire product (only a subset of the producers is included in the database), but also that some categories of products cannot be taken into account when considering this result. Additionally, the variation between total and sold production could be quite significant, even if we can observe that the ranking between countries is not highly affected when adding this data to the data arrays for energy, human activity and value added from the previous chapter, obtaining Table V-7:

Table V-7 Paper, Pulp & Print metabolic matrix of EU22 for the year 2012

2012						Total Production	Sold Production		
Paper, Pulp and Print	**HA** (10^6 h/year)	**EMR_elec** (MJ/h)	**EMR_heat** (MJ/h)	**EMR_fuel** (MJ/h)	**EJP** (€/h)	**PPR_pulp** (kg90%sdt/h)	**PPR_pulp** (kg90%sdt/h)	**PPR_paper** (kg/h)	**PPR_papro** (kg/h)
EU-22	1.937	218	391	15	34	23	9,5	26	24
Austria	48	358	1.040	8,5	57	19	-	51	18
Belgium	38	279	380	26	60	-	-	8,6	39
Bulgaria	29	44	256	6,8	6,3	-	-	1,10	8,8
Croatia	21	48	101	7,5	12	3,4	1,4	7,37	10
Czech Republic	63	96	280	3,2	16	-	-	3,28	14
Finland	50	1.386	3.095	61	67	206	93	213	9,3
Germany	445	192	285	5,0	39	6,7	0,17	34	27
Greece	27	72	49	30	20	0,0	-	5,7	12
Hungary	42	47	71	2,8	13	-	-	-	13
Ireland	14	55	9,0	6,2	38	0,0	-	0,26	19
Italy	232	142	123	8,8	36	0,38	0,38	28	46
Latvia	7,4	16	23	0,0	11	0,0	-	-	5,8
Lithuania	12	38	72	3,6	12	0,13	0,13	9,0	16
Netherlands	64	140	221	0,0	47	-	-	7,3	31
Norway	15	968	527	101	56	-	-	-	7,1
Poland	150	91	245	11	18	8,4	-	5,9	25
Portugal	47	216	896	43	26	51	44	41	22
Romania	59	25	29	2,1	6,5	0,0	-	2,0	8,3
Slovakia	21	174	538	3,9	19	-	-	1,8	8,3
Spain	174	107	313	26	32	16	7,9	21	29
Sweden	77	1.069	2.023	98	57	145	60	72	10
United Kingdom	302	129	88	3,7	35	-	0,0	8,9	18

In this table, we can corroborate the relation between high EMRs and the production of Pulp (PPR_{pulp}). Moreover, we can see how the countries presenting the highest PPR in pulp such as Finland (206 kg_90%_sdt/h) and Sweden (145 kg_90%_sdt/h) also present the highest PPR on Paper and Paperboard (PPR_{paper}): 213 and 72 kg/h respectively. This relation can be explained by the integration of these two processes in many companies producing pulp and paper in combination. Additionally, we can see how Portugal is also an important pulp and paper producer with a PPR_{pulp} of 51 kg_90%_sdt/h and a PPR_{paper} of 41 kg/h. Nonetheless, we can observe a low value of PPRs and EMRs indicating a low level of capitalization of the industry that could be linked to the low level of salaries/price of labor (the EJP of Portugal of 26 €/h is less than half of Finland's, of 67 €/h, or Sweden's, of 57 €/h). On the other hand, we can see that the production of Pulp does not only require more energy than the other products in the PPP sector, but also more HA (when looking at the average production ratio at the level of EU22, we can see that $PPR_{pulp} < PPR_{paper} \approx PPR_{papro}$).

Going back to the classification of typology of industry discussed at the beginning of this section, because of lack of data regarding inputs, one cannot properly categorize the subsectors' patterns found in EU countries. However, we can assume that the production of pulp in these three countries is based on raw materials that are coming from outside the subsector (basically wood and some used paper). In this sense, we can say that Finland, Sweden and Portugal present a Paper, Pulp and Print (PPP) subsector profile which typical of a ***Primary Subsector Industry***. Namely, they are not cost shifting the environmental impacts associated with this intensive process to other social-ecological systems. Lastly, we can take their EMRs and PPRs as typical benchmarks for this type of subsector.

On the other hand, when observing the metabolic pattern presented by Italy and probably (due to lack of data) Belgium, one can see two countries having the highest PPR in the "Articles of paper" and "paperboard category" (46 and 39 kg/h respectively), while their EMRs profiles and the PPRs of pulp and paper are low. As a consequence of this fact, one can classify the PPP subsectors of these two countries as ***Final Subsector Industry***. This difference can be confirmed comparing the value of EMRs and EJPs. In fact, EMRs from these two countries are pretty low compared with the ones from the Primary Subsector Industry. However, their EJPs (36 and 60 €/h) are similar to the other primary ones.

Due to the lack of data, it is difficult to identify other countries presenting a clear pattern of Intermediate or Vertical Integrated industry. However, analyzing imports and exports, we will get more information regarding this issue.

From the Import and Export data I obtain Table V-8, which is based on available data. In this table, we can see once again how Finland, Sweden and Portugal are exporters of Pulp; and Italy a main importer of it for producing paper products for exports. Thanks to this new data, one can detect that the Netherlands clearly represent an Intermediate ***Subsector Industry***. This pattern can be identified by the fact that the Netherlands present intensive importation and exportation in all the products. When looking at its EMRs and EJP, we can see a high EJP (47 €/h), coupled with a low EMRs. When looking at the Economic Energy Intensity (MJ/€) of this sector, one could say that the country presents a decoupling or dematerialization of the chrematistic (VA generation) and biophysical performance. However, the reality is quite different as we can see, and it is just the effect produced by trade allocating chrematistic benefits to the traders of the country and shifting the biophysical (or socioenvironmental) costs to other Social-Ecological Systems.

Additionally, we can see that the UK is a net importer for all types of PPP products when looking the Physical Products Trade Balance (Export-Imports). This analysis makes us aware of the fact that values of EMRs and EJP found in this country **are not relevant benchmarks**. They are instances of processes reflecting historic circumstances. When talking about expected characteristics of typologies of product industries in the PPP subsector, the data describing processes in the UK do not indicate an industry that has been shaped by constrains (their production is not essential in shaping the metabolic pattern of the economy). This type of information can be used to reduce the variability showed in the boxplots represented in chapter 4 when looking for benchmarks to be used for creating scenarios.

Table V-8 Export, Import and Physical products trade balance for EU22 countries, year 2012

2012	Export			Import			Physical Products Trade Balance		
Paper, Pulp and Print	Paper pulp (kg 90% sdt)	Paper & paperboard (kg)	Paper & paperboard products (kg)	Paper pulp (kg 90% sdt)	Paper & paperboard (kg)	Paper & paperboard products (kg)	Paper pulp (kg 90% sdt)	Paper & paperboard (kg)	Paper & paperboard products (kg)
Austria	3,8E+08	4,2E+9	5,3E+8	6,8E+08	1,4E+9	4,7E+8	-3,0E+08	2,7E+09	6,8E+07
Belgium	8,5E+08	3,5E+9	8,6E+8	1,0E+09	4,1E+9	8,4E+8	-1,4E+08	-5,9E+08	1,7E+07
Bulgaria	8,0E+07	1,2E+8	3,3E+7	2,1E+07	3,0E+8	7,0E+7	5,9E+07	-1,7E+08	-3,7E+07
Croatia	0,0E+00	1,3E+8	7,2E+7	1,0E+05	2,9E+8	8,1E+7	-1,0E+05	-1,6E+08	-9,4E+06
Czech Republic	3,6E+08	6,7E+8	5,1E+8	1,6E+08	1,3E+9	4,7E+8	2,0E+08	-5,9E+08	4,0E+07
Finland	2,5E+09	8,9E+9	2,0E+8	4,9E+08	4,8E+8	9,5E+7	2,0E+09	8,4E+09	1,0E+08
Germany	1,0E+09	1,4E+10	3,0E+9	4,4E+09	1,1E+10	1,6E+9	-3,4E+09	2,8E+09	1,4E+09
Greece	1,2E+07	9,1E+7	5,2E+7	9,8E+07	6,0E+8	1,4E+8	-8,6E+07	-5,1E+08	-8,5E+07
Hungary	4,4E+06	6,1E+8	2,2E+8	9,4E+07	7,8E+8	2,5E+8	-9,0E+07	-1,7E+08	-2,3E+07
Ireland	0,0E+00	2,3E+7	9,7E+7	3,9E+07	3,9E+8	2,4E+8	-3,9E+07	-3,6E+08	-1,4E+08
Italy	9,8E+06	3,4E+9	1,3E+9	2,9E+09	5,0E+9	3,4E+8	-2,9E+09	-1,6E+09	1,0E+09
Latvia	8,3E+06	3,3E+7	5,9E+7	9,3E+06	1,7E+8	5,2E+7	-1,0E+06	-1,4E+08	7,4E+06
Lithuania	3,8E+07	1,3E+8	1,0E+8	4,9E+07	2,3E+8	1,3E+8	-1,2E+07	-1,1E+08	-2,9E+07
Netherlands	2,2E+09	2,5E+9	8,7E+8	2,7E+09	2,6E+9	9,7E+8	-5,3E+08	-1,0E+08	-9,9E+07
Norway	0,0E+00	0,0E+0	0,0E+0	0,0E+00	0,0E+0	0,0E+0	0,0E+00	0,0E+00	0,0E+00
Poland	1,7E+07	2,2E+9	1,1E+9	6,4E+08	3,4E+9	4,2E+8	-6,2E+08	-1,1E+09	6,7E+08
Portugal	1,1E+09	1,8E+9	1,8E+8	9,1E+07	8,3E+8	1,8E+8	9,8E+08	9,7E+08	-6,2E+05
Romania	7,8E+05	1,0E+8	6,6E+7	7,4E+07	5,6E+8	1,7E+8	-7,3E+07	-4,6E+08	-1,1E+08
Slovakia	1,9E+08	6,5E+8	2,4E+8	1,2E+08	4,0E+8	2,3E+8	7,8E+07	2,4E+08	9,6E+06
Spain	1,1E+09	3,0E+9	7,4E+8	8,6E+08	2,9E+9	5,2E+8	2,1E+08	1,0E+08	2,3E+08
Sweden	3,0E+09	1,1E+10	4,4E+8	4,8E+08	9,4E+8	3,5E+8	2,6E+09	9,6E+09	8,9E+07
United Kingdom	8,9E+06	1,4E+9	4,5E+8	9,1E+08	6,2E+9	1,0E+9	-9,0E+08	-4,8E+09	-5,7E+08

Another interesting observation about Germany emerging here is that it is a country importing raw materials and exporting finished products (in relation to the subsectors, that means, importing pulp and exporting Paper and Paperboard products). This is a clear Final Subsector Industry (FSI) following the classification proposed. When comparing its EMRs and EJP with our other FSI (Italy, and Belgium less because it produces some pulp as shown the Import-Export data that show their slightly higher EMRs), we can see that the method proposed presents robust relations between energy metabolic patterns, product metabolic ones and the specific classification of type of subsector in relation to the types of input-outputs. This study basically consists in trying to identify the specific biophysical processes happening at lower levels in the subsectors.

5 Value added, labor, energy or material efficiency?

Sadi Carnot already warned in his seminal book *Reflections on the motive power of fire, and on machines fitted to develop that power* (Carnot, 1897) about giving too much credibility to field of thermodynamics and its conception of efficiency when conducting political decisions:

> *"We should not expect ever to utilize in practice all the motive power of combustibles. The attempts made to attain this result would be far more hurtful than useful if they caused other important considerations to be neglected. The economy of the combustible [**efficiency**] is only one of the conditions to be fulfilled in heat-engines. In many cases it is only secondary. It should often give precedence to safety, to strength, to the durability of the engine, to the small space which it must occupy, to small cost of installation, etc. To know how to appreciate in each case, at their true value, the considerations of convenience and economy which may present themselves; to know how to discern the more important of those which are only accessories; to balance them properly against each other; in order to attain the best results by the simplest means: such should be the leading characteristics of the man called to direct, to co-ordinate among themselves the labors of his comrades, to make them co-operate towards a useful end, of whatsoever sort it may be" [p. 126 emphasis added].*

Additionally, as has already been discussed in the introduction of this chapter, there are two distinct interpretations of the concept of efficiency in energetics: (1) the maximum ratio between output and input; and (2) the maximum power output (per unit of time).

Here I will discuss the tradeoff of these conceptions using the indicators in relation to the requirement of human activity (productivity of labor). To do so, I use two different indicators: (i) Energy Metabolic Rates (e.g. Electricity, Heat and Fuel consumption in the sector per hour of work) – this indicator reflects the level of capitalization of the sector, based on the assumption that in order to use more commercial energy per hour of labor more power capacity must be available to the workers; (ii) Product Production Rate (Production of Pulp, Paper and Paper Products per hour of work); and (iii) Economic Job Productivity (Value Added in monetary terms per hour of work in the sector). All these indicators are related to the required investment of human time (hour of labor) and are effective to analyze features of Societal Metabolism. On the contrary, when analyzing the effect of human actions on Ecosystem Metabolism we can look at the metabolic pattern from a less anthropocentric view and study the effects on the environment using assessments of densities of flows per hectare (Madrid, Cabello and Giampietro, 2013; Madrid-López and Giampietro, 2015; Lomas and Giampietro, 2017). This would require considering the same indicators but per hectare of land use.

The analysis of the performance of a sector or subsector shows the existence of trade-offs over the use of production factors. For example, in the process of production of products there is an effect of substitution of human labor with energy inputs (especially electricity). That is to say, we can detect the differences between one country that produces 10 kg of paper and 1 € of VA with 1 hour of labor and consumes 10 MJ of electricity vs. one that produces 10kg of paper and 1 € with 10 hours of labor and consumes 10 MJ. The trade-offs associated with these two different profiles cannot be studied using simple indicators such as Economic Energy Intensity and Material intensity. Following this logic, we can get a distinction over two types of definitions of input/output as illustrated in Figure V-5.

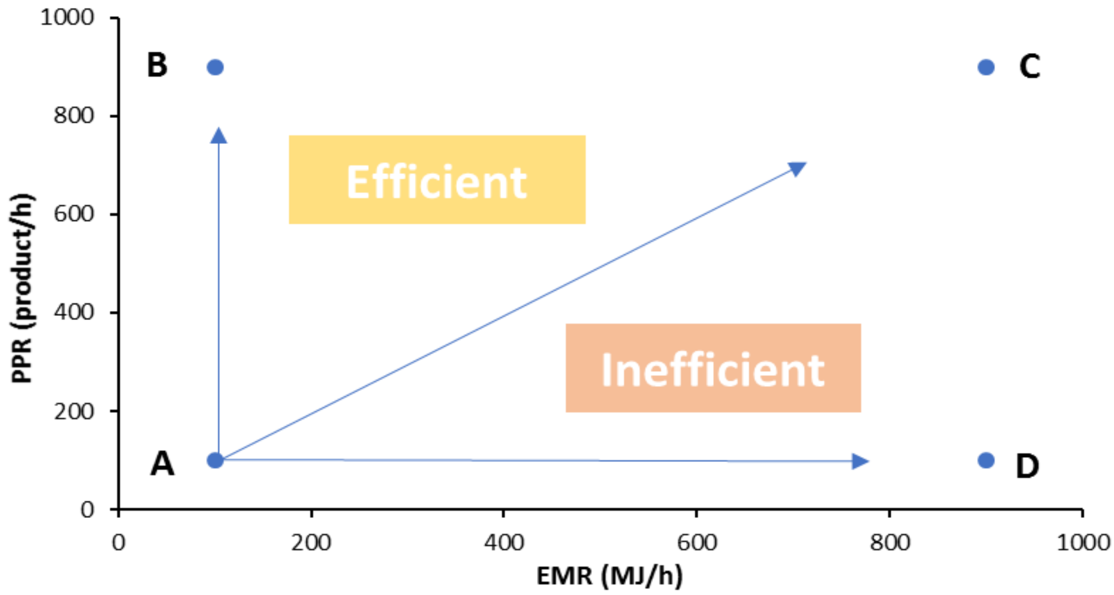


Figure V-5. Discussing efficiency with EMR vs PPR.

In the plane of Figure V-5 we can identify three types of directions: (i) direction A-D, indicates an inefficient change that increases the use of energy without increasing production; (ii) direction A-B, indicates an efficient change that increases production without increasing energy use; and (iii) direction A-C, indicates that we are just increasing the scale of production consuming the same proportion of energy per product. In this plane, all the slopes lower than |1| (in absolute value) are inefficient and all the slopes higher than |1| are efficient.

On the other hand, if we adopt a multiscale integrated approach, we can see that what can be perceived as inefficient at one level could generate benefits at another level. This will happen, for example, when moving between two points creating a slope lower than 1. That is, by increasing PPR at a lower grade than the increase in EMR. In that case, we are consuming more energy per product. However, as we are increasing the PPR we require less human time per product, which means that at the scale of the society we are getting a net benefit on the human time budget (we need less time for producing food for example). This assumes that the extra hours that we are freeing from this subsector can be invested in a more remunerative sector – e.g. the service sector - improving the services provided by society.

As we can see with this example, optimizing efficiency at one level (and within a subsector) at a time is misleading. In this way, we are neglecting other important trade-offs taking place in society when re-adjusting the overall profile of production factors among sectors. On the other hand, an increase in the production per hour (PPR), by consuming more exosomatic energy per product, could also be a desirable objective for many social actors if this translates into increased salaries for workers, more taxes for the government, surplus value for the capitalists, and a reduction in price for the consumers. Human history shows that many social conflicts generated by the class struggle have been resolved with this logic – making all social actors happy by using more natural resources. As we can see, this way of solving social conflicts increase environmental impacts associated with the direct use of energy in the production, but also the ones associated with the concentration of production (requirement of big infrastructures, concentration of environmental impacts, more transport requirement, etc.). Are we aware of this problem when dealing with environmental problems? How useful is the narrative of "maximizing efficiency" (which efficiency?) for dealing with sustainability issues? Are Material Intensity and Economic Energy Intensity proper indicators to carry out an informed discussion on these topics?

6 Using the plan EMR and PPR to discuss of efficiency

In chapter 2 I have already analyzed the correlation between EMR and EJP discussing the Economic Energy Intensity indicator. Here I will analyze the relation of the value of EMR electricity (the assessment is per a specific type of energy carrier instead of per Gross Energy Requirement) with the values of PPR and EJP at the level of the Paper, Pulp and Print subsector. I skip the figures illustrating the relations between the other two energy carriers (heat and fuel) metabolic rates to simplify the analysis as they do not add relevant information for what I want to discuss here. It is important to mention that the correlation between energy and heat EMRs (R^2= 0,95 without Norway) is very strong in the PPP subsector, as only Norway presents a more intensive use of electricity than the other countries (which could be explained by their huge amount of hydro resources making electricity cheaper).

In Figure V-6 we can see the relation between the production per hour of work (PPR) and the consumption of electricity per hour of work (EMR_{elec}). Both variables are correlated (R^2 =0,96), which is in line with the assumption of using EMR as a proxy of capitalization: more power capacity will consume more energy and produce more. Moreover, the slope is 0,15, which means that the increment of production of pulp is done by consuming more energy per unit of output (almost 7 MJ more per 1 kg 90%sdt). Therefore, we can argue that there is no decoupling or dematerialization when investing more capital in the production of pulp, but the contrary. The maximum power principle (maximum EMR) is imposed in this case to the maximum output per input efficiency conception (Product per energy consumed).

