EUFORIE

European Futures for Energy Efficiency

Characterizing the factors determining "energy efficiency" of an economy using the multi-level end use matrix of energy carriers

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History of changes

HISTORY OF CHANGES		
Version	**Publication date**	**Change**
1.0	March 2017	Initial version
2.0	November 2017	Revision in response to Project Review (Reporting Period 1): - *Policy summary* section has been introduced addressed to the overall general public. Different examples have been introduced in order to illustrate the contribution and discussion made in the deliverable in relation to energy policies. - Section 2.5 has been revised changing the formal equations illustrating the relation between extensive variables through different scales to clarified them better. - Table 3-14 have been updated. - Two paragraphs have been added in the Conclusions to relate the method proposed here with recommendations in Deliverable 5.3 and to clarify the statistics problems in relation to sustainability analysis. - Last paragraph in the Conclusions have been reworded.
3.0	April, 2019	Revision in response to project review: - An executive summary section has been introduced. - Boxes explaining MuSIASEM, Sudoku effect and End use Matrix have been introduced. - Sections has been reorganized - Correction of typos.

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Executive Summary

I.The issue to be explored

After accepting that the concept of efficiency is simplistic and therefore not useful for analyzing the performance of the set of energy conversions taking place in an economy (discussed in D4.1), it becomes essential to find an alternative approach capable of handling the complexity associated with energetics. In this deliverable we explore the option of using an innovative method of accounting of energy flows. The challenge is to track how different energy forms to be observed simultaneously at different levels of analysis are used in the society to maintain and reproduce the structural elements and express the various functions associated with the identity of a society. That is to say:

> ***Who*** *is using these energy flows?* ***Why*** *are these energy flows used?* ***How*** *these energy flows are used?* ***Where****?* ***What*** *type of energy flows are we considering?* ***How much*** *of each type of energy flow is used? What* ***material standard of living*** *is associated with the use of these flows? What is the effect on the* ***employment*** *associated with the used of these flows? Can we link this multi-scale integrated analysis of the use of energy flows to* ***economic analysis****? Can we link this multi-scale integrated analysis of the use of energy flows to* ***demographic analysis****? Can we link this multi-scale integrated analysis of the use of energy flows to an analysis of* ***environmental impact****?*

Although this set of question represents a very "tall order" for an integrative accounting framework the answer given in this deliverable to it is that "***yes we can***" answer all these questions. The integrated system of accounting proposed in this deliverable can be used to characterize the energy performance of a society in relation to a set of different quality criteria. In relation to this point the deliverable illustrates: (i) the conceptual framework of the ***end use matrix***, that can be used to achieve this integrated set of answers; (ii) the specific protocols to be used to generate end use matrices; (iii) an application of this protocol to EU 28 countries illustrating the type of results that can be achieved.

II. What was done to investigate it

The investigation has been carried out in three phases: (i) Phase 1 illustrates the conceptual approach that has been developed: the *end-use matrix* allowing to establish a bridge between assessments of the energy performance of functional elements of the economic sectors defined at different levels of analysis; (ii) Phase 2 illustrates the protocol developed to generate *end use matrices* and the gathering of the required data for an application to EU28 countries; and (iii) Phase 3 illustrates the results and their significance.

III. The method employed

The end use matrix is based on the application of the Multi-Scale Integrated Analysis of Societal Ecosystem Metabolism (MuSIASEM) accounting framework to the description of the metabolic pattern of EU countries.

IV. The data and sources

(i) Eurostat (2008) *Statistical classification of economic activities in the European Community. NACE Rev. 2*. Available at: http://ec.europa.eu/eurostat/documents/3859598/5902521/KS-RA-07-015-EN.PDF.

(ii) Eurostat (2012) *Motor vehicle movements on national territory, by vehicles registration*.

http://ec.europa.eu/eurostat/web/products-datasets/-/road_tf_vehmov.

(iii) Eurostat (2015a) *Annual detailed enterprise statistics for construction (NACE Rev. 2, F)*. http://ec.europa.eu/eurostat/web/products-datasets/-/sbs_na_con_r2

(iv) Eurostat (2015b) *Annual detailed enterprise statistics for industry (NACE Rev. 2, B-E)* http://ec.europa.eu/eurostat/web/products-datasets/-/sbs_na_ind_r2

(v) Eurostat (2015c) *Energy Balances*. http://ec.europa.eu/eurostat/web/energy/data/energy-balances

(vi) Eurostat (2015d) *National Accounts by 10 branches - aggregates at current prices*. http://ec.europa.eu/eurostat/web/products-datasets/-/nama_nace10_c

(vii) Eurostat (2015e) *Population on 1 January by age and sex*. http://ec.europa.eu/eurostat/web/products-datasets/-/demo_pjan