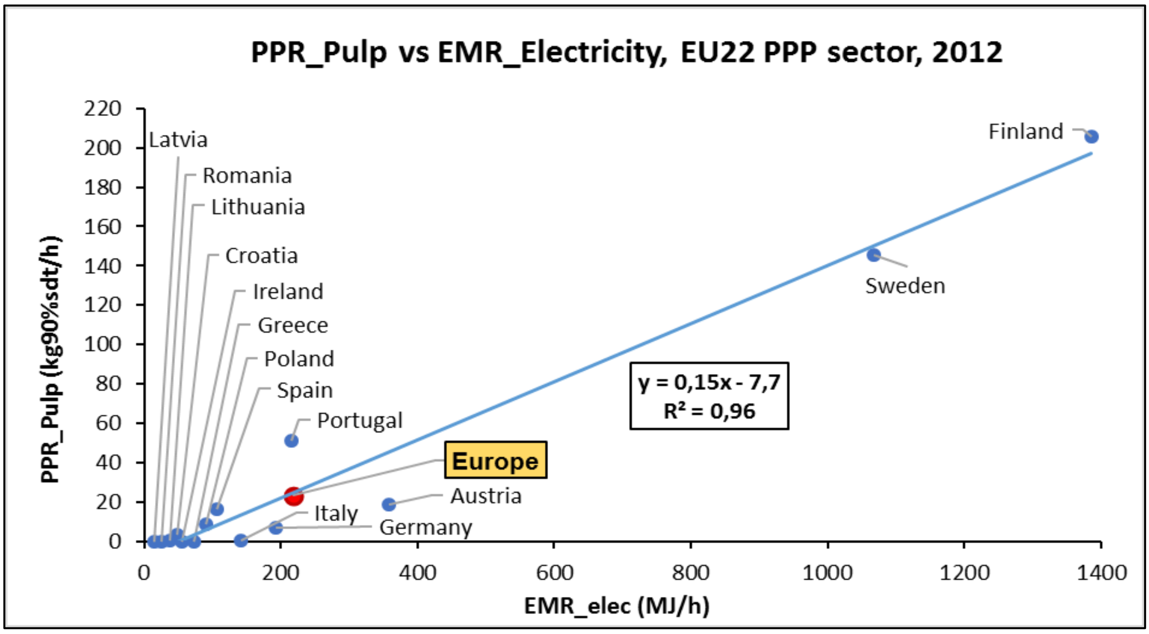


Figure V-6. PPR_Pulp vs EMR_electricity at the Paper, Pulp and Print subsector of EU22, year 2012

In Figure V-7 I represent the relation between the PPR of paper and paperboard and the EMR electricity. As one can see, the correlation is also high (R^2=0,83), and again the slope is tending to be in favor of productivity instead of saving energy.

When we look at the Paper products PPR in relation to electricity EMR, we get Figure V-8. Here we can see clearly two groups of countries in relation of the type of subsector industry already discussed: one performing a metabolic pattern of a Final Subsector Industry (the majority of European countries) and another as a Primary subsector industry (Finland, Norway and Sweden). On the other hand, we can see how the first group of countries presents a slope that seems to be more towards an efficient trend, that is, consuming less quantity of energy per unit of product produced when increasing the capitalization (EMR).

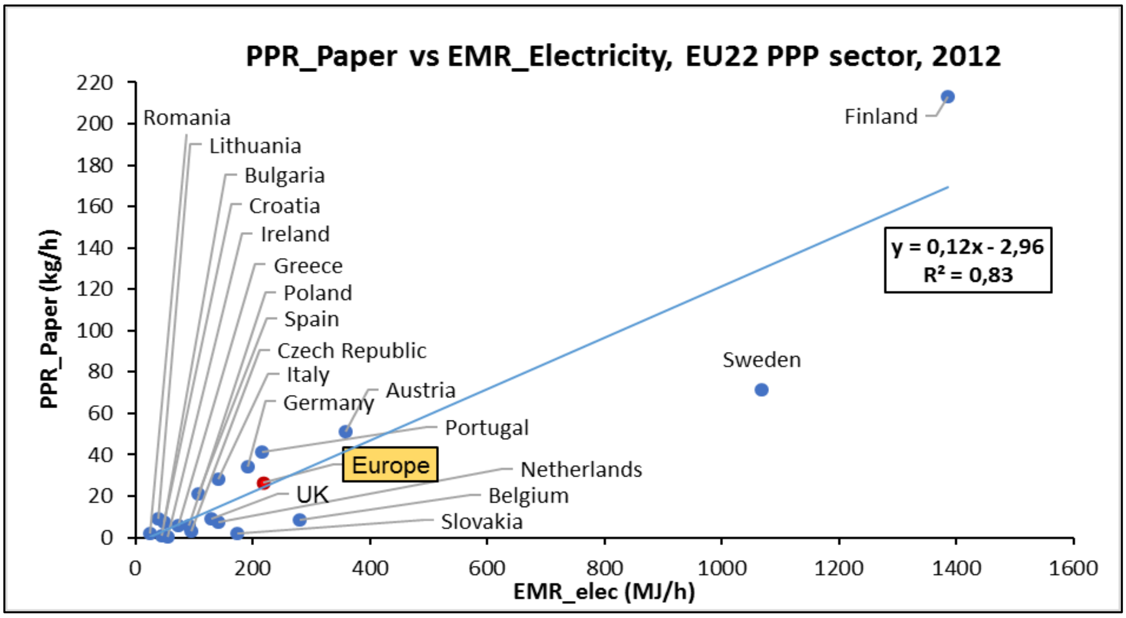


Figure V-7. PPR_Paper vs EMR_electricity at the Paper, Pulp and Print subsector of EU22, year 2012

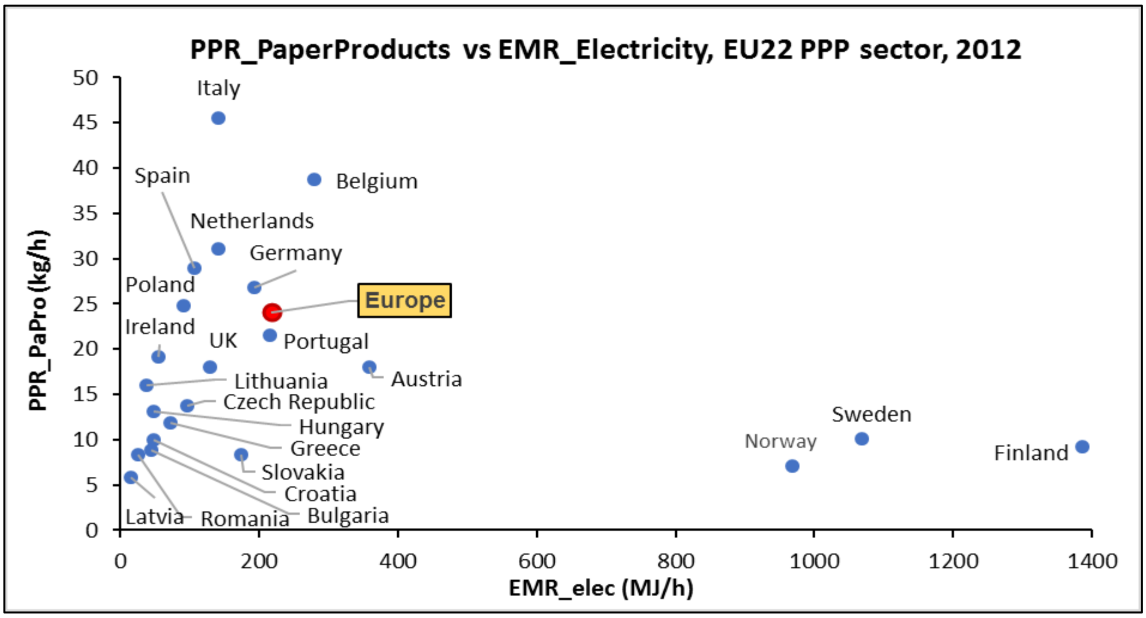


Figure V-8. PPR_PaPro vs EMR_electricity at the Paper, Pulp and Print subsector of EU22, year 2012

On the other hand, if we analyze the PPR in relation to EJP (Figure V-9), we can see that there is no clear correlation between these two indicators. However, this plane makes it possible to clearly identify the different behavior of the countries producing mostly pulp (Portugal, Sweden and Finland). The cluster of pulp producers is still on the top of the line if we look at the production of paper (Figure V-10) – even though Finland and Sweden are quite distant from Portugal (more capitalization and more forests!). The last graph referring to the plane PPR_{Paper} and EJP clearly shows that, when dealing with Final Product Industry (Figure V-11), the biophysical root of the process is less important. In this graph, it is difficult to detect clusters or clear patterns. These product categories require a more sophisticated economic analysis than one based on the PRODCOM database.

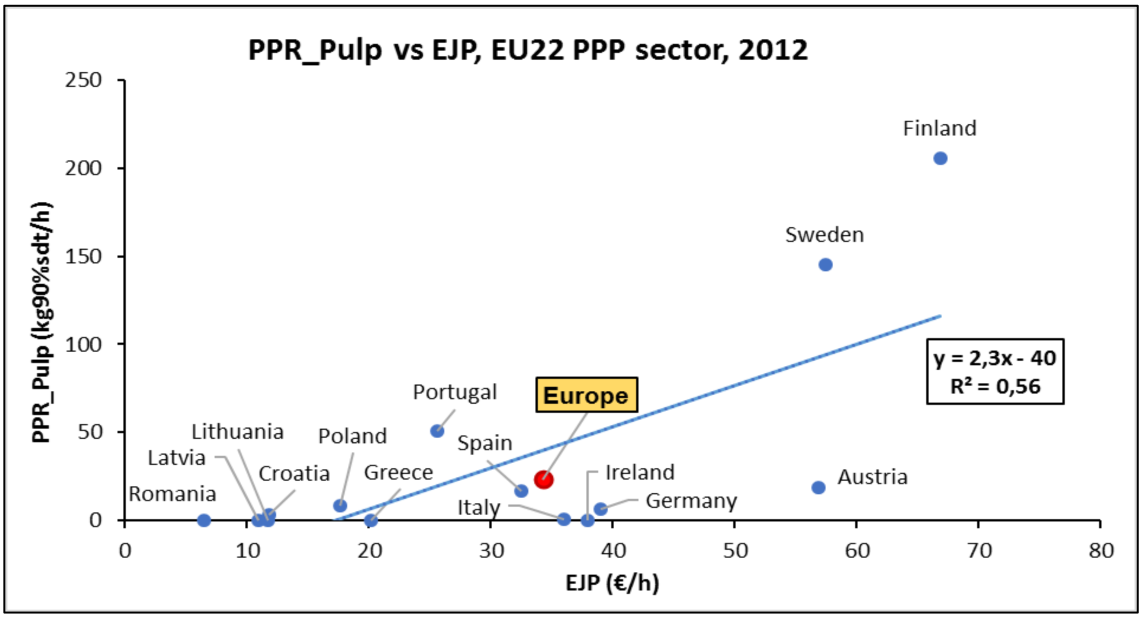


Figure V-9. PPR_Pulp vs EJP at the Paper, Pulp and Print subsector of EU22, year 2012

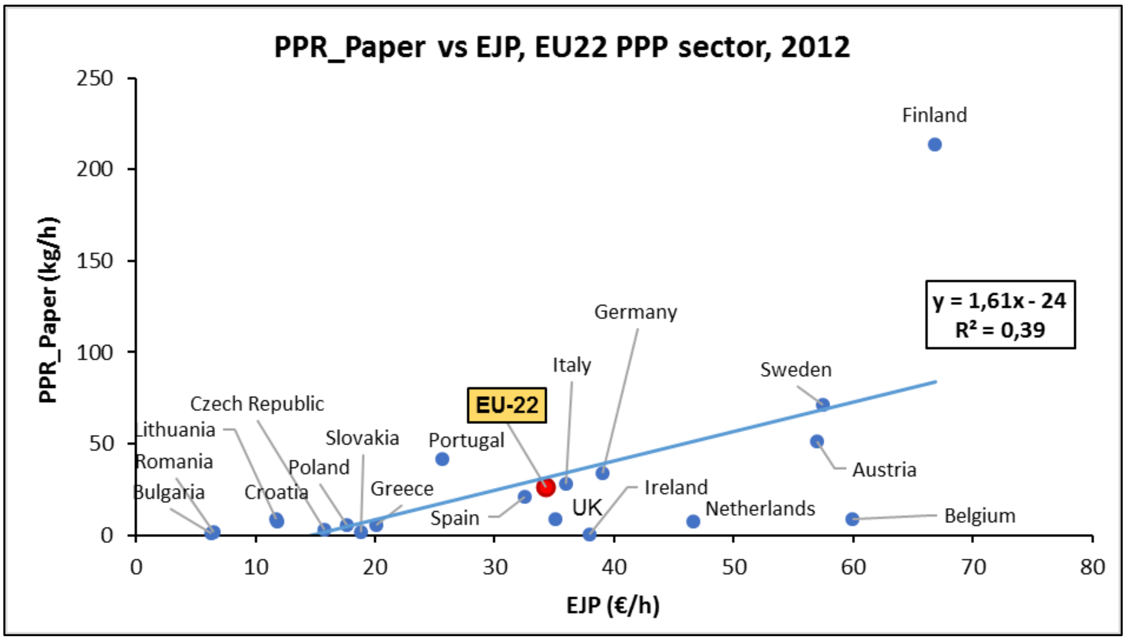


Figure V-10. PPR_Paper vs EJP at the Paper, Pulp and Print subsector of EU22, year 2012

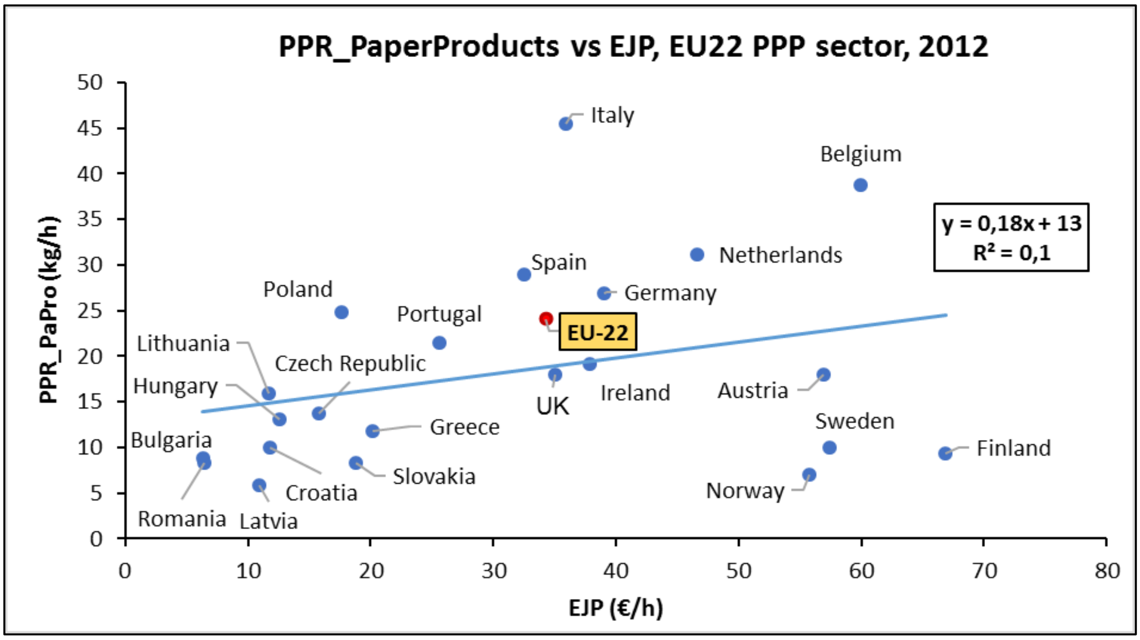


Figure V-11. PPR_PaperProducts vs EJP at the Paper, Pulp and Print subsector of EU22, year 2012

Last but not least, analyzing the relation between electricity EMR vs EJP for the Paper, Pulp and Print subsector I arrive at Figure V-12. This figure could have been already generated in chapter 3 or 4 as it is not using any material product data. Nonetheless, after seeing the data regarding production, exports and imports of products we can now identify the different types of subsector industries operating in this compartment. In this sense, we can understand better the patterns identified there: the pulp producers follow one trend (Finland, Sweden, Norway and Portugal) whereas the other follow another one.

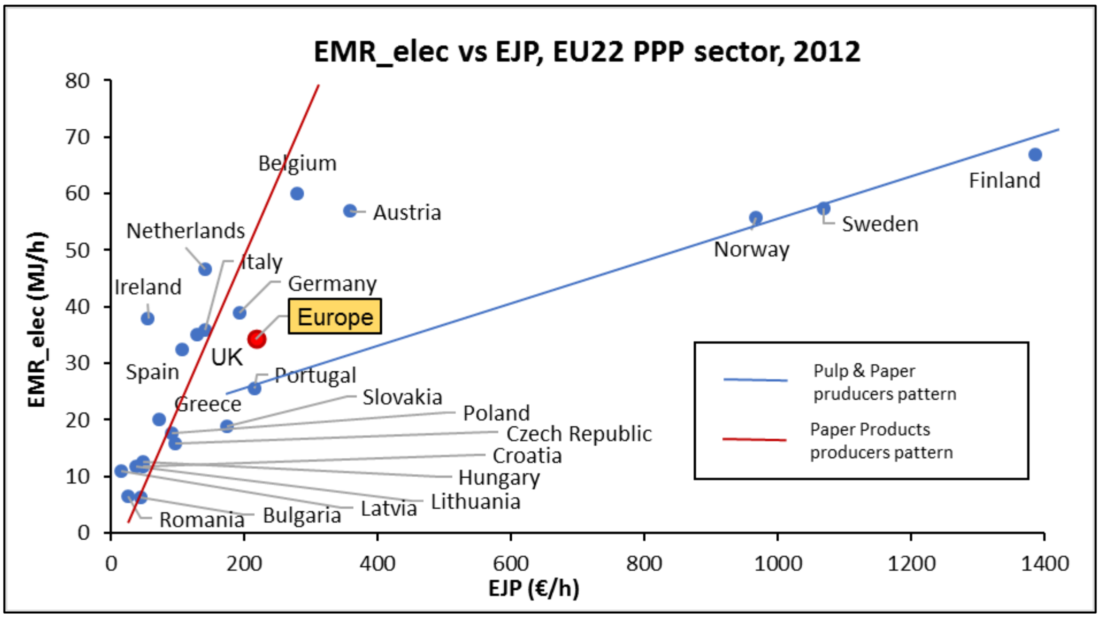


Figure V-12. EMR_electricity vs EJP at the Paper, Pulp and Print subsector of EU22, year 2012

7 Conclusions

In this chapter, I have introduced the possibility of using data about material products in order to improve the analysis of the metabolic pattern of society. To do this, I have developed a new protocol according to the general framework of MuSIASEM and new theoretical elements that open a wide new range of assessment opportunities.

Thanks to the introduction of material products data in the data arrays, I have been able to identify new metabolic patterns inside the subsectors that can only be detected when looking at material flows. In this sense, the import and export data have been crucial to see what countries are producing *what* and for *whom*. This information is essential to increase our understanding of *why* and *for what* countries are using energy. Therefore, this extended integrated assessment could be used for improving the quality of the information used to discuss environmental agreements between countries.

Additionally, this information could also be used to calculate cost shifting associated with particular production processes and trace who is getting the benefits of consuming the final products. A better identification of the metabolic patterns associated with more specific processes allows us to reduce the variability of boxplots used to identify benchmarks, which can then be used for building scenarios. Finally, an integrated analysis of this type can be used to identify more competitive countries (with a higher level of export) and more capitalized ones (with higher EMRs and PPR) for each type of material product.

The new methodological tools presented here make it possible to operationalize the analysis of the concept of efficiency, by clarifying the implications of its different interpretations: maximum power principle and maximum output per input. Both principles are operating at the same time but at different scales: (i) the maximum output allows increasing diversity at the large scale; (ii) the minimum input per unit of output allows the optimization of specific processes at the local scale. Only a multiscale integrated approach can handle the co-existence of these two principles in a coherent analysis. Moreover, I have shown how Economic Material Intensity and Economic Energy Intensity are not useful indicators for handling these discussions over sustainability. In fact, they are blind to the important tradeoffs between the use of resources and the working time allocated in a concrete mode of production.

When looking at the specific outputs of the analysis of the Paper, Pulp and Print subsector, we can say that Finland, Sweden and Portugal (but no PRODCOM data for Norway!) are clearly net producers of Pulp and Paper. This issue makes them consume more energy per unit of value added generated (in chapter 3 we saw that Finland consumes 106 MJ/€, while Bulgaria and Spain just 64 and 20 MJ/€ respectively). Their metabolic patterns are clearly different from the others. Portugal, another net producer, presents a clearly lower level of capitalization when comparing its EMRs and EJP with Finland and Sweden. In spite of this big difference, the use of the set of indicators presented here - levels of exportation and PPR_{pulp} and PPR_{paper} - makes it possible to identify its subsector as a Primary Subsector Industry. On the other hand, the physical products trade balances and its PPRs rates makes the PPP sector of Italy a clear Final Subsector Industry. That is, it imports pulp and paper produced elsewhere and then it produces paper articles for exporting. Therefore, Italy present low EMRs in relation to pulp and paper producers, but is still able of having a higher $PPR_{papro.}$ Finally, the Netherlands is the only country that I have been able to identify as a clear Intermediate subsector industry. That is, it is importing and exporting a great amount of all types of products in the subsectors, presenting a high EJP for low values of EMRs.

The analysis of product production rate vs. electricity metabolic rate shows the co-existence of different tendencies in the evolution of pulp and paper processes. Those having natural resources optimize the production per hour (PPR) at the expense of consuming more energy carriers per product. On the other hand, it seems that the production of paper product technologies represents a saving on energy when having a greater capitalization process.

This chapter represents an important step forward in the development of the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism methods integrating and systematizing the material products to the general energy analysis. Applying this method for the analysis of all manufacturing and mining sectors will represent an enormous challenge due to the huge variety of product types (more than 3900 in PRODCOM!).

Nonetheless, I have shown here that by looking at some smart aggregations of these products in semantically relevant categories it becomes possible to identify the existence of different metabolic patterns in analogous sectors and subsectors across countries.

Another important result is the awareness that the present indicators based on the analysis of material flows (as (Material intensity or Domestic Material Consumption) do not provide accurate information regarding sustainability issues. this chapter shows that an effective integration of biophysical and monetary analysis in a multiscale integrated approach is crucial for generating relevant information for the governance of sustainability issues.

Chapter VI

"Scientific knowledge is as much an understanding of the diversity of situations for which a theory or its models are relevant as an understanding of its limits."

Elinor Ostrom

Conclusions

Throughout this study, I have presented the evolution of my work trying to answer the main research question of my PhD thesis: *How to identify the most relevant factors determining the performance of the metabolic pattern of modern societies?* This progression has started from a conventional application of the MuSIASEM method looking at the relation of energy (gross energy requirement thermal), value added and human activity for the cases of China and India – this is the analysis presented in chapter 2. From an historical analysis of these factors in these countries, I have been able to individuate relevant aspects explaining the differences in the changes of the metabolic patterns of these countries: (i) the differences in the level of capitalization of the different sectors in the two countries; (ii) the different effects that this capitalization generated on the materials standard of living in the household sector in the two countries. Another important factor identified by the MuSIASEM analysis is the role played by demographic structural changes that took place in the studied period.

Once familiarized with the MuSIASEM method, I have introduced a new protocol of analysis to capable of keeping separated the accounting of energy forms of different quality by carrying out the accounting of "energy" no longer in Joule of gross energy requirement, but in different "Joules" referring to different energy carriers. This distinction became crucial when discussing the feasibility (Primary Energy Sources availability), viability (productive forces converting PES to End Uses) and desirability (the compatibility of the effect of end uses with normative values and institutions guaranteeing he stability of the social fabric) of the energy systems. With this new distinction, I have analyzed the metabolic pattern of the main economic sectors for EU27+Norway. This analysis has shown the existence of important differences among the values found in different sectors and countries confirming the usefulness of the approach proposed. Two main points were evident from this analysis: (i) by looking at metabolic characteristics (the relation between the consumption of energy carriers, the input of labor and the generation of value added) at the level of the whole country does not provide the information required to study the performance of the economy; (ii) when considering the economic sector as composed of lower level sub-compartments, in order to understand the characteristics observed when looking at a compartment, one has to study the characteristics of the sub-compartments composing it.

The attempt to extend the analysis of the end-use matrix to lower level subcomponents has been quite challenging for three reasons: (i) the incompatibility of sector and subsectors databases in relation to human activity and value added accountings; (ii) the huge amount of data to be handle multiplying the splits of sectors and subsectors across 28 countries; (iii) the energy balances databases do not split satisfactorily the service sector (the most important sectors in the countries analyzed). These represent limits of the protocols presented here when using the set of databases I used in this thesis. On the other hand, this can also be considered as a positive result of this thesis. My analysis shows that that current organization and data sets supplied by official statistical offices need further homogenization to make possible a multiscale integrated analysis. As discussed in chapter 3 the analysis provided shows that using existing databases we cannot study the complex relation between environmental, social and economic aspects affecting the pattern socio-ecological systems.

Because of these reasons I have been able to present in detail the end-use matrix for only the industrial subsectors of EU22 countries. The results obtained at this lower level of analysis complement and confirm the previous ones. The overall performance of a country cannot be obtained by using simplistic indicators or ratios. It requires a complex analysis across scales and levels of organization. For this analysis, I had to introduce new analytical tools as the Metabolic Structural table or the Normalized Chromatic Intensity in order to help the visualization of the complex set of relations studied. Both tools show significant potentialities when presenting multiscale integrated analysis. Furthermore, the use of boxplots presented in chapter 4 proved to be effective in identifying some benchmarks that can be used for creating scenarios.

However, at the end of this investigation I could clearly see that also when moving to the subsector level there are still significant metabolic differences among the same type of compartment operating in different countries. The analysis of the metabolic rates can tell us something about the difference in typologies of processes, but in order to be able to explain differences in performance across the metabolic pattern of socio-economic systems something more is needed (i.e. a more accurate tracking of the biophysical processes on the basis of homogeneous characteristics of their production functions – the technical coefficients used to produce products). Unfortunately, open access databases do not allow to get this information. For this reason, I decided to expand the inputs of information getting into the end-use matrix accounting also for materials flows. By doing so, I could achieve two important improvements: (i) identify relevant categories of production processes taking place at lower level than subsectors, and (ii) characterize the level of openness of the subsectors (the degree of externalization to other socio-ecological systems). The problem to face for this task was data availability. In fact, the EW-MFA material databases do not map into NACE classification, and this makes it impossible to relate them to the results obtained in my previous analysis. On the other hand, I found that PRODCOM databases - accounting for production, products sold, exported and imported products - do map into NACE classification. This made me able to relate it with my previous analysis. To achieve this result, I have developed a protocol that is able to differentiate types of products in relation to the compartment analyzed and to classify this compartment in relation to its openness to the market. An exploration of these ideas presented in Chapter 5 confirms the potentialities of the proposed method. Again, this exploration has been limited by the lack of coherence and availability of data: PRODCOM database presents a large amount of missing and confidential data, and some limitations when relating with SBS database.

In conclusion, I can answer my research question by saying that the MuSIASEM approach: (i) is a very promising tool to be used for identifying the factors determining the performance of the metabolic pattern of modern society; (ii) it is possible to develop protocols capable of integrating quantitative data coming from non-equivalent descriptive domains across scales and dimensions; (iii) this method present great potentialities for the identification of the trade-offs associated with policies determining changes in the mix of energy carriers, mix of products, end uses and level of openness of the compartments. On the negative side: (i) this approach requires the ability of handling, storing and processing a huge amount of data, and therefore it would require a team of people pooling together different typologies of expertise; (ii) the application of the proposed protocols requires a huge effort for forcing different statistics talk to each other. Available databases present problems of incoherence when using data referring to different scales of analysis and data gathered using different logics in the choice of the statistical categories. It should be noted that the required data are maybe gathered by statistical offices, but the problem is that they are not included in the statistical products they provide to the public. In my view, the possibility of flagging the importance of this problem, using practical examples of analysis, should be considered as another important result of the present work. I can only hope that in the future when statistical offices will be required to support sustainability analysis with more effective data, they will produce the data input required for a more effective characterization of the metabolic pattern of modern societies.

Outlook for future research

As already mentioned in the introduction, I did not have time to carry out the last exploration I had planned to do in my PhD.

The idea I wanted to explore was to analyze the relation between the utilization factor (UF) of energy converters (the technology used to use energy carriers) and the human activity associated with the given end uses. In a practical example, this would be the UF of a car (UF is 3% of the total hours in a year) and the effect that this energy converter has on the standard of living of the person using it. In fact, depending the different type of institution – e.g. private property vs. shared property – the utilization factor of an energy converter can be greatly changed, without a similar change in the standard of living of the user – e.g. car sharing. This issue refers to the complex relations we can find between both energy (input flows) and energy converters (fund elements) used to satisfy human necessities and generate enjoyment of life (Georgescu-Roegen, 1975).

From previous analyses carried out in the MuSIASEM group, one of the surprising observations made when analyzing the metabolic pattern of modern societies, was that most of the power capacity (PC, energy converters giving the capacity of consuming useful energy) is not allocated in the production sector, but in the household one (see Table VI-1). This fact is totally overlooked by economic analyses focusing only on "factors of production" missing the elephant in the room: for being able to consume a lot you also need "factors of consumption"! Every household in a modern society is equipped with many appliances: a fridge, a freezer, a washing machine, a stereo, a television, a computer, a stove, an extractor hood, a dishwasher, an iron, a clothes dryer, a toaster, an oven, an air conditioner, a hair dryer, a coffeemaker, etc. The most powerful machine that we found in the household sector is not inside the homes, but in front of them: the car.

Another striking result when looking at the analysis of the power capacity used by the household sector is its very low utilization factor (UF) when compared with the UF of the energy converters (capital technology) used in the paid work sector. Many of the appliances used in the household are used a negligible fraction of time over the year (see Table VI-1

Power Capacity and its Utilization Factor of Spain per capita, for the year 2004. Adaptation from Diaz-Maurin, F. (2016) and Giampietro M. et al. (2014).).

Table VI-1 Power Capacity and its Utilization Factor of Spain per capita, for the year 2004. Adaptation from Diaz-Maurin, F. (2016) and Giampietro M. et al. (2014).

	Energy Throughput (GJ-GER)	Human Activity (hours)	Energy Metabolic Rate (MJ/hour)	Power Capacity (kW)			Utilization Factor (%)		
				PC-Elec	PC-Heat	PC-Fuels	PC-Elec	PC-Heat	PC-Fuels
Whole Society	141	8.760	16	7,9	5,1	42	-	-	-
Households	37	7.825	5	6,3	4,0	26	3	8	2
Service & Government	43	598	70	0,95	-	14	20	16	6
Building & Manufacturing	43	280	159	0,48	1,0	-	60	60	-
Agricultures	4,3	48	90	0,05	0,1	0,79	32	32	8
Energy & Minig	12	8	1.537	0,11	-	1,1	60	60	20

This difference becomes logic when considering the different functional roles that converters are fulfilling in the two sectors: (i) in the paid work sector, when producing, the goal is to maximize the production of the capital invested, (ii) in the household, when consuming, the goal is to maximize the enjoyment of life determined by the diversity of functions that one can carry out whenever wanted (i.e. cars are parked most of the time because people want to use them whenever they want). This maximization of the diversity of owned durable goods is promoted by advertising and by the material values proposed by the consumer society, but it can also be associated with a feeling of freedom and independence perceived by many people when they have a great diversity of energy converters under control. One could also see that this logic follows the maximum energy flux principle (Lotka, 1922) or the maximum power principle (Odum and Pinkerton, 1955). Then, the idea I wanted to study was: when dealing with the metabolic pattern of modern societies is it possible to complement the maximization of the energy flux with a concomitant maximization of UF? Can we still enjoy the advantages of a very high level of energy services while reducing at the same time the requirement of technological funds?

When discussing how to deal with the shortage of resources and how to reduce the socio-environmental impacts of the metabolism of modern societies, the goal of obtaining a low utilization factor of the energy converters used in the household sector should be a top priority in terms of policies to be implemented. In fact, if the UF of the converters in the households was to be increased, we could maintain the material standard of living while using a lower quantity of converters. This would translate into an important reduction of the overall requirement of energy, materials and human time in the productive sectors and relative pollution. This idea can be found in many authors claiming alternative solutions such as the prosperous way down (Odum and Odum, 2001), prosperity without growth (Jackson, 2009), living better with less (Sempere, 2009), the wealth of commons (Bollier and Helfrich, 2012) and the de-growth narrative (D'Alisa, Demaria and Kallis, 2014). In spite of the fact that this idea has been out there for a while now, there is an important lack of quantitative assessments of the possible trade-offs that can be associated with such a policy. A multiscale integrated approach to the analysis of scenarios of end-uses could fill this gap of information.

Mainstream economics tends to neglect all the economic activities happening outside the market. Ecological economics criticized mainstream economics for the lack of consideration of environmental issues. But only feminist and informal economics has been interested in a systemic analysis – including quantitative assessments - of the other relevant economic relations taking place outside the market in modern societies.

Using the MuSIASEM approach, one can look inside the Household (HH) sector to gather this type of quantitative information (which I do not develop during this thesis). On the other and, some quantitative studies of the metabolic pattern of households based on applications of MuSIASEM have been carried out in the European Project SMILE (www.smile-fp7.eu/). According to the grammar developed there, within the HH sector, the categories to be used for the accounting of human activity have been defined as: (i) physiological overhead (PO): i.e. the maintenance and reproduction of humans, including activities such as sleeping, eating or personal care; (ii) unpaid work (UW) or chores, i.e. the transformation and transaction activities carried out either by individuals or by social organizations in informal economy; (iii) leisure and education (LE), i.e. transformation and transaction activities carried out either by individuals or by social organization in the informal economy in relation to leisure and education (Giampietro, Mayumi and Sorman, 2012). In these categories of human activity we can find all the activities taking place outside the market, including the activities of people under the legal age, the workers when outside work, and the retired, disabled and unpaid homemakers.

Starting from an analysis of the UF of converters in relation to the set of activities done under the labels "work" or "unpaid work", we should explore a richer taxonomy of definitions for human activities and define in which institutional settings these different categories can be implemented. This will depend on the different logics that characterize the relation between work and the distribution of its benefits (see Figure VI-1 Typologies of work in relation to the distribution of its benefits.).

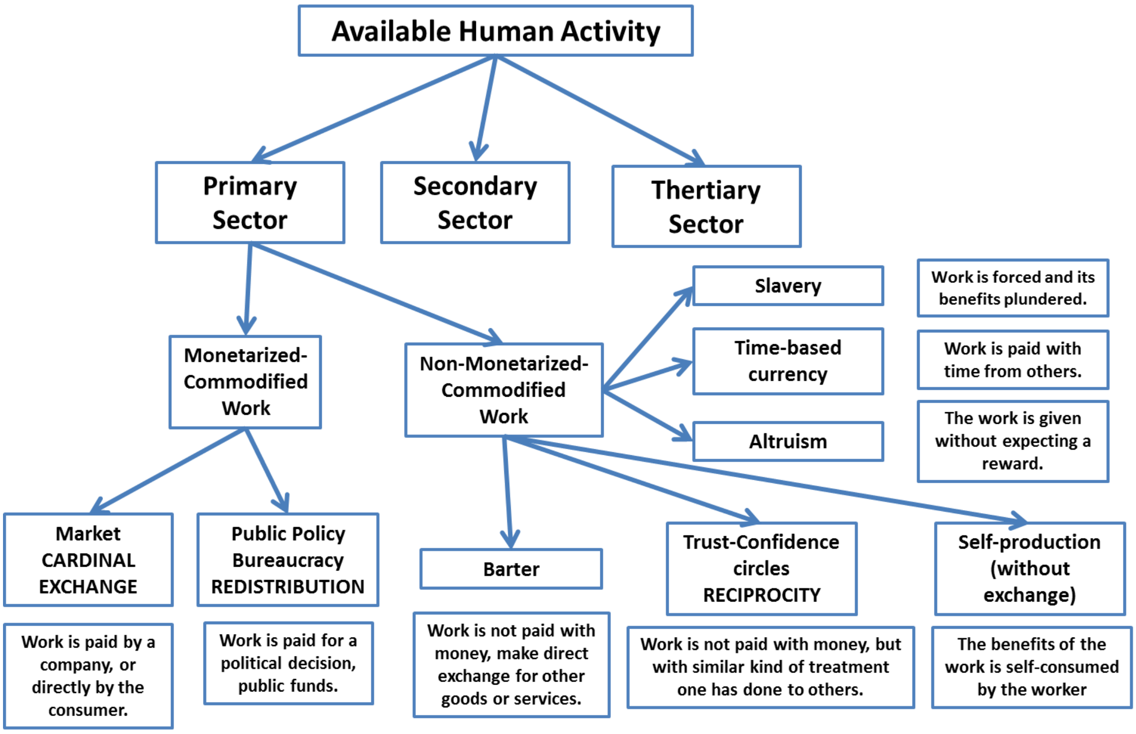


Figure VI-1 Typologies of work in relation to the distribution of its benefits.

In this richer taxonomy of work types, work is defined as any human activity that can generates some type of benefit that is possible to be distributed. In that sense, only sleeping, resting, and personal care (the physiological overhead) are subtracted from THA and all the rest is considered in MuSIASEM as Disposable Human Activity (DHA). DHA represents all the amount of human time that can be interpreted as invested in "different" typologies of valuable work. With this new taxonomy, the categories of education, leisure and unpaid work should be substituted by fuzzy set of categories, which can overlap with each other within the concept of conviviality. For example, a person can learn (education) from doing reciprocity work (e.g., organizing a party for his/her community) and at the same time taking pleasure in doing so (leisure) (Max-Neef, 1994).

The idea with this new taxonomy of definitions of work is to analyze the possibility of generating different metabolic patterns associated with different work institutions. Humans could cover their basic needs with a wide range of alternative ways when considering new types of institutions. It would be an interesting exercise to check the feasibility, viability and desirability of different metabolic patterns generated in this alternative characterization. The first step would be to explore the interesting benefits of creating commons managing converters, which could boost the UF of many devices reducing the energy and material use in the production sector without renouncing to the material benefits of using them (access). The relevant effects of *distinction* and other psychosocial effects associated with the ownership of products (Bourdieu, 1984) would also need some attention, but could probably be compensated by the benefits obtained when building identity through collectivity. However, increasing the UF of converters (reducing the requirement of technological funds) can be upset by the increase in the time required to build and run the institutions needed to regulate the use of the common converters. It is not sure in terms of desirability what the final effects of this trade-off will be. In fact, following the work of Elionor Ostrom (1990), creating a common is not costless, it needs: (i) time for building trust; (ii) monitoring and enforcement costs, making sure the other party sticks to the terms of the arrangement, and taking appropriate action, and (iii) managing difficulties to overcome spatial (and temporal) disconnects between benefiters and damaged actors.

On the other hand, after having characterized the biophysical patterns of the production sectors, we can assess (at least in very coarse terms) the energy and HA that could be potentially reduced by reducing the production (consumption) of durable products in a scenario of sharing energy converters.

Nowadays, we see a flourishing of initiatives in this direction: community gardens, tool libraries, joint workshops, banking cooperatives, etc. These initiatives emphasize the empowerment of people and the social benefits of the creation of communities. However, one cannot ignore the effects on the overall socio-ecological systems where they are embedded. Some of the questions to be answer would be: can we generalize these practices? Which types of trade-offs on the profile of human time have to be handled? What types of personal and social skills are needed for these types of organizations? How can we educate for conflict resolutions? Some of the preliminary exploration of these questions seems to point to the fact that people hate the continuous risk of experiencing social conflicts and prefer to have their own properties (sharing avoidance). Moreover, some people prefer to pay some amount of money for someone to manage the converters rather than managing them directly. This means moving the use of durable goods to a service paid sector (privately or publicly managed). Moreover, different convertors follow very different patterns of use and different people present very different patterns of use of the same convertors.

In conclusion, further research is needed to clarify the potential role of the sharing of energy converters and exosomatic devices. The first step would be to identify which convertors present better opportunities (as transport devices), and which do not (smartphones, for example, seem to be one of the most personal devices). Moreover, new information and communication technologies (ITC) are reducing the transaction costs not only in the market, but also in the informal economy, which is creating a new pool of opportunities that need to be evaluated accordingly. Within this context, we will have to keep asking ourselves: are these new improvements generating additional problems because of Jevons' paradox? How does society use the resources which have been saved? Is it possible to implement this kind of policy in the absence of a real shortage of resources? Which kind of regulation could handle the elusive trade-offs of local and global performance?

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APPENDIX A

Table A - 1 Main indicators of China at level n from 1971 to 2010

China Level *n*

*Constant values 2000

Year	TET	THA	GDP	EMRSA	EEI		GDP per capita
	(PJ)	(h)	(10^9 US$*)	(MJ/h)	(MJ/US $*)	(MJ/person)	(US$*/person)
1971	16.348	7,47E+12	107	2,19	152,7	19.181	126
1972	17.184	7,64E+12	111	2,25	154,6	19.711	127
1973	17.817	7,81E+12	120	2,28	148,6	19.972	134
1974	18.276	7,96E+12	123	2,30	149,0	20.114	135
1975	20.168	8,10E+12	133	2,49	151,2	21.822	144
1976	20.845	8,21E+12	131	2,54	158,9	22.243	140
1977	22.692	8,32E+12	141	2,73	160,7	23.893	149
1978	24.721	8,43E+12	158	2,93	156,7	25.682	164
1979	25.131	8,54E+12	170	2,94	148,1	25.765	174
1980	25.051	8,65E+12	183	2,90	136,9	25.380	185
1981	24.864	8,77E+12	192	2,84	129,2	24.846	192
1982	25.639	8,90E+12	210	2,88	122,1	25.222	207
1983	26.660	9,02E+12	233	2,95	114,5	25.881	226
1984	28.275	9,14E+12	268	3,09	105,4	27.095	257
1985	28.990	9,27E+12	304	3,13	95,2	27.387	288
1986	29.998	9,42E+12	331	3,19	90,6	27.903	308
1987	31.533	9,57E+12	370	3,29	85,3	28.850	338
1988	33.260	9,73E+12	411	3,42	80,8	29.957	371
1989	33.947	9,87E+12	428	3,44	79,3	30.120	380
1990	36.514	1,00E+13	445	3,65	82,1	31.936	389
1991	35.850	1,01E+13	486	3,53	73,8	30.952	419
1992	37.054	1,03E+13	554	3,61	66,8	31.624	473
1993	39.201	1,04E+13	632	3,78	62,0	33.076	533
1994	40.988	1,05E+13	715	3,90	57,3	34.200	596
1995	43.802	1,06E+13	793	4,13	55,3	36.164	655
1996	45.368	1,07E+13	872	4,23	52,0	37.069	713
1997	46.911	1,08E+13	953	4,33	49,2	37.946	771
1998	47.803	1,09E+13	1.028	4,37	46,5	38.315	824
1999	47.414	1,10E+13	1.106	4,30	42,9	37.694	879
2000	49.517	1,11E+13	1.198	4,46	41,3	39.069	946
2001	50.330	1,12E+13	1.298	4,50	38,8	39.435	1.017
2002	53.008	1,13E+13	1.416	4,71	37,4	41.267	1.102
2003	60.303	1,13E+13	1.558	5,33	38,7	46.664	1.205
2004	67.956	1,14E+13	1.715	5,97	39,6	52.279	1.319
2005	73.276	1,15E+13	1.909	6,40	38,4	56.041	1.460
2006	80.053	1,15E+13	2.151	6,95	37,2	60.901	1.637
2007	84.357	1,16E+13	2.457	7,29	34,3	63.844	1.859
2008	87.341	1,16E+13	2.693	7,51	32,4	65.768	2.027
2009	94.175	1,17E+13	2.940	8,06	32,0	70.569	2.203
2010	101.200	1,17E+13	3.246	8,62	31,2	75.471	2.421

Sources: IEA (2010), NBSC (2011) & World Bank (2012).

Table A - 2 Main indicators of India at level n from 1971 to 2010

India Level *n*

*Constants values 2000

Year	TET (PJ)	THA (h)	GDP (10^9 US$*)	EMRSA (MJ/h)	EEI (MJ/US $*)	(MJ/person)	GDP per capita (US$*/person)
1971	6.551	4,96E+12	119		55,0	11.561	210
1972	6.704	5,08E+12	118		56,6	11.562	204
1973	6.886	5,20E+12	122	1,32	56,3	11.602	206
1974	7.175	5,32E+12	124		57,9	11.809	204
1975	7.441	5,45E+12	135		55,1	11.962	217
1976	7.748	5,58E+12	137		56,4	12.164	216
1977	7.964	5,71E+12	147		54,0	12.209	226
1978	7.995	5,85E+12	156	1,37	51,3	11.97	233
1979	8.370	5,99E+12	148		56,7	12.24	216
1980	8.589	6,13E+12	158	1,40	54,5	12.27	225
1981	9.044	6,28E+12	167		54,1	12.623	233
1982	9.405	6,42E+12	173	1,46	54,4	12.829	236
1983	9.718	6,57E+12	185	1,48	52,4	12.956	247
1984	10.141	6,72E+12	193	1,51	52,7	13.219	251
1985	10.668	6,87E+12	203	1,55	52,7	13.598	258
1986	11.066	7,03E+12	212	1,58	52,1	13.797	265
1987	11.497	7,18E+12	221	1,60	52,1	14.025	269
1988	12.117	7,34E+12	242	1,65	50,1	14.465	289
1989	12.708	7,50E+12	256	1,70	49,6	14.851	300
1990	13.261	7,65E+12	270	1,73	49,0	15.177	310
1991	13.795	7,81E+12	273	1,77	50,5	15.467	307
1992	14.345	7,97E+12	288	1,80	49,7	15.763	317
1993	14.673	8,13E+12	302	1,80	48,6	15.808	325
1994	15.242	8,29E+12	322	1,84	47,3	16.106	340
1995	16.089	8,45E+12	347	1,90	46,4	16.682	359
1996	16.608	8,61E+12	373	1,93	44,6	16.903	379
1997	17.258	8,76E+12	388	1,97	44,5	17.249	388
1998	17.679	8,92E+12	412	1,98	42,9	17.358	404
1999	18.771	9,08E+12	442	2,07	42,4	18.114	427
2000	19.143	9,23E+12	460	2,07	41,6	18.164	437
2001	19.448	9,39E+12	484	2,07	40,2	18.152	452
2002	19.992	9,54E+12	502	2,10	39,8	18.363	462
2003	20.494	9,69E+12	544	2,12	37,6	18.532	492
2004	21.733	9,84E+12	590	2,21	36,9	19.353	525
2005	22.578	9,99E+12	644	2,26	35,0	19.805	565
2006	23.729	1,01E+13	704	2,34	33,7	20.508	609
2007	25.071	1,03E+13	773	2,44	32,4	21.355	659
2008	26.213	1,04E+13	812	2,51	32,3	22.012	681
2009	28.269	1,06E+13	885	2,67	31,9	23.407	733
2010	29.002	1,07E+13	963	2,70	30,1	23.682	787

Sources: IEA (2010), OECD (2012) & World Bank (2012).

Table A - 3 Main indicators of China at level n-1 from 1971 to 2010.

China Level *n-1*

*Constants values 2000

Year	ET_{PW} (PJ)	ET_{HH} (PJ)	HA_{PW} (h)	HA_{HH} (h)	EMR_{PW} (MJ/h)	EMR_{HH} (MJ/h)	ELP_{PW} (10^3 US$*/h)	ELP_{PW}/EMR_{PW} (10^3 US$*/MJ)
1971	8.098	8.250						
1972	8.670	8.514						
1973	9.110	8.707						
1974	9.418	8.857						
1975	10.847	9.321	9,02E+11	7,19E+12	12,02	1,30	0,15	12,3
1976	11.383	9.462						
1977	12.821	9.871						
1978	14.530	10.191	9,49E+11	7,48E+12	15,31	1,36	0,17	10,9
1979	14.772	10.359	9,69E+11	7,58E+12	15,24	1,37	0,18	11,5
1980	14.733	10.318	1,00E+12	7,65E+12	14,72	1,35	0,18	12,4
1981	14.336	10.527	1,03E+12	7,73E+12	13,88	1,36	0,19	13,4
1982	14.932	10.707	1,07E+12	7,84E+12	13,96	1,37	0,20	14,1
1983	15.713	10.947	1,10E+12	7,93E+12	14,33	1,38	0,21	14,8
1984	17.037	11.238	1,14E+12	8,00E+12	14,97	1,40	0,24	15,7
1985	17.391	11.599	1,18E+12	8,10E+12	14,77	1,43	0,26	17,5
1986	18.190	11.808	1,21E+12	8,21E+12	15,03	1,44	0,27	18,2
1987	19.446	12.087	1,25E+12	8,33E+12	15,61	1,45	0,30	19,0
1988	20.792	12.467	1,28E+12	8,44E+12	16,22	1,48	0,32	19,8
1989	21.386	12.560	1,31E+12	8,57E+12	16,38	1,47	0,33	20,0
1990	23.945	12.568	1,53E+12	8,49E+12	15,68	1,48	0,29	18,6
1991	23.084	12.766	1,54E+12	8,60E+12	14,95	1,48	0,31	21,0
1992	24.438	12.615	1,56E+12	8,70E+12	15,67	1,45	0,36	22,7
1993	26.513	12.688	1,58E+12	8,81E+12	16,83	1,44	0,40	23,8
1994	28.435	12.553	1,59E+12	8,91E+12	17,88	1,41	0,45	25,1
1995	30.946	12.855	1,60E+12	9,01E+12	19,28	1,43	0,49	25,6
1996	34.333	11.035	1,63E+12	9,10E+12	21,12	1,21	0,54	25,4
1997	34.076	12.835	1,65E+12	9,18E+12	20,70	1,40	0,58	28,0
1998	35.481	12.321	1,67E+12	9,26E+12	21,31	1,33	0,62	29,0
1999	34.971	12.443	1,68E+12	9,34E+12	20,78	1,33	0,66	31,6
2000	36.942	12.574	1,70E+12	9,40E+12	21,74	1,34	0,71	32,4
2001	37.607	12.723	1,72E+12	9,46E+12	21,91	1,34	0,76	34,5
2002	40.036	12.972	1,73E+12	9,53E+12	23,18	1,36	0,82	35,4
2003	46.799	13.503	1,74E+12	9,58E+12	26,92	1,41	0,90	33,3
2004	53.728	14.228	1,75E+12	9,64E+12	30,69	1,48	0,98	31,9
2005	58.470	14.806	1,76E+12	9,69E+12	33,23	1,53	1,08	32,6
2006	64.619	15.434	1,77E+12	9,75E+12	36,56	1,58	1,22	33,3
2007	68.184	16.173	1,78E+12	9,80E+12	38,40	1,65	1,38	36,0
2008	70.877	16.464	1,78E+12	9,85E+12	39,79	1,67	1,51	38,0
2009	76.910	17.265	1,79E+12	9,90E+12	43,03	1,74	1,65	38,2
2010	83.037	18.163	1,79E+12	9,95E+12	46,29	1,82	1,81	39,1

Sources: IEA (2010), NBSC (2011), ILO (2012) & World Bank (2012).

Table A - 4 Main indicators of India at level n-1 from 1971 to 2010

India Level n-1

*Constant values 2000

Year	ET_{PW} (PJ)	ET_{HH} (PJ)	HA_{PW} (h)	HA_{HH} (h)	EMR_{PW} (MJ/h)	EMR_{HH} (MJ/h)	ELP_{PW} (10^3 US$*/h)	ELP_{PW}/EMR_{PW} (10^3 US$*/MJ)
1971	2.963	3.588						
1972	3.041	3.664						
1973	3.154	3.732	5,06E+11	4,69E+12	6,23	0,80	0,24	38,8
1974	3.373	3.802						
1975	3.538	3.903						
1976	3.741	4.007						
1977	3.853	4.111						
1978	3.789	4.206	5,29E+11	5,32E+12	7,17	0,79	0,29	41,1
1979	4.067	4.304						
1980	4.199	4.390	5,63E+11	5,57E+12	7,46	0,79	0,28	37,5
1981	4.563	4.481						
1982	4.822	4.584	6,13E+11	5,81E+12	7,87	0,79	0,28	35,8
1983	5.046	4.672	5,98E+11	5,97E+12	8,44	0,78	0,31	36,7
1984	5.371	4.769						
1985	5.797	4.870						
1986	6.092	4.974						
1987	6.392	5.105						
1988	6.898	5.219						
1989	7.362	5.346						
1990	7.828	5.433	6,97E+11	6,96E+12	11,24	0,78	0,39	34,6
1991	8.262	5.533	7,12E+11	7,10E+12	11,60	0,78	0,38	33,1
1992	8.715	5.630	7,28E+11	7,24E+12	11,96	0,78	0,40	33,1
1993	8.972	5.701	7,44E+11	7,39E+12	12,06	0,77	0,41	33,7
1994	9.433	5.809	7,68E+11	7,52E+12	12,29	0,77	0,42	34,2
1995	10.156	5.933	7,80E+11	7,67E+12	13,03	0,77	0,44	34,1
1996	10.678	5.930	7,91E+11	7,82E+12	13,49	0,76	0,47	34,9
1997	11.198	6.060	8,00E+11	7,96E+12	13,99	0,76	0,48	34,6
1998	11.480	6.199	7,93E+11	8,13E+12	14,48	0,76	0,52	35,9
1999	12.462	6.309	8,15E+11	8,26E+12	15,30	0,76	0,54	35,5
2000	12.752	6.390	8,32E+11	8,40E+12	15,32	0,76	0,55	36,1
2001	12.978	6.470	8,56E+11	8,53E+12	15,17	0,76	0,57	37,3
2002	13.388	6.604	8,72E+11	8,67E+12	15,36	0,76	0,58	37,5
2003	13.752	6.742	8,89E+11	8,80E+12	15,47	0,77	0,61	39,6
2004	14.775	6.959	9,26E+11	8,91E+12	15,95	0,78	0,64	39,9
2005	15.478	7.101	9,38E+11	9,05E+12	16,50	0,78	0,69	41,6
2006	16.416	7.312	9,41E+11	9,19E+12	17,45	0,80	0,75	42,9
2007	17.575	7.496	9,59E+11	9,32E+12	18,33	0,80	0,81	44,0
2008	18.530	7.683	9,78E+11	9,45E+12	18,96	0,81	0,83	43,8
2009	20.395	7.874	9,93E+11	9,59E+12	20,54	0,82	0,89	43,4
2010	20.930	8.071		1,07E+13				

Sources: IEA (2010), OECD (2012), ILO (2012) & World Bank (2012).

Table A - 5 Main indicators of China at level n-2 from 1971 to 2010. Sources: IEA (2010), NBSC (2011), ILO (2012), World Bank (2012) & UN (2011).

China Level n-2

*Constant values 2000

Year	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (10^9 US$*)	GDP_{PS} (10^9 US$*)	GDP_{SG} (10^9 US$*)	EMR_{AG} (MJ/h)	EMR_{PS} (MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (US$*/h)	ELP_{PS} (US$*/h)	ELP_{SG} (US$*/h)
1971	480	7.109	509				36	41	30						
1972	530	7.589	551				37	43	31						
1973	576	7.943	591				40	47	34						
1974	602	8.181	636				42	48	33						
1975	660	9.490	696	6,92E+11	1,21E+11	8,90E+10	43	55	36	0,95	78,39	7,82	0,06	0,45	0,40
1976	679	9.998	707				43	54	34						
1977	746	11.296	778				42	61	38						
1978	825	12.855	850	6,65E+11	1,63E+11	1,20E+11	44	69	44	1,24	78,76	7,07	0,07	0,43	0,37
1979	848	13.037	887	6,73E+11	1,70E+11	1,27E+11	53	75	42	1,26	76,90	6,98	0,08	0,44	0,33
1980	789	13.096	847	6,84E+11	1,81E+11	1,35E+11	55	80	48	1,15	72,31	6,26	0,08	0,44	0,35
1981	782	12.727	828	7,00E+11	1,88E+11	1,45E+11	62	81	50	1,12	67,67	5,71	0,09	0,43	0,34
1982	801	13.246	885	7,25E+11	1,96E+11	1,48E+11	69	86	55	1,10	67,54	5,96	0,10	0,44	0,37
1983	832	13.929	953	7,32E+11	2,04E+11	1,61E+11	77	93	63	1,14	68,29	5,93	0,10	0,46	0,39
1984	895	15.133	1.010	7,25E+11	2,25E+11	1,87E+11	86	105	78	1,23	67,15	5,39	0,12	0,46	0,42
1985	890	15.459	1.041	7,32E+11	2,44E+11	2,02E+11	85	116	104	1,22	63,35	5,16	0,12	0,47	0,51
1986	944	16.144	1.103	7,34E+11	2,64E+11	2,12E+11	89	126	116	1,28	61,25	5,19	0,12	0,48	0,55
1987	982	17.291	1.173	7,44E+11	2,76E+11	2,26E+11	96	140	133	1,32	62,75	5,19	0,13	0,51	0,59
1988	1.029	18.475	1.288	7,58E+11	2,86E+11	2,39E+11	103	156	152	1,36	64,70	5,39	0,14	0,55	0,64
1989	1.018	19.021	1.347	7,81E+11	2,81E+11	2,43E+11	107	163	158	1,30	67,59	5,54	0,14	0,58	0,65
1990	1.265	21.369	1.311	9,14E+11	3,26E+11	2,87E+11	120	165	160	1,38	65,63	4,57	0,13	0,51	0,56
1991	1.314	20.340	1.430	9,19E+11	3,29E+11	2,96E+11	117	180	189	1,43	61,76	4,83	0,13	0,55	0,64
1992	1.298	21.533	1.607	9,09E+11	3,37E+11	3,13E+11	116	211	227	1,43	63,83	5,13	0,13	0,62	0,73
1993	1.320	23.231	1.962	8,85E+11	3,52E+11	3,38E+11	126	253	253	1,49	66,06	5,80	0,14	0,72	0,75
1994	1.379	25.253	1.803	8,61E+11	3,60E+11	3,70E+11	143	293	279	1,60	70,18	4,87	0,17	0,81	0,75
1995	1.525	27.457	1.964	8,35E+11	3,68E+11	4,02E+11	159	325	309	1,83	74,63	4,89	0,19	0,88	0,77
1996	1.020	30.601	2.712	8,18E+11	3,81E+11	4,27E+11	174	366	331	1,25	80,37	6,36	0,21	0,96	0,78
1997	1.594	30.156	2.325	8,19E+11	3,89E+11	4,39E+11	172	400	381	1,95	77,55	5,30	0,21	1,03	0,87
1998	1.722	31.517	2.242	8,27E+11	3,90E+11	4,49E+11	185	411	432	2,08	80,79	5,00	0,22	1,05	0,96
1999	1.824	30.610	2.538	8,41E+11	3,86E+11	4,57E+11	177	442	486	2,17	79,32	5,56	0,21	1,15	1,07
2000	761	32.884	3.297	8,47E+11	3,81E+11	4,71E+11	180	479	539	0,90	86,28	7,00	0,21	1,26	1,14
2001	792	33.471	3.344	8,55E+11	3,81E+11	4,79E+11	182	519	597	0,93	87,74	6,98	0,21	1,36	1,25
2002	847	35.732	3.457	8,61E+11	3,69E+11	4,98E+11	198	552	666	0,98	96,96	6,94	0,23	1,50	1,34
2003	965	42.050	3.785	8,51E+11	3,74E+11	5,13E+11	202	623	732	1,13	112,35	7,38	0,24	1,66	1,43
2004	1.137	48.098	4.493	8,19E+11	3,93E+11	5,39E+11	223	703	789	1,39	122,49	8,33	0,27	1,79	1,46
2005	1.252	52.427	4.791	7,86E+11	4,18E+11	5,56E+11	229	802	878	1,59	125,57	8,61	0,29	1,92	1,58
2006	1.305	58.132	5.182	7,51E+11	4,44E+11	5,73E+11	237	904	1011	1,74	130,92	9,05	0,32	2,03	1,77
2007	1.269	61.374	5.540	7,22E+11	4,74E+11	5,79E+11	270	1032	1155	1,76	129,38	9,57	0,37	2,18	1,99
2008	1.216	64.047	5.614	7,03E+11	4,83E+11	5,95E+11	296	1104	1292	1,73	132,60	9,44	0,42	2,29	2,17
2009	1.265	70.061	5.584	6,79E+11	4,95E+11	6,13E+11	294	1176	1470	1,86	141,43	9,11	0,43	2,37	2,40
2010	1.341	75.816	5.880	6,56E+11	5,13E+11	6,24E+11	325	1331	1591	2,04	147,71	9,42	0,49	2,59	2,55

Table A - 6 Main indicators of India at level n-2 from 1971 to 2010. Sources: IEA (2010), OECD (2012), ILO (2012), World Bank (2012), UN (2011) & Planning Commission (2012).

India Level n-2

*Constant values 2000

Year	ET_{AG} (PJ)	ET_{PS} (PJ)	ET_{SG} (PJ)	HA_{AG} (h)	HA_{PS} (h)	HA_{SG} (h)	GDP_{AG} (10^9 US$*)	GDP_{PS} (10^9 US$*)	GDP_{SG} (10^9 US$*)	EMR_{AG} (MJ/h)	EMR_{PS} (MJ/h)	EMR_{SG} (MJ/h)	ELP_{AG} (US$*/h)	ELP_{PS} (US$*/h)	ELP_{SG} (US$*/h)
1971	58	2.273	632				50	20	49						
1972	65	2.351	624				50	20	49						
1973	72	2.460	622				55	20	48						
1974	70	2.653	650				52	22	50						
1975	65	2.801	672				53	24	58						
1976	71	2.991	679				51	26	60						
1977	77	3.079	697				56	27	65						
1978	90	2.994	706				58	31	67						
1979	92	3.206	769				52	31	65						
1980	110	3.336	754				58	32	68						
1981	123	3.649	791				58	35	73						
1982	109	3.915	797				59	36	78						
1983	111	4.097	838				65	39	82						
1984	123	4.348	900				64	40	89						
1985	133	4.773	891				65	45	93						
1986	148	5.070	875				66	47	100						
1987	173	5.310	909				66	46	108						
1988	185	5.728	985				75	53	114						
1989	209	6.139	1.014				77	56	123						
1990	233	6.522	1.073				81	60	130						
1991	269	6.858	1.135				82	57	134						
1992	286	7.267	1.162				87	61	141						
1993	325	7.480	1.168				88	63	151						
1994	381	7.824	1.229	5,27E+11	1,34E+11	1,06E+11	93	71	158	0,72	58,17	11,56	0,18	0,53	1,49
1995	388	8.439	1.329				94	80	173						
1996	436	9.094	1.148				104	86	183						
1997	480	9.528	1.190				101	85	202						
1998	506	9.832	1.143				107	87	218						
1999	517	10.731	1.214				111	88	243						
2000	481	11.039	1.232	4,96E+11	1,34E+11	2,03E+11	106	97	258	0,97	82,66	6,07	0,21	0,72	1,27
2001	467	11.290	1.222				111	97	276						
2002	486	11.647	1.255				106	106	291						
2003	560	11.936	1.257				114	109	321						
2004	568	12.944	1.263				112	118	360						
2005	561	13.674	1.243	5,22E+11	1,78E+11	2,39E+11	122	129	393	1,08	76,95	5,21	0,23	0,73	1,65
2006	613	14.470	1.334				127	148	430						
2007	647	15.487	1.440				139	162	472						
2008	666	16.294	1.571				138	162	511						
2009	564	18.122	1.709				159	168	558						
2010	593	18.512	1.825				183	173	607						

APPENDIX B

Table B - 1 NCI by countries of electricity EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_elec (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	3	0,7	33	8,0	280	57	19	8	5	19	13
Austria	3,4	0,9	27	6	487	65	12	6	0	10	46
Belgium	3,2	0,8	76	12	556	158	36	12	-	34	-
Bulgaria	1,9	0,6	35	1	257	28	23	1	-	22	-
Cyprus	2,1	0,9	15	9	202	14	15	9	10	15	0
Czech Republic	2,5	0,6	20	11	301	27	11	11	15	10	22
Denmark	2,5	0,8	22	69	310	44	13	71	0	13	10
Estonia	2,7	0,7	22	15	245	27	13	15	17	14	4
Finland	6,4	1,9	54	22	517	142	23	23	0	23	14
France	3,0	1,0	58	17	720	81	37	17	-	34	-
Germany	3,0	0,7	58	0	387	90	33	0	-	31	-
Greece	2,3	0,8	18	10	469	37	11	11	0	11	2
Hungary	1,5	0,5	13	5	149	18	10	5	10	10	13
Ireland	2,3	0,8	20	11	217	53	10	11	0	10	1
Italy	2,2	0,5	52	9	349	66	35	9	-	31	-
Latvia	1,5	0,4	40	2	55	59	31		-	29	-
Lithuania	1,4	0,4	27	2	161	29	18	2	-	18	-
Luxembourg	5,3	0,8	43	49	684	115	24	49	-	25	18
Malta	2,0	0,7	17	3		32	14	3	2	14	0
Netherlands	2,8	0,7	26	79	559	60	14	81	0	14	15
Norway	9,8	3,5	76	61	245	235	33	72	25	35	11
Poland	1,6	0,3	14	1	111	18	9	1	0	10	8
Portugal	1,9	0,6	16	5	268	30	10	5	11	11	6
Romania	1,1	0,3	9	1	101	18	5	1	0	4	7
Slovakia	2,1	0,4	21	8	269	38	10	8	0	9	14
Slovenia	2,8	0,7	25	0	251	51	13	0	0	13	11
Spain	2,2	0,7	21	10	379	45	13	10	0	13	16
Sweden	5,8	1,8	47	14	503	120	22	14	0	21	35
United Kingdom	2,2	0,8	36	21	220	60	22	-	-	21	-

Table B - 2 NCI by countries of heat EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_heat (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	4	1,7	47	15	612	103	15	15	10	14	28
Austria	6,4	2,0	49	23	671	170	7	23	37	6	34
Belgium	6,2	1,9	133	85	1.686	316	34	85	-	32	-
Bulgaria	2,4	0,7	45	2	144	58	27	2	-	6	-
Cyprus	1,4	0,6	9	4	0	37	3	4	0	3	0
Czech Republic	5,0	1,9	33	19	284	65	12	20	0	11	14
Denmark	3,6	1,4	29	74	1.459	73	4	76	0	4	4
Estonia	3,1	1,8	15	9	79	42	3	9	0	3	0
Finland	7,4	1,4	70	38	1.200	244	3	40	0	2	15
France	3,6	1,6	59	18	591	134	23	18	-	22	-
Germany	5,0	1,8	85	0	661	164	28	0	-	25	-
Greece	2,3	0,7	20	2	884	65	5	2	5	2	50
Hungary	3,6	1,9	23	10	274	35	15	10	6	16	4
Ireland	3,0	1,3	23	0	131	85	8	0	0	8	8
Italy	4,6	2,2	76	4	898	99	42	4	-	31	-
Latvia	4,0	1,9	78	6	35	212	31		-	25	-
Lithuania	3,5	1,4	58	6	712	61	22	6	-	9	-
Luxembourg	6,8	2,3	45	61	2	185	17	61	-	18	4
Malta	0,47	0,28	3	0	-	3	3	0	0	3	0
Netherlands	7,5	2,4	62	248	2.645	140	22	247	313	22	32
Norway	6,6	0,7	68	9	1.392	110	3	11	3	1	24
Poland	4,2	1,9	26	19	161	48	12	19	0	8	58
Portugal	2,4	0,8	19	1	400	67	4	1	3	3	24
Romania	3,1	1,6	19	1	186	46	5	1	0	5	4
Slovakia	5,3	1,1	51	16	507	117	16	16	0	13	67
Slovenia	3,0	1,6	17	2	12	60	2	2	0	1	7
Spain	3,2	0,8	33	22	1.704	99	4	23	0	4	11
Sweden	4,6	0,7	45	45	632	171	3	46	0	2	25
United Kingdom	4,3	2,2	54	22	897	86	20	-	-	20	-

Table B - 3 NCI by countries of fuel EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_fuel (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	4	1,9	37	26	17	7,1	48	24	182	3,7	523
Austria	5,6	2,8	33	22	4	11	41	22	0	1	827
Belgium	5,9	2,9	94	126	2	12	119	126	-	15	-
Bulgaria	1,7	0,3	37	7	0	1	61	7	-	0	-
Cyprus	6,2	2,2	48	19	56	6	62	20	0	1	1.779
Czech Republic	2,8	1,0	20	43	5	1	29	44	0	0	445
Denmark	5,0	2,4	35	180	27	12	35	140	1.567	1	759
Estonia	3,5	1,7	21	61	34	7	24	64	0	3	236
Finland	5,6	3,0	33	65	46	22	33	62	129	4	458
France	4,4	2,0	72	74	17	6	87	67	-	7	-
Germany	4,8	2,8	53	0	6	5	78	0	-	17	-
Greece	3,5	2,6	14	1	19	9	16	0	24	0	279
Hungary	2,0	0,7	17	16	4	3	23	16	0	0	383
Ireland	6,0	3,0	42	45	55	14	48	46	0	7	888
Italy	3,3	2,1	39	37	7	6	52	35	-	1	-
Latvia	2,9	1,2	62	20	10	18	71	-	-	5	-
Lithuania	2,3	1,4	25	6	6	3	35	6	-	0	-
Luxembourg	26	3	212	256	0	6	254	256	-	7	3.980
Malta	3,4	1,0	32	14	-	4	39	17	0	1	992
Netherlands	4,4	2,0	30	54	8	9	34	41	856	0	787
Norway	6,1	1,9	51	218	95	21	48	60	736	3	617
Poland	2,2	1,1	13	19	4	2	17	19	0	1	205
Portugal	3,1	1,3	22	17	31	4	29	13	128	1	700
Romania	1,4	0,5	11	3	8	3	21	3	0	0	224
Slovakia	1,9	1,1	10	21	7	1	14	21	0	0	251
Slovenia	5,3	2,5	36	19	5	6	52	19	0	5	838
Spain	3,9	1,3	36	46	12	6	43	48	21	2	941
Sweden	4,4	2,3	26	25	12	7	31	21	336	2	581
United Kingdom	4,3	1,8	62	10	62	24	74	-	-	1	-

Table B - 4 NCI by countries of EJPs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

ELP (€/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	3	0	46	9	122	36	50	9	36	50	21
Austria	3,8	0	40	10	119	45	40	10	28	41	31
Belgium	3,4	0	104	20	201	73	112	20	-	109	-
Bulgaria	0,53	0	14	3	23	8	17	3	-	16	-
Cyprus	2,1	0	24	8	97	15	27	7	13	28	15
Czech Republic	1,5	0	15	10	60	14	16	10	9	16	13
Denmark	4,3	0	53	28	401	47	52	26	99	52	61
Estonia	1,3	0	14	12	32	11	14	11	19	15	7
Finland	3,5	0	40	18	141	37	41	18	11	42	32
France	3,2	0	90	21	142	55	100	21	-	96	-
Germany	3,3	0	86	18	115	70	93	18	-	90	-
Greece	1,8	0	21	6	90	16	23	6	13	24	27
Hungary	0,9	0	12	7	39	11	12	7	5	12	10
Ireland	3,5	0	45	13	110	63	42	12	50	42	36
Italy	2,7	0	81	12	121	46	99	12	-	94	-
Latvia	0,92	0	34	5	28	22	36	-	-	33	-
Lithuania	1,1	0	27	4	32	19	29	4	-	26	-
Luxembourg	7,2	0	67	47	118	36	73	47	-	76	36
Malta	1,6	0	20	8	-	18	21	7	9	22	7
Netherlands	3,7	0	43	25	565	42	41	25	20	41	31
Norway	7,0	0	81	33	794	56	57	23	66	58	51
Poland	0,98	0	10	3	26	9	12	3	4	12	8
Portugal	1,6	0	17	4	117	15	19	4	20	20	18
Romania	0,7	0	7	2	22	9	9	2	13	9	8
Slovakia	1,4	0	16	15	65	16	16	15	5	16	18
Slovenia	1,7	0	20	5	54	19	22	5	11	22	19
Spain	2,3	0	31	16	177	35	30	15	14	30	26
Sweden	4,3	0	48	25	299	43	48	25	28	48	38
United Kingdom	2,9	0	69	16	151	43	75	-	-	72	-

Table B - 5 NCI by sectors of electricity EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_elec (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	3	0,7	33	8,0	280	57	19	8	9	19	37
Austria	3,4	0,9	27	6	487	65	12	6	0	10	46
Belgium	3,2	0,8	76	12	556	158	36	12	-	34	-
Bulgaria	1,9	0,6	35	1	257	28	23	1	-	22	-
Cyprus	2,1	0,9	15	9	202	14	15	9	10	15	0
Czech Republic	2,5	0,6	20	11	301	27	11	11	15	10	22
Denmark	2,5	0,8	22	69	310	44	13	71	0	13	10
Estonia	2,7	0,7	22	15	245	27	13	15	17	14	4
Finland	6,4	1,9	54	22	517	142	23	23	0	23	14
France	3,0	1,0	58	18	720	81	37	17	-	34	-
Germany	3,0	0,7	58	0	387	90	33	0	-	31	-
Greece	2,3	0,8	18	10	469	37	11	11	0	11	2
Hungary	1,5	0,5	13	5	149	18	10	5	10	10	13
Ireland	2,3	0,8	20	11	217	53	10	11	0	10	1
Italy	2,2	0,5	52	9	349	66	35	9	-	31	-
Latvia	1,5	0,4	40	3	55	59	31	-	-	29	-
Lithuania	1,4	0,4	27	2	161	29	18	2	-	18	-
Luxembourg	5,3	0,8	43	49	684	115	24	49	-	25	18
Malta	2,0	0,7	17	4	-	32	14	3	2	14	0
Netherlands	2,8	0,7	26	79	559	60	14	81	0	14	15
Norway	9,8	3,5	76	61	245	235	33	72	25	35	11
Poland	1,6	0,3	14	1	111	18	9	1	0	10	8
Portugal	1,9	0,6	16	5	268	30	10	5	11	11	6
Romania	1,1	0,3	9	1	101	18	5	1	0	4	7
Slovakia	2,1	0,4	21	8	269	38	10	8	0	9	14
Slovenia	2,8	0,7	25	0	251	51	13	0	0	13	11
Spain	2,2	0,7	21	10	379	45	13	10	0	13	16
Sweden	5,8	1,8	47	14	503	120	22	14	0	21	35
United Kingdom	2,2	0,8	36	21	220	60	22	-	-	21	-

Table B - 6 NCI by sectors of heat EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_heat (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	4	1,7	47	15	612	103	15	16	16	14	64
Austria	6,4	2,0	49	23	671	170	7	23	37	6	34
Belgium	6,2	1,9	133	85	1.686	316	34	85	-	32	-
Bulgaria	2,4	0,7	45	2	144	58	27	2	-	6	-
Cyprus	1,4	0,6	9	4	0	37	3	4	0	3	0
Czech Republic	5,0	1,9	33	19	284	65	12	20	0	11	14
Denmark	3,6	1,4	29	74	1.459	73	4	76	0	4	4
Estonia	3,1	1,8	15	9	79	42	3	9	0	3	0
Finland	7,4	1,4	70	38	1.200	244	3	40	0	2	15
France	3,6	1,6	59	19	591	134	23	18	-	22	-
Germany	5,0	1,8	85	0	661	164	28	0	-	25	-
Greece	2,3	0,7	20	2	884	65	5	2	5	2	50
Hungary	3,6	1,9	23	10	274	35	15	10	6	16	4
Ireland	3,0	1,3	23	0	131	85	8	0	0	8	8
Italy	4,6	2,2	76	4	898	99	42	4	-	31	-
Latvia	4,0	1,9	78	6	35	212	31	-	-	25	-
Lithuania	3,5	1,4	58	6	712	61	22	6	-	9	-
Luxembourg	6,8	2,3	45	61	2	185	17	61	-	18	4
Malta	0,5	0,3	3	0		3	3	0	0	3	0
Netherlands	7,5	2,4	62	248	2.645	140	22	247	313	22	32
Norway	6,6	0,7	68	9	1.392	110	3	11	3	1	24
Poland	4,2	1,9	26	19	161	48	12	19	0	8	58
Portugal	2,4	0,8	19	1	400	67	4	1	3	3	24
Romania	3,1	1,6	19	1	186	46	5	1	0	5	4
Slovakia	5,3	1,1	51	16	507	117	16	16	0	13	67
Slovenia	3,0	1,6	17	2	12	60	2	2	0	1	7
Spain	3,2	0,8	33	22	1.704	99	4	23	0	4	11
Sweden	4,6	0,7	45	45	632	171	3	46	0	2	25
United Kingdom	4,3	2,2	54	23	897	86	20	-	-	20	-

Table B - 7 NCI by sectors of fuel EMRs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

EMR_fuel (MJ/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	3,9	1,9	37	26	17	7,1	48	25	260	3,7	1.224
Austria	5,6	2,8	33	22	4	11	41	22	0	1	827
Belgium	5,9	2,9	94	126	2	12	119	126	-	15	-
Bulgaria	1,7	0,3	37	7	0	1	61	7	-	0	-
Cyprus	6,2	2,2	48	19	56	6	62	20	0	1	1.779
Czech Republic	2,8	1,0	20	43	5	1	29	44	0	0	445
Denmark	5,0	2,4	35	180	27	12	35	140	1.567	1	759
Estonia	3,5	1,7	21	61	34	7	24	64	0	3	236
Finland	5,6	3,0	33	65	46	22	33	62	129	4	458
France	4,4	2,0	72	75	17	6	87	67	-	7	-
Germany	4,8	2,8	53	0	6	5	78	0	-	17	-
Greece	3,5	2,6	14	1	19	9	16	0	24	0	279
Hungary	2,0	0,7	17	16	4	3	23	16	0	0	383
Ireland	6,0	3,0	42	45	55	14	48	46	0	7	888
Italy	3,3	2,1	39	38	7	6	52	35	-	1	-
Latvia	2,9	1,2	62	20	10	18	71		-	5	-
Lithuania	2,3	1,4	25	6	6	3	35	6	-	0	-
Luxembourg	25,7	3,4	212	256	0	6	254	256	-	7	3.980
Malta	3,4	1,0	32	17	-	4	39	17	0	1	992
Netherlands	4,4	2,0	30	54	8	9	34	41	856	0	787
Norway	6,1	1,9	51	218	95	21	48	60	736	3	617
Poland	2,2	1,1	13	19	4	2	17	19	0	1	205
Portugal	3,1	1,3	22	17	31	4	29	13	128	1	700
Romania	1,4	0,5	11	3	8	3	21	3	0	0	224
Slovakia	1,9	1,1	10	21	7	1	14	21	0	0	251
Slovenia	5,3	2,5	36	19	5	6	52	19	0	5	838
Spain	3,9	1,3	36	46	12	6	43	48	21	2	941
Sweden	4,4	2,3	26	25	12	7	31	21	336	2	581
United Kingdom	4,3	1,8	62	10	62	24	74	-	-	1	-

Table B - 8 NCI by sectors of EJPs tables for level n, n-1, n-2 and n-3 of EU27+N year 2012

ELP (€/h) 2012	AS	HH	PW	AF	EM	MC	SG	AFO	FI	SG_nTS	TS
EU27+N	2,6	0	46	9,3	122	36	50	9,3	36	41	17
Austria	3,8	0	40	9,8	119	45	40	9,8	28	41	31
Belgium	3,4	0	104	20	201	73	112	20	-	109	-
Bulgaria	0,5	0	14	2,9	23	7,8	17	2,9	-	16	-
Cyprus	2,1	0	24	7,5	97	15	27	7,4	13	28	15
Czech Republic	1,5	0	15	10	60	14	16	10	9	16	13
Denmark	4,3	0	53	28	401	47	52	29	99	52	61
Estonia	1,3	0	14	12	32	11	14	11	19	15	7,5
Finland	3,5	0	40	18	141	37	41	18	11	42	32
France	3,2	0	90	22	142	55	100	21	-	96	-
Germany	3,3	0	86	18	115	70	93	18	-	90	-
Greece	1,8	0	21	6,1	90	16	23	5,7	13	24	27
Hungary	0,9	0	12	7,3	39	11	12	7,3	5	12	10
Ireland	3,5	0	45	13	110	63	42	12	50	42	36
Italy	2,7	0	81	12	121	46	99	12	-	94	-
Latvia	0,9	0	34	4,7	28	22	36	-	-	33	-
Lithuania	1,1	0	27	3,7	32	19	29	3,6	-	26	-
Luxembourg	7,2	0	67	47	118	36	73	47	-	76	36
Malta	1,6	0	20	9,7	-	18	21	7,4	9,4	22	7,2
Netherlands	3,7	0	43	25	565	42	41	25	20	41	31
Norway	7,0	0	81	33	794	56	57	23	66	58	51
Poland	1,0	0	10	3,4	26	9	12	3,4	4,3	12	7,9
Portugal	1,6	0	17	4,3	117	15	19	4,0	20	20	18
Romania	0,7	0	7,3	1,6	22	9,3	9	1,6	13	9	8,5
Slovakia	1,4	0	16	15	65	16	16	15	5,1	16	18
Slovenia	1,7	0	20	5,4	54	19	22	5,4	11	22	19
Spain	2,3	0	31	16	177	35	30	15	14	30	26
Sweden	4,3	0	48	25	299	43	48	25	28	48	38
United Kingdom	2,9	0	69	16	151	43	75	-	-	72	-

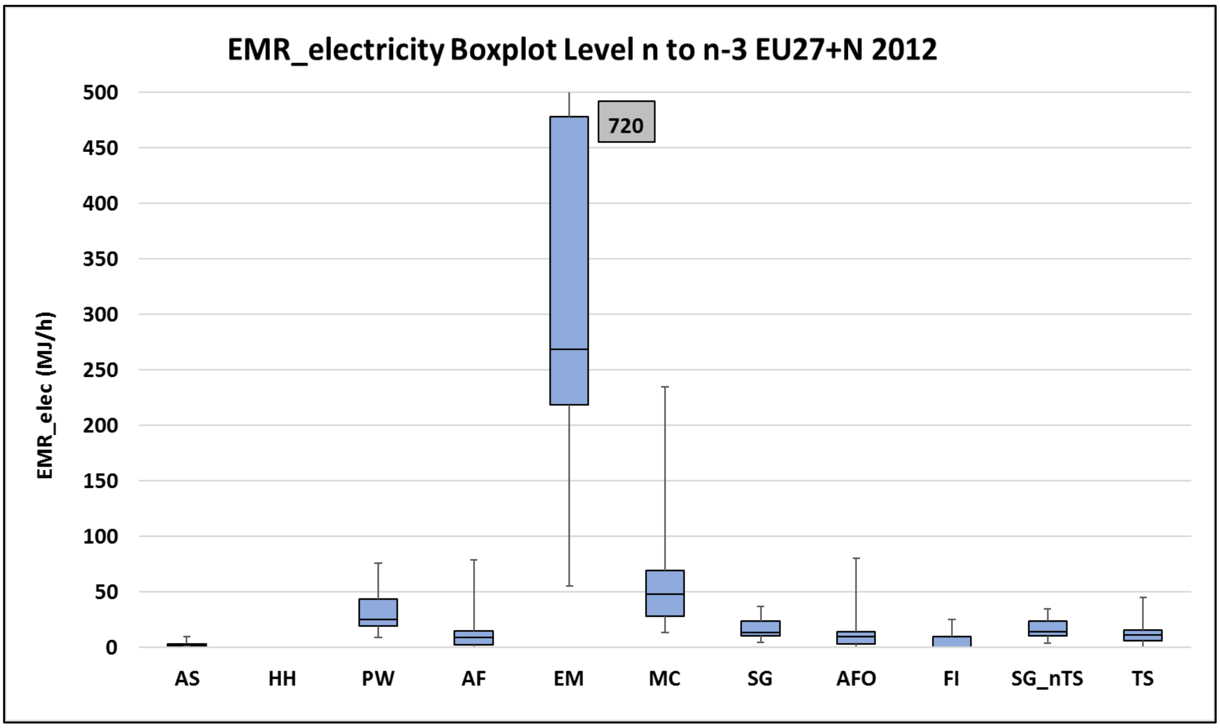

Figure B - 1 Boxplot by sectors for electricity EMRs for level n, n-1, n-2 and n-3 of EU27+N year 2012

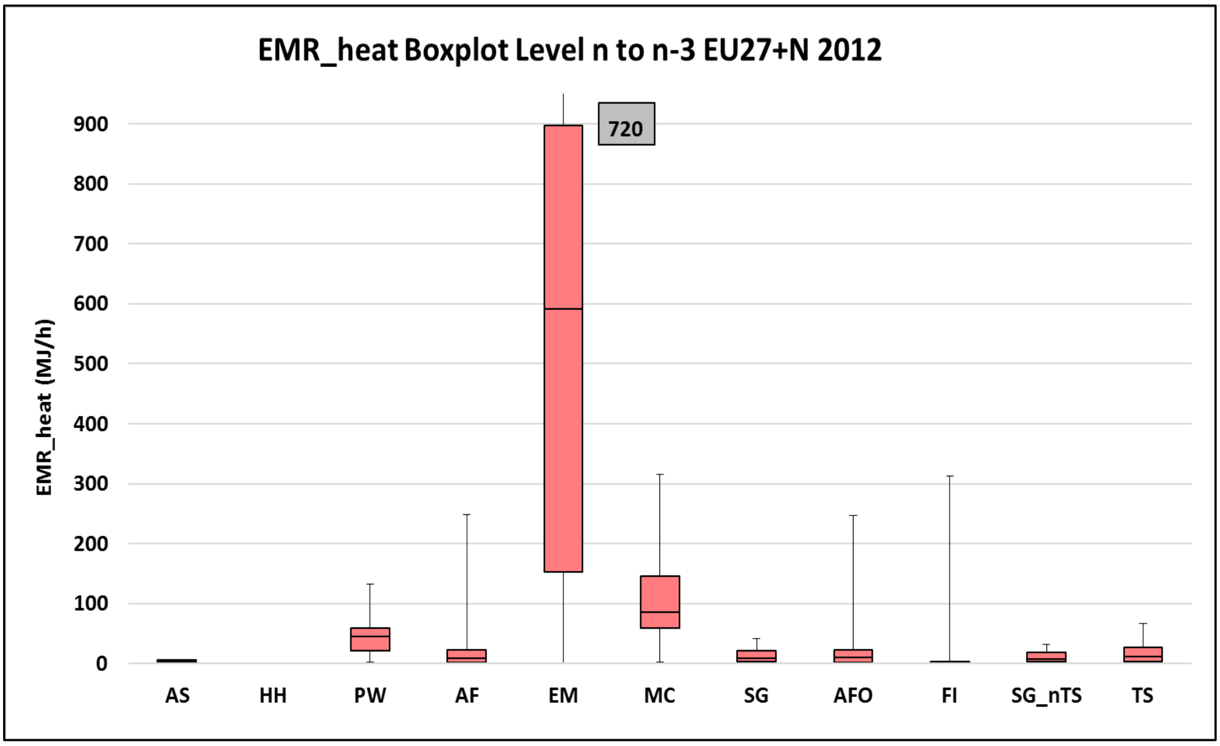

Figure B - 2 Boxplot by sectors for heat EMRs for level n, n-1, n-2 and n-3 of EU27+N year 2012

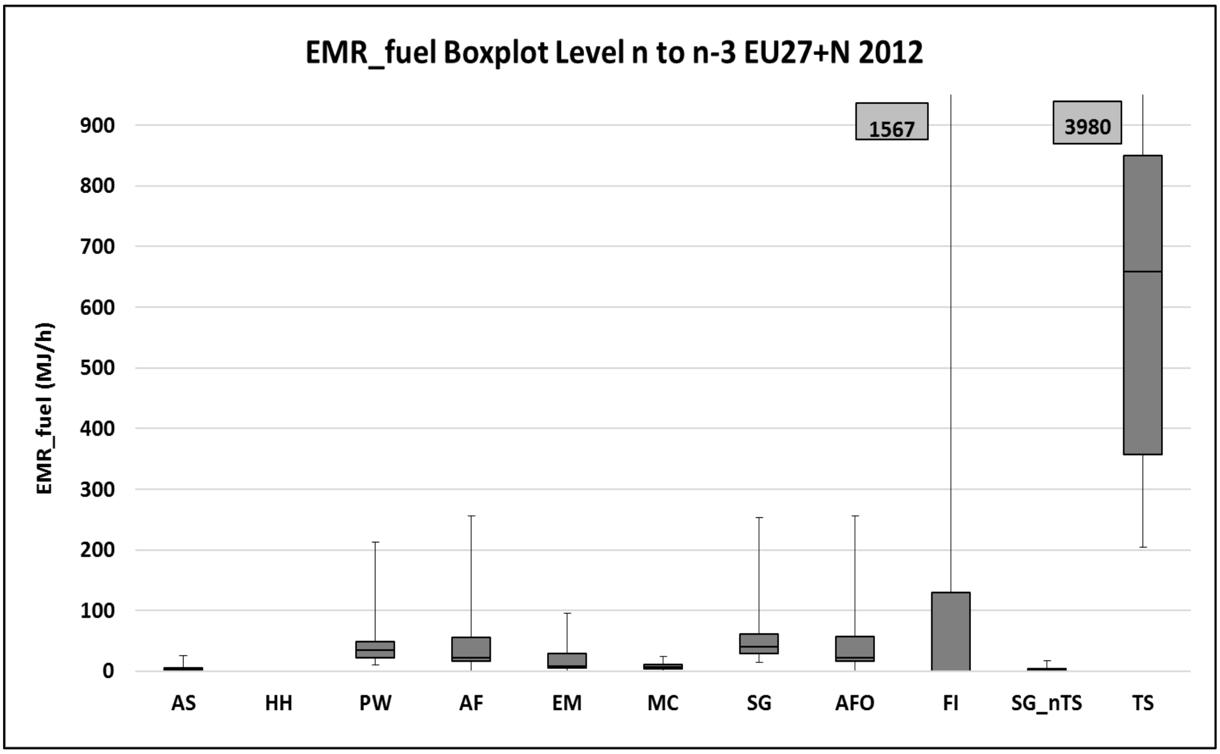

Figure B - 3 Boxplot by sectors for fuel EMRs for level n, n-1, n-2 and n-3 of EU27+N year 2012

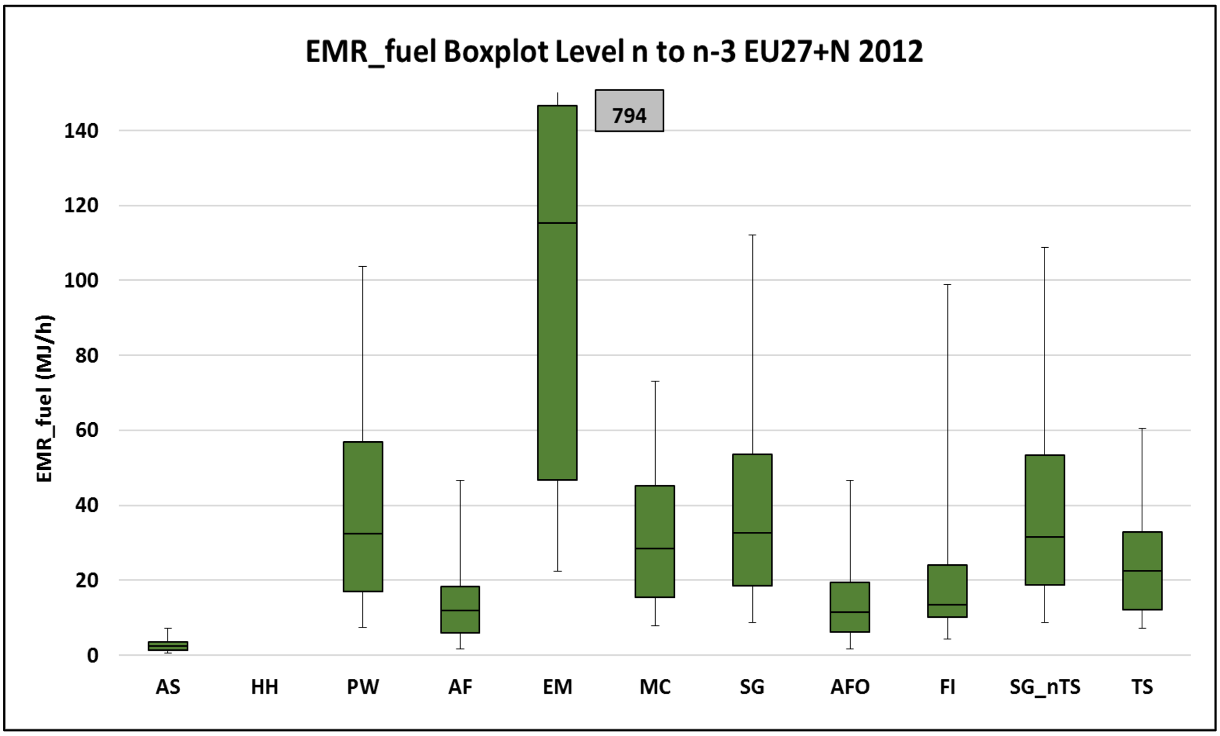

Figure B - 4 Boxplot by sectors for EJP for level n, n-1, n-2 and n-3 of EU27+N year 2012

Table B - 9 NCI by country Electricity, heat and fuel EMRs and EJP patterns for level n, n-1 of EU27+N year 2012

	Average Society				Household			Paid Work			
2012	EMR_elec (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)	EMR_elec (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EMR_elec (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)
EU27+N	2,6	4,3	3,9	2,6	0,7	1,7	1,9	33	47	37	46
Austria	3,4	6,4	5,6	3,8	0,9	2,0	2,8	27	49	33	40
Belgium	3,2	6,2	5,9	3,4	0,8	1,9	2,9	76	133	94	104
Bulgaria	1,9	2,4	1,7	0,5	0,6	0,7	0,3	35	45	37	14
Cyprus	2,1	1,4	6,2	2,1	0,9	0,6	2,2	15	9,2	48	24
Czech Republic	2,5	5,0	2,8	1,5	0,6	1,9	1,0	20	33	20	15
Denmark	2,5	3,6	5,0	4,3	0,8	1,4	2,4	22	29	35	53
Estonia	2,7	3,1	3,5	1,3	0,7	1,8	1,7	22	15	21	14
Finland	6,4	7,4	5,6	3,5	1,9	1,4	3,0	54	70	33	40
France	3,0	3,6	4,4	3,2	1,0	1,6	2,0	58	59	72	90
Germany	3,0	5,0	4,8	3,3	0,7	1,8	2,8	58	85	53	86
Greece	2,3	2,3	3,5	1,8	0,8	0,7	2,6	18	20	14	21
Hungary	1,5	3,6	2,0	0,9	0,5	1,9	0,7	13	23	17	12
Ireland	2,3	3,0	6,0	3,5	0,8	1,3	3,0	20	23	42	45
Italy	2,2	4,6	3,3	2,7	0,5	2,2	2,1	52	76	39	81
Latvia	1,5	4,0	2,9	0,9	0,4	1,9	1,2	40	78	62	34
Lithuania	1,4	3,5	2,3	1,1	0,4	1,4	1,4	27	58	25	27
Luxembourg	5,3	6,8	26	7,2	0,8	2,3	3,4	43	45	212	67
Malta	2,0	0,5	3,4	1,6	0,7	0,3	1,0	17	2,6	32	20
Netherlands	2,8	7,5	4,4	3,7	0,7	2,4	2,0	26	62	30	43
Norway	9,8	6,6	6,1	7,0	3,5	0,7	1,9	76	68	51	81
Poland	1,6	4,2	2,2	1,0	0,3	1,9	1,1	14	26	13	10
Portugal	1,9	2,4	3,1	1,6	0,6	0,8	1,3	16	19	22	17
Romania	1,1	3,1	1,4	0,7	0,3	1,6	0,5	9,3	19	11	7,3
Slovakia	2,1	5,3	1,9	1,4	0,4	1,1	1,1	21	51	10	16
Slovenia	2,8	3,0	5,3	1,7	0,7	1,6	2,5	25	17	36	20
Spain	2,2	3,2	3,9	2,3	0,7	0,8	1,3	21	33	36	31
Sweden	5,8	4,6	4,4	4,3	1,8	0,7	2,3	47	45	26	48
United Kingdom	2,2	4,3	4,3	2,9	0,8	2,2	1,8	36	54	62	69

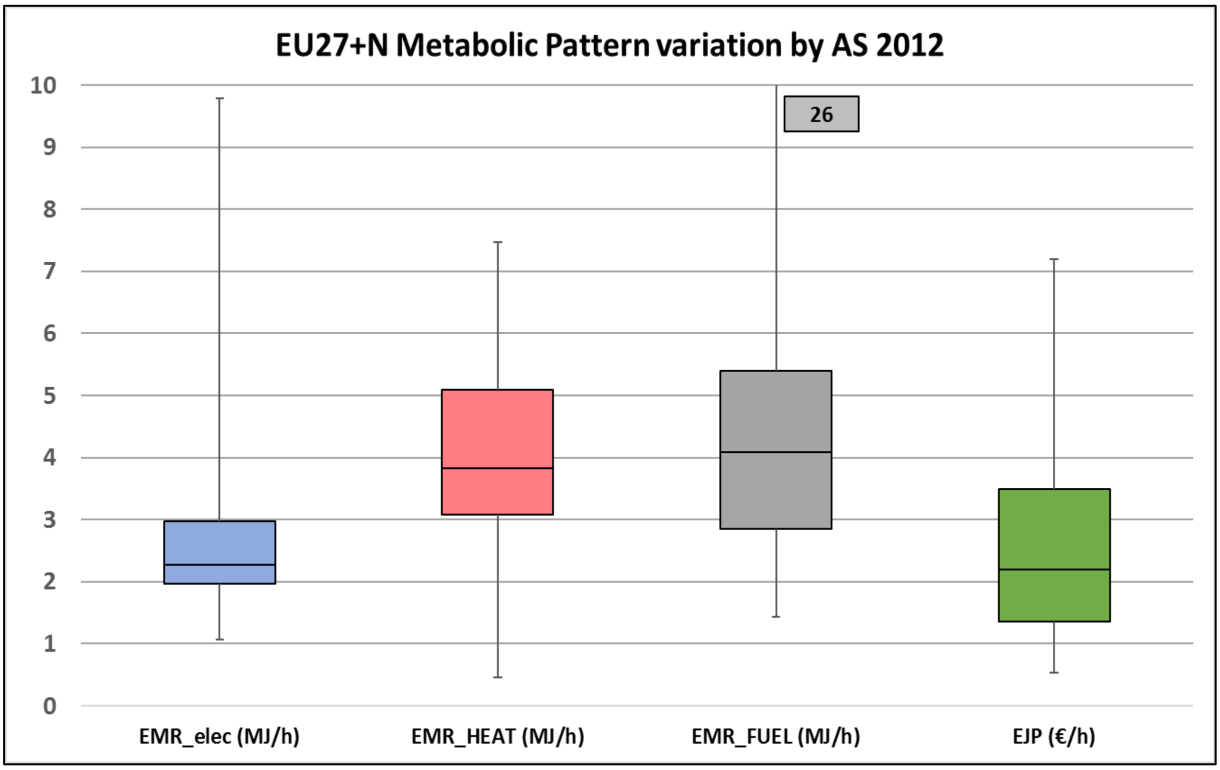

Figure B - 5 Boxplot mapping the benchmarks of EMRs and EJP of EU27+Norway for year 2012 at the level of the Average Society

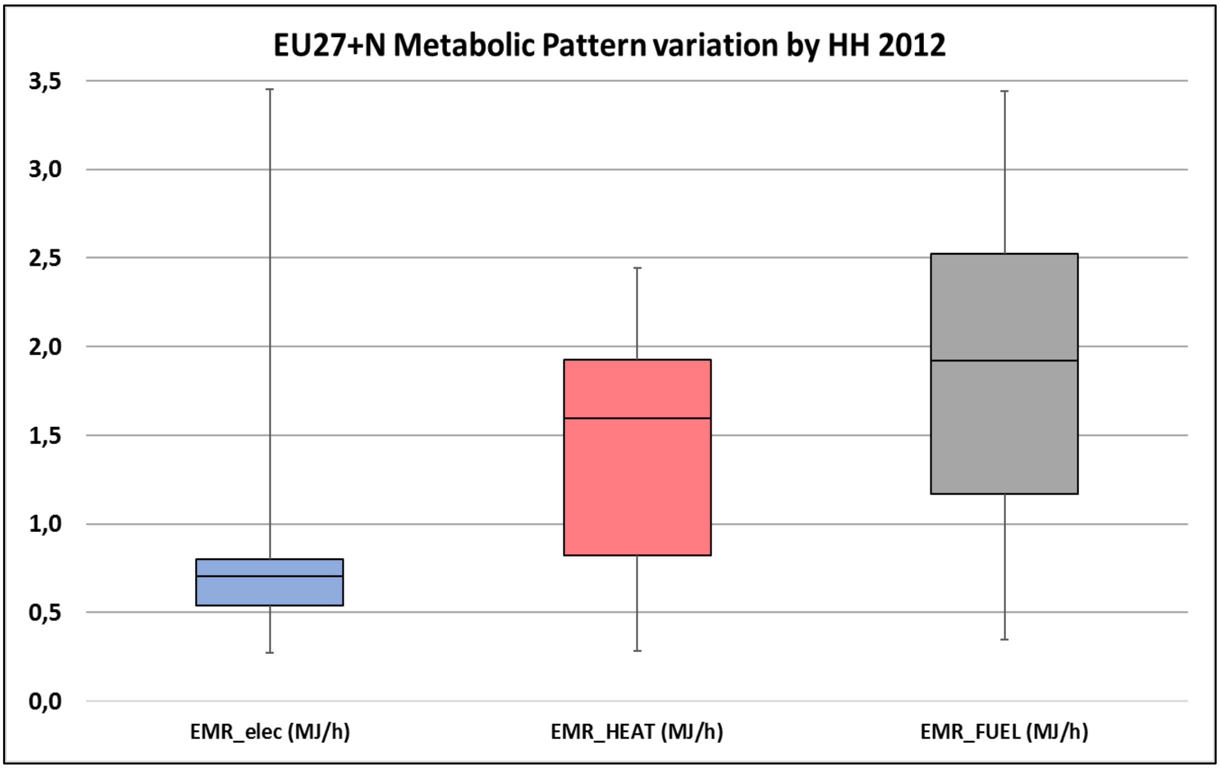

Figure B - 6 Boxplot mapping the benchmarks of EMRs of EU27+Norway for year 2012 at the level of Households

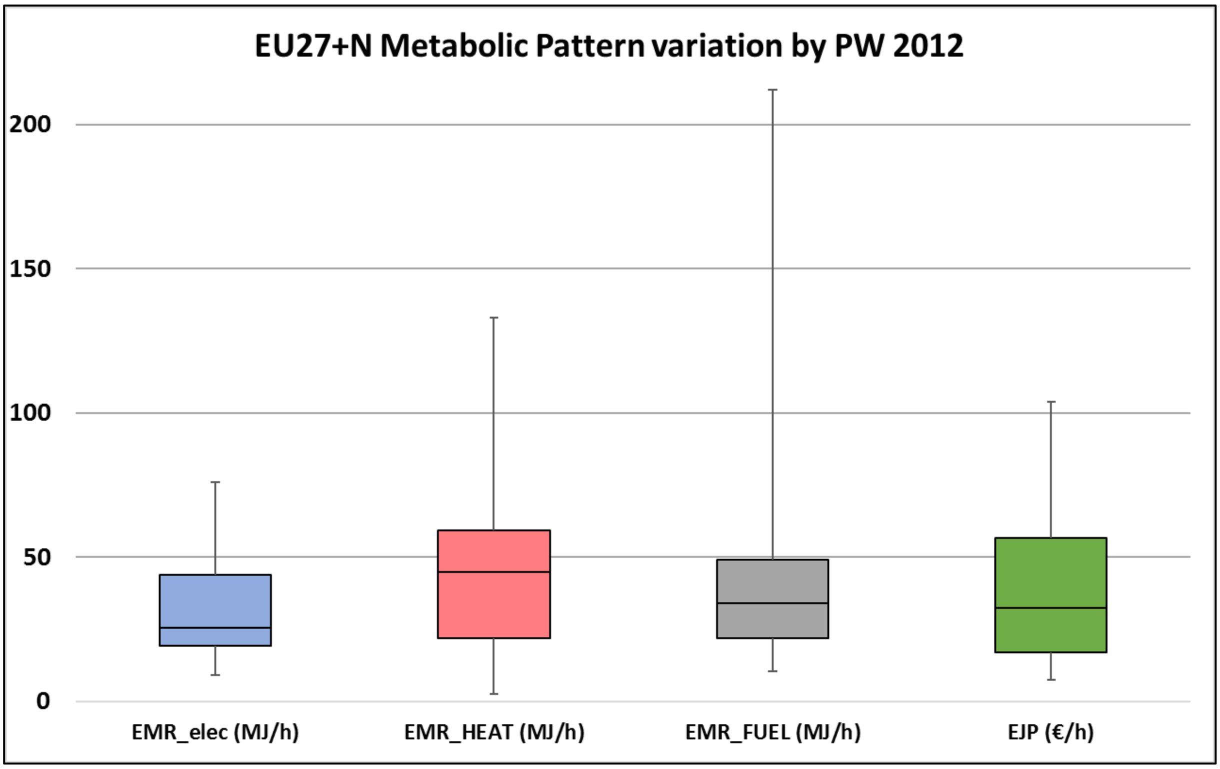

Figure B - 7 Boxplot mapping the benchmarks of EMRs and EJP of EU27+Norway for year 2012 at the level of the Paid Work sector

Table B - 10 Metabolic Structural tables for Paid Work sector and subsectors of EU27+N using Nama database, year 2012

2012	Paid Work	AFO	FI	EM	SG_nTS	TS	IS_NF	CP	NM	FT	TL	PPP	TE	MA	WWP	CO	NS	EMR_ELEC (MJ/h)	EMR_HEAT (MJ/h)	EMR_FUEL (MJ/h)	EJP (€/h)	HA_i/HA_PW
EU27+N	255	21	0,37	3,9	166	6,3	0,90	2,9	1,2	8,3	4,2	1,1	2,3	12	1,2	27	3,1	33	47	37	46	
Austria	6,9	6,5%	0,01%	0,9%	68%	3,5%	0,8%	0,7%	0,8%	1,8%	0,5%	0,7%	0,9%	5,2%	0,8%	7,3%	1,8%	27	49	33	40	2,7%
Belgium	3,2	3,9%	-	1,3%	72%	-	-	3,4%	-	4,6%	1,2%	-	-	3,2%	-	14%	-	76	133	94	104	1,3%
Bulgaria	2,4	32%	0,1%	4,2%	56%	-	-	1,6%	-	8,6%	11%	-	-	4,9%	-	14%	-	35	45	37	14	0,9%
Cyprus	0,67	7,9%	0,2%	0,6%	71%	2,5%	0,1%	0,6%	0,7%	3,4%	0,3%	0,5%	0,1%	1,5%	0,7%	9,3%	0,9%	15	9	48	24	0,3%
Czech Republic	9,0	3,5%	0,03%	1,3%	58%	4,0%	0,8%	0,8%	1,1%	2,5%	1,2%	0,9%	3,4%	9,0%	1,3%	9,4%	3,2%	20	33	20	15	3,5%
Denmark	3,9	2,7%	0,08%	0,7%	75%	3,6%	0,2%	1,2%	0,5%	1,9%	0,2%	0,5%	0,3%	4,6%	0,3%	6,9%	1,2%	22	29	35	53	1,5%
Estonia	1,1	4,7%	0,2%	2,5%	60%	6,0%	-	0,6%	0,7%	2,3%	2,4%	0,8%	0,9%	5,2%	2,7%	8,4%	2,4%	22	15	21	14	0,4%
Finland	4,2	6,0%	0,3%	0,9%	66%	4,5%	0,5%	0,6%	0,6%	1,4%	0,4%	1,2%	0,5%	5,6%	0,9%	9,4%	1,1%	54	70	33	40	1,6%
France	20	8,3%	0,2%	1,2%	74%	-	-	1,2%	-	4,8%	0,9%	-	-	2,5%	-	16%	-	58	59	72	90	7,9%
Germany	27	4,1%	0,04%	1,9%	65%	-	-	2,5%	-	4,7%	0,8%	-	-	10%	-	14%	-	58	85	53	86	11%
Greece	8,3	11,2%	0,6%	0,8%	70%	4,2%	0,4%	0,6%	0,5%	2,6%	0,9%	0,5%	0,2%	1,5%	0,4%	4,6%	1,1%	18	20	14	21	3,3%
Hungary	7,0	7,6%	0,04%	1,3%	62%	3,8%	0,6%	1,1%	0,7%	3,0%	1,5%	0,7%	2,4%	6,2%	0,6%	6,5%	2,3%	13	23	17	12	2,7%
Ireland	3,2	5,7%	0,1%	1,0%	71%	3,5%	0,3%	1,5%	0,5%	2,6%	0,2%	0,6%	0,3%	2,8%	0,2%	6,8%	2,3%	20	23	42	45	1,2%
Italy	17	13%	0,3%	1,4%	61%	-	-	1,9%	-	4,8%	5,0%	-	-	7,4%	-	19%	-	52	76	39	81	6,8%
Latvia	0,49	43%	0,5%	6,1%	69%	-	-	-	-	-	-	-	-	-	-	24%	-	40	78	62	34	0,2%
Lithuania	1,0	31%	0,2%	3,0%	62%	-	-	1,0%	-	8,6%	5,7%	-	-	2,6%	-	17%	-	27	58	25	27	0,4%
Luxembourg	0,49	0,6%	-	0,5%	78%	5,1%	-	0,3%	-	1,7%	0,5%	-	-	-	0,2%	14%	-	43	45	212	67	0,2%
Malta	0,29	3,4%	0,8%	-	76%	3,0%	0,02%	0,2%	-	2,3%	0,5%	1,1%	-	0,9%	0,2%	7,2%	2,6%	17	3	32	20	0,1%
Netherlands	12	2,9%	0,05%	0,5%	76%	3,4%	0,3%	0,8%	0,3%	1,6%	0,2%	0,6%	0,5%	2,9%	0,2%	7,3%	2,1%	26	62	30	43	4,9%
Norway	3,8	2,5%	0,8%	3,3%	70%	5,6%	0,4%	-	0,5%	2,1%	0,2%	0,4%	1,2%	2,8%	0,6%	8,5%	0,6%	76	68	51	81	1,5%
Poland	32	12%	0,04%	2,9%	53%	4,7%	0,7%	0,9%	1,1%	3,3%	1,6%	0,8%	1,8%	4,1%	1,1%	8,6%	2,9%	14	26	13	10	12%
Portugal	8,3	8,9%	0,3%	0,5%	65%	2,7%	0,2%	0,4%	0,9%	2,4%	4,4%	0,6%	0,8%	2,7%	0,8%	7,4%	1,6%	16	19	22	17	3,3%
Romania	16	26%	0,02%	2,3%	42%	4,2%	0,8%	0,5%	0,7%	2,4%	4,6%	0,2%	2,1%	3,5%	1,0%	7,9%	2,0%	9,3	19	11	7,3	6,1%
Slovakia	4,0	3,4%	0,01%	1,2%	63%	3,7%	1,0%	0,5%	0,9%	2,0%	1,7%	0,7%	2,9%	7,0%	1,3%	8,5%	2,4%	21	51	10	16	1,6%
Slovenia	1,5	9,9%	0,03%	1,2%	59%	3,5%	0,8%	1,4%	0,8%	1,7%	1,3%	0,9%	1,5%	7,3%	1,0%	7,4%	2,4%	25	17	36	20	0,6%
Spain	30	4,5%	0,3%	0,6%	73%	3,3%	0,5%	0,8%	0,6%	2,8%	0,9%	0,7%	1,0%	2,8%	0,4%	7,1%	1,2%	21	33	36	31	12%
Sweden	7,3	3,0%	0,04%	1,0%	72%	3,8%	0,7%	0,4%	0,5%	1,3%	0,2%	1,2%	1,7%	5,3%	0,8%	7,4%	1,2%	47	45	26	48	2,9%
United Kingdom	23	2,8%	0,09%	1,9%	73%	-	-	1,3%	-	3,2%	0,8%	-	-	3,4%	-	17%	-	36	54	62	69	9,0%
EMR_ELEC (MJ/h)	33	8	5	280	19	13	420	230	82	49	19	233	25	36	41	2	31					
EMR_HEAT (MJ/h)	47	15	10	612	14	28	811	350	421	82	24	529	15	25	101	4	27					
EMR_FUEL (MJ/h)	37	24	182	17	4	523	7	16	11	5	2	3	2	3	3	4	7					
EJP (€/h)	46	9	36	122	50	21	24	68	23	29	15	28	23	45	14	25	18					
HA_i/HA_PW		8,3%	0,1%	1,5%	65%	2,5%	0,4%	1,1%	0,5%	3,2%	1,6%	0,4%	0,9%	4,7%	0,5%	11%	1,2%					

Table B - 11 Metabolic Structural tables for Manufacturing and Construction sector and subsectors of EU27+N using Nama database, year 2012

2012	MC	IS_NF	CP	NM	FT	TL	PPP	TE	MA	WWP	CO	NS					
EU27+N	65	0,9	2,9	1,2	8,3	4,2	1,1	2,3	12	1,2	27	3,1	57	103	7,1	36	
Austria	1,5	3,8%	3,4%	3,6%	9%	2,2%	3,4%	4,3%	24%	3,9%	34%	8,5%	65	170	11	45	2,3%
Belgium	0,8	-	13%	-	18%	4,4%	-	-	12%	-	53%	-	158	316	12	73	1,3%
Bulgaria	0,9	-	4,0%	-	21%	28%	-	-	12%	-	35%	-	28	58	1,3	7,8	1,5%
Cyprus	0,1	0,4%	3,1%	3,6%	19%	1,8%	2,7%	0,4%	8,4%	4,0%	52%	5,0%	14	37	5,7	15	0,2%
Czech Republic	3,0	2,5%	2,4%	3,3%	8%	3,5%	2,7%	10%	27%	3,8%	28%	9,4%	27	65	0,9	14	4,7%
Denmark	0,7	1,0%	7,0%	2,8%	11%	1,1%	2,7%	1,4%	26%	1,8%	39%	6,8%	44	73	12	47	1,1%
Estonia	0,3	-	2,4%	2,7%	9%	9,1%	3,1%	3,2%	20%	10%	32%	9,0%	27	42	6,6	11	0,5%
Finland	0,9	2,4%	2,8%	2,7%	6%	1,9%	5,2%	2,4%	25%	4,2%	42%	5,1%	142	244	22	37	1,4%
France	5,1	-	4,8%	-	19%	3,4%	-	-	10%	-	63%	-	81	134	6,1	55	7,8%
Germany	9,0	-	7,6%	-	14%	2,5%	-	-	32%	-	44%	-	90	164	5,4	70	14%
Greece	1,1	3,1%	4,4%	3,8%	20%	6,6%	3,5%	1,7%	11%	3,0%	35%	8,1%	37	65	9,1	16	1,7%
Hungary	1,8	2,2%	4,3%	2,5%	12%	5,9%	2,8%	9,4%	24%	2,2%	26%	8,9%	18	35	2,5	11	2,8%
Ireland	0,6	1,5%	8,0%	3,0%	14%	1,3%	3,5%	1,8%	15%	1,3%	37%	13%	53	85	14	63	0,9%
Italy	6,5	-	4,9%	-	13%	13%	-	-	20%	-	49%	-	66	99	5,7	46	10%
Latvia	0,1	-	-	-	-	-	-	-	-	-	100%	-	59	212	18	22	0,2%
Lithuania	0,4	-	3,0%	-	24%	16%	-	-	7,4%	-	49%	-	29	61	2,9	19	0,6%
Luxembourg	0,08	-	1,8%	-	10%	2,9%	-	-	-	1,2%	84%	-	115	185	5,8	36	0,1%
Malta	0,04	0,1%	1,2%	-	15%		7,6%	-	5,9%	1,4%	48%	17%	32	2,9	3,9	18	0,1%
Netherlands	2,1	1,7%	4,6%	2,0%	9%	1,3%	3,4%	3,0%	17%	1,1%	44%	13%	60	140	8,6	42	3,2%
Norway	0,7	2,3%	-	2,6%	12%	1,0%	2,5%	7,1%	16%	3,4%	49%	3,3%	235	110	21	56	1,0%
Poland	8,5	2,5%	3,3%	4,1%	12%	5,9%	3,2%	6,7%	15%	4,0%	32%	11%	18	48	1,6	9,2	13%
Portugal	1,8	0,8%	1,8%	4,3%	11%	20%	2,7%	3,5%	12%	3,6%	33%	7,3%	30	67	3,7	15	2,8%
Romania	4,0	3,0%	2,0%	2,8%	9%	18%	0,8%	8,1%	14%	3,8%	31%	7,8%	18	46	3,1	9,3	6,2%
Slovakia	1,1	3,4%	1,8%	3,0%	7%	5,9%	2,3%	10%	24%	4,4%	30%	8,4%	38	117	0,7	16	1,8%
Slovenia	0,4	2,9%	5,4%	3,0%	6%	5,0%	3,5%	5,4%	28%	3,8%	28%	9,1%	51	60	5,5	19	0,6%
Spain	5,7	2,6%	4,5%	3,1%	15%	4,8%	3,7%	5,5%	15%	1,9%	38%	6,7%	45	99	6,2	35	8,8%
Sweden	1,5	3,5%	2,0%	2,4%	6%	0,9%	5,6%	8,4%	25%	4,0%	36%	5,9%	120	171	6,5	43	2,3%
United Kingdom	5,8	-	5,0%	-	13%	3,28%	-	-	13%	-	66%	-	60	86	24	43	9,0%
	57	420	230	82	49	19	233	25	36	41	2,1	31	EMR_ELEC				
	103	811	350	421	82	24	529	15	25	101	3,7	27		EMR_HEAT			
	7,1	7,0	16	11	4,6	1,8	2,7	2,2	2,7	2,6	4,4	6,8			EMR_FUEL		
	36	24	68	23	29	15	28	23	45	14	25	18				EJP (€/h)	
		1,4%	4,5%	1,8%	13%	6,5%	1,7%	3,5%	19%	1,8%	43%	4,8%					HA_i/HA_MC

Table B - 12 Metabolic Structural tables for Agriculture, Forestry & Fishing sector and subsectors of EU27+N using Nama database, year 2012

2012	AF	AFO	FI					
EU27+N	21	21	0,4	8,0	15	26	9,2	
Austria	0,5	99,8%	0,2%	6,3	23	22	9,8	2,1%
Belgium	0,1	100%	-	12	85	126	20	0,6%
Bulgaria	0,7	99,7%	0,3%	1,3	1,9	7,5	2,9	3,5%
Cyprus	0,05	98%	2,1%	8,6	4,2	19	7,5	0,3%
Czech Republic	0,3	99%	0,9%	11	19	43	10	1,5%
Denmark	0,1	97%	2,8%	69	74	180	28	0,5%
Estonia	0,05	96%	3,6%	15	9,0	61	12	0,3%
Finland	0,3	95%	4,5%	22	38	65	18	1,2%
France	1,7	98%	2,2%	17	18	74	21	7,9%
Germany	1,1	99%	0,9%	-	-	-	18	5,3%
Greece	1,0	95%	4,7%	10	2,3	1,2	6,1	4,6%
Hungary	0,5	99,5%	0,5%	5,3	9,8	16	7,3	2,5%
Ireland	0,2	98%	2%	11	-	45	13	0,9%
Italy	2,4	98%	2,4%	9,0	4,1	37	12	11%
Latvia	0,2	99%	1,2%	2,5	5,6	20	4,6	1,0%
Lithuania	0,3	99%	0,7%	2,0	5,5	6,1	3,6	1,5%
Luxembourg	0,003	100%	-	49	61	256	47	0,0%
Malta	0,01	80%	20%	2,9	-	14	7,8	0,1%
Netherlands	0,4	98%	2%	79	248	54	25	1,7%
Norway	0,1	77%	23%	61	9,3	218	33	0,6%
Poland	3,9	99,7%	0%	1,5	19	19	3,4	18%
Portugal	0,8	96%	3,6%	4,7	1,0	17	4,3	3,6%
Romania	4,1	99,9%	0,1%	0,7	0,9	3,2	1,6	19%
Slovakia	0,1	99,8%	0,2%	7,7	16	21	15	0,6%
Slovenia	0,2	99,7%	0,3%	-	2,0	19	5,4	0,7%
Spain	1,5	95%	5,4%	9,9	22	46	16	6,8%
Sweden	0,2	99%	1,3%	14	45	25	25	1,1%
United Kingdom	0,7	97%	2,9%	21	22	10	16	3,1%
	8,0	7,6	5,2	EMR_ELEC (MJ/h)				
	15	15	10		EMR_HEAT (MJ/h)			
	26	24	182			EMR_FUEL (MJ/h)		
	9,2	9,3	36				EJP (€/h)	
		98%	2,1%					HA_i/HA_AF

Table B - 13 Metabolic Structural tables for Service and Government sector and subsectors of EU27+N using Nama database, year 2012

2012	**SG**	**SG_nTS**	**TS**					
EU27+N	172	166	6,3	19	15	48	50	
Austria	4,9	95%	4,9%	12	7,4	41	40	2,9%
Belgium	2,3	100%	-	36	34	119	112	1,4%
Bulgaria	1,3	100%	-	23	27	61	17	0,8%
Cyprus	0,5	97%	3,4%	15	2,9	62	27	0,3%
Czech Republic	5,5	93%	6,6%	11	12	29	16	3,2%
Denmark	3,1	95%	4,5%	13	3,6	35	52	1,8%
Estonia	0,7	91%	9,0%	13	3,0	24	14	0,4%
Finland	2,9	94%	6,4%	23	3,2	33	41	1,7%
France	15	100%	-	37	23	87	100	8,6%
Germany	18	100%	-	33	28	78	93	10%
Greece	6,2	94%	5,7%	11	4,8	16	23	3,6%
Hungary	4,6	94%	5,9%	9,9	15	23	12	2,6%
Ireland	2,4	95%	4,7%	9,6	7,9	48	42	1,4%
Italy	11	100%	-	35	42	52	99	6,1%
Latvia	0,3	100%	-	31	31	71	36	0,2%
Lithuania	0,6	100%	-	18	22	35	29	0,4%
Luxembourg	0,4	94%	6,2%	24	17	254	73	0,2%
Malta	0,2	96%	3,8%	14	2,8	39	21	0,1%
Netherlands	10	96%	4,2%	14	22	34	41	5,8%
Norway	2,9	93%	7,4%	33	2,8	48	57	1,7%
Poland	18	92%	8,0%	9,4	12	17	12	11%
Portugal	5,7	96%	4,0%	10	3,6	29	19	3,3%
Romania	7,2	91%	9,2%	4,6	5,0	21	8,8	4,2%
Slovakia	2,6	94%	5,6%	9,6	16	14	16	1,5%
Slovenia	1,0	94%	5,7%	13	1,5	52	22	0,6%
Spain	23	96%	4,4%	13	4,0	43	30	13%
Sweden	5,5	95%	5,0%	22	2,9	31	48	3,2%
United Kingdom	17	100%	-	22	20	74	75	9,7%
	19	19	13	**EMR_ELEC (MJ/h)**				
	15	14	28		**EMR_HEAT (MJ/h)**			
	48	3,7	523			**EMR_FUEL (MJ/h)**		
	50	50	21				**EJP (€/h)**	
		97%	3,4%					**HA_i/HA_SG**

APPENDIX C Curriculum Vitae

Raúl Velasco-Fernández

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Brief bio

My research focuses on the study of the Societal Metabolism within the framework of Ecological Economics from a biophysical and multiscale approach, applying concepts of thermodynamics and complex systems theory. I have experience in the field of cooperation and education for sustainable development at local and international level with Enginyeria Sense Fronteres. Master's in Environmental Studies major in Ecological Economics and Environmental Management at the Autonomous University of Barcelona (UAB, 2012), BA in Sociology from the University of Barcelona (UB, 2012) and Industrial Engineering from the Polytechnic University of Catalonia (UPC, 2008). I'm currently in my last year of PhD in Environmental Science and Technology at the Institute of Environmental Science and Technology (ICTA) at UAB within the IASTE research group (Integrated Assessment: Sociology, Technology and the Environment) and working in the EUFORIE project funded by the Horizon2020 program of the European Commission.

ACTUAL POSITION

- April 2013 – present: **PhD candidate** at Institute for Environmental Science and Technology (ICTA), Universitat Autònoma de Barcelona. *New perspectives on Societal Metabolism Analysis, Advances in Methodological Tools in MuSIASEM.* FPU Scholarship from Spanish Government. Supervisors: Mario Giampietro and Jesús Ramos-Martín.

- July 2015 – present: ***EUFORIE – European Futures for Energy Efficiency, European project Horizon2020*** *funded by European Commission.* Development of the Workpackage 4, study of the efficiency of the energy metabolic rate of industrial sectors of EU. *Partners: University of Turku, Turku School of Economics, Finland Futures Research Centre (Lead partner);Parthenope University of Naples, Department of Sciences and Technologies; Autonomous University of Barcelona, The Institute of Environmental Science and Technology; Sustainable Europe Research Institute Germany.*

ACADEMIC EDUCATION

- Jan 2011 – June 2012: **Master in Environmental Studies, Ecological Economics and Environmental Management** specialised approaches (60 ECTS). **Universitat Autònoma de Bellaterra**. Topic of the dissertation: *China and Indian social metabolism pattern (2009-2011): An application of multi-scale integrated analysis of societal metabolism (MuSIASM).* Supervisors: Mario Giampietro and Jesús Ramos.
- Nov 2008 – Feb 2012: **Sociology degree** (300 ECTS) at **Universitat de Barcelona**. 87 ECTS with Honours and 84 with excellent calcification. Average Mark 8,7/10.
- Sep 2001 – Oct 2008: **Industrial Engineering** degree (375 ECTS) at Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB), **Universitat Politècnica de Catalunya (UPC)**. Last course realized in **Universität Stuttgart**, Umweltschutztechnik programme **with ERASMUS** scholarship. Project realized with collaboration of GREDCH (Research Group on Cooperation and Human Development): *Energy for Sustainable Development: Off-grid system combining water and energy supply to avoid the use of lead-acid batteries.*

Complementary education:

- July 2016: ***The Nexus between Food, Energy, Water and Land-use: Quantitative Storytelling with MuSIASEM*** 2016 Edition LIPHE[4] **Summer School.**
- July 2013: ***Developing Toolkits for Analyzing the Nexus between Land, Water, Food, Energy and Population across Scales.*** 8th LIPHE[4] **Summer School.**
- September 2012: ***Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSISEM****): An innovative approach to energy analysis***.** 7th LIPHE[4] **Summer School.**
- February- July 2014. ***1st Nicholas Georgescu-Roegen seminar*** at ICTA. Reading in group *The Entropy Law and the Economic Process.*
- June 2013: ***Research Design and methods in Political Ecology course*** inside Training Program of the European Project: *European Network of Political Ecology*
- July 2006: ***III International Course on Photovoltaic's Systems & Micro Hydroenergy*** at CEDECAP (Centro de Demostración y Capacitación en Tecnologías Apropiadas). Cajamarca, Peru.

RESEARCH OUTCOMES, PROJECTS AND CONGRESSES

- **Paper:** Velasco-Fernández R, Ramos-Martín J, Giampietro M. *The energy metabolism of China and India between 1971 and 2010: Studying the bifurcation*. Renewable and Sustainable Energy Reviews. 2015;41:1052-66.
- **Paper:** Velasco-Fernández R, Giampietro M. and Bukkens, G. F. Sandra. *A novel approach to the analysis of the energy efficiency of the industrial sector. Energy, Accepted with revisions.*

- **Project report:** Giampietro M., Sorman A.H. and Velasco-Fernández R. *Characterizing Energy Efficiency from the Matrix of Production of Energy Carriers at the National Level.* September 2016 EUFORIE project.
- **Project report:** Giampietro M., Velasco-Fernández R. and Ripa M. *Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers.* March 2017 EUFORIE project.
- **Project participation & Research Stay:** September – December 2016, at the Center for Energy and Environmental Economics (CENERGIA), COPPE, Universidade Federal do Rio de Janeiro (UFRJ), Brasil with the Professor Roberto Schaeffer. NETEP - European-Brazilian Network on Energy Planning joint research project financed by the European Commission under the 7th Framework Program (FP7), within the Marie Curie Actions International Research Staff Exchange Scheme (IRSES).
- **Research Stay:** September – November 2014, at the Global Institute of Sustainability, School of Sustainability, Arizona State University (ASU), Tempe (USA) with the Professor David Manuel-Navarrete. Financed by the Ministerio de Educación, Cultura y Deporte, Estancias Breves FPU.
- **Congress Participation & Oral presentation:** Stockholm, Sweden, 4–7 May 2015,. *Metabolic patterns of the industrial sector across Europe: studying the forgotten maker or Service Cities.* BIWAES 2015, Biennial International Workshop Advances in Energy Studies 2015. Energy and Urban Systems.
- **Congress Participation & Oral presentation:** Piran, Slovenia, 15–18 June 2016, *Comparing changes in the pattern of Industrial-Energy Metabolism of South East European Countries between 2008 and 2013.* 2nd SEE Sustainable Development of Energy Water and Environment Systems (SDEWES) conference.
- **Congress Participation & Oral presentation:** Budapest, Hungary, 30 Aug - 3 Sep 2016**,** *Social organization strategies for a reduction of energy consumption: Looking for institutions increasing the utilization factor.* 5th Degrowth Conference, Walking the meaningful great transformations?
- **Congress Participation & Oral presentation:** Barcelona, Spain, 12-13 July 2007, Speaker on the 1st *Congress UPC Sustainable 2015*. Paper: *Les Mancances a la docència de la UPC en educació per a un desenvolupament humà sostenible.*
- **Congress Participation:** Barcelona, Spain, 29-30 April 2011**,** IV Congrés Català de Joves Sociòlegs: Joves Perspectives.

TEACHING EXPERIENCE

- <u>September – January 2016:</u> **Teaching** *Environmental Economics* at the Faculty of Economics and Business, Department of Economics and Economic History teaching of the Universitat Autònoma de Barcelona.

- September – January 2015: **Teaching** *Human uses of the Earth System* at the Faculty of Economics and Business, Department of Economics and Economic History teaching of the Universitat Autònoma de Barcelona.
- July 2016: **Invited Lecturer**: "*Integrar i promoure les problemàtiques globals als ensenyaments científico-tècnics*" organized by Escola de Cultura de Pau and Universitat Autònoma de Barcelona.
- March 2010, February 2011 & March 2012: **Invited Lecturer**: *A critical introduction to Appropriated Technologies and Technologies for Human Development* in the Specialist Postgraduate Degree in International Cooperation. Universitat Rovira i Virgili (Tarragona).
- February 2012: **Invited Lecturer**: *A critical introduction to Appropriated Technologies and Technologies for Human Development.* Master in International Development. Setem – Universitat Politécnica de Catalunya (Barcelona).
- December 2011 & April 2012: **Invited Lecturer:** *Appropriated Technologies projects and Advocacy campaigns of Engineering Without Borders.* Introductory course on International Cooperation Volunteering. Catalan Federation of NGOs for Development (FCONGD).
- January – May 2016: **Mentor of STEM Program** in IES Juan Manuel Zafra in Barcelona. Program promoted by the *Ajuntament de Barcelona* in collaboration with *The New York Academy of Sciences* and *Consorci Educació Barcelona*.
- 2009 – 2012: **Consultant** of several on-line courses of EWB:
  - *Volunteering, Cooperation and Technology for Human development. (7th and 8th editions)*
  - *Energy provision projects in Rural Areas (4th, 5th and 6th editions)*
  - *Energy and Cooperation for Development (4th and 5th editions)*

Teacher Trainings courses:

- February 2017: *Gestió I adrministració del temps*
- January 2017: *El pensament critic I el compromís ètic com a competencies transversals de l'alumnat univsersitari*
- January 2017: *Science with and for society PERFORM project*
- January 2017: FDES 1: *La docència en el nou context d'enseyament-aprenentatge*
- January 2017: FDES 2: *Pràctiques sobre el discurs oral.*

OTHER WORK EXPERIENCE

- December 2008 – June 2009: **Manager** of volunteering and sensitization at the GCCT NGO (Grup de Cooperació del Campus de Terrassa).
- January – July 2010: **Review coordinator** of contents of the course *Energy and Cooperation for Development.* Engineering Without Borders (EWB).
- September 2006 – July 2007: **Coordinator** of the UPC Students Council. Foundation of the Council's magazine. Student representative in the Social Council of the UPC.
- June 1996 – February 2008: **Waiter** and **kitchen helper** at *Bar Granja Plaza.*

• LANGUAGES

- **Catalan** (mother tongue)
- **Spanish** (mother tongue)
- **English** (C.1: fluent speaking & reading, good writing)
- **German** (B.2: reasonable speaking & reading, poor writing)

• COMPUTER SKILLS

- Microsoft & Open Office
- Basic GIS (Arcgis 9.1)
- Programming notions in C.
- Drawing & technical design: SolidWorks, Autocad.
- Statistical and sociological software: MiniTab, SPSS, QCA, UCINET, Atlas.ti.

VOLUNTEERING

International cooperation projects experience

- 2005 – 2007: Participation in the **Rural Electrification Project in Andes** (EWB). Collaboration with the Group Training and Intervention for Sustainable Development (GRUFIDES), Practical Actions- ITDG and GRECDH. Three month of field work in rural areas of Cajamarca (Peru) during summer 2006. Participation in renewable energy project: evaluation, training and participatory processes with communities.

- 2007 – 2011: Participation in the **Project**: **Training educative skills from the technology with youths at marginalization risk**. Collaboration with the Indian NGO CCDT. Three month of field work during summer 2007. Actual responsible of new volunteers' formation.

Other activities

- June 2009 – present**:** Member of **training team** of Engineering Without Boarders.

- 2002 – 2007: Active participation in the university group of EWB. **Coordination and dynamization** of several activities: expositions, conferences, campaigns, courses, magazine, critical cinema with debates, demonstration, etc.
- 2001 – 2007**:** Active participation in the **Student Union** of ETSEIB. Member of the school parliament and participative in different commissions. Organization of cultural activities, courses, newspaper, conferences or cultural parties.

- 2006 – 2007**:** Member of the **University Senate**. Member of the Govern Council and the commissions of teaching and economy.