(viii) Eurostat (2015f) *Stock of vehicles by category and NUTS 2 regions [tran_r_vehst]*. Available at: http://ec.europa.eu/eurostat/statistics-explained/index.php/Stock_of_vehicles_at_regional_level

(ix) Eurostat and Commission, E. (2015) *Energy statistics of the European Union: concepts and definitions on all flows ('aggregates') and products used in the Energy Statistics on quantities*. Luxemburg. Available at: http://ec.europa.eu/eurostat/documents/38154/4956233/RAMON-CODED-ENERGY-20150212.pdf/4814055b-de02-404a-b8e0-909fb82cbd54

V. The results

The energy end use matrix (Fig. 1) represents a useful tool to answer the set of questions described before and to evaluate the efficacy of policies aimed at achieving environmental targets, such as reduction of GHG emissions and economic competitiveness in an integrated and transparent way (as recommended in the Energy Efficiency Directive 2012/27/EU). In particular:

1. The energy end use matrix makes it possible to study the energy performance of a country simultaneously at different levels and scales of analysis (national economy, sectors, sub-sectors, sub-sub-sectors) by keeping the distinction between "primary energy sources" and "energy carriers", and within the categories of energy carriers between electricity, fuels and process heat;

2. It combines qualitative and quantitative variables into a multi-scale assessment obtained by keeping coherence in an integrated set of categories of accounting (fund vs flow elements) and data referring to different dimensions of analysis: biophysical, economic, socio-demographic data (it includes also hours of labor, gross added value, and economic energy intensity);

3. It makes it possible to bridge top-down (national statistics) and bottom-up (technical coefficients) information into a coherent multi-level assessment. In fact, it can scale quantitative information across different levels of analysis by generating a "sudoku effect". Non-equivalent assessments based on intensive (bottom-up – unitary processors – technical coefficient coming from engineering analysis – e.g. quantities of energy carriers consumed per hour of labor or per unit of output) and extensive (top-down – scaled processors – e.g. national and sectorial statistical data about the consumption of energy carriers per year) are integrated in the analytical accounting framework;

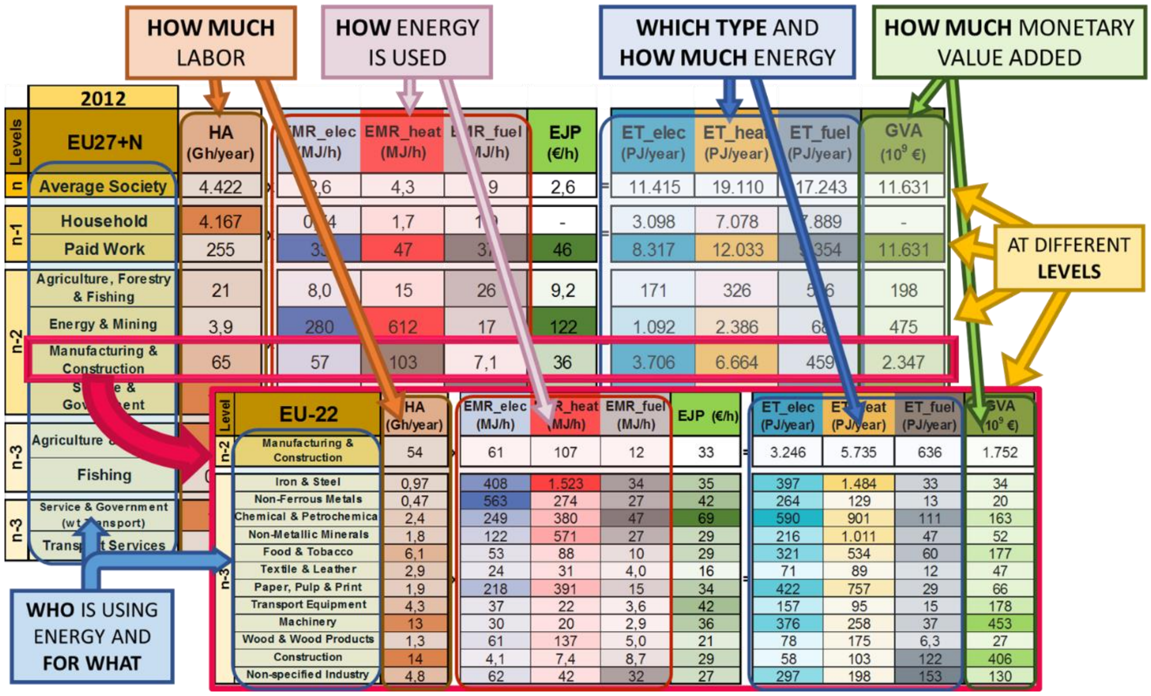

Figure 1: Example of energy end use matrix describing patterns of energy uses across levels - n = national economy, n-1 = paid work, n-2 = economic sector, n-3 = sub-sectors (e.g. within manufacturing)

4. It readily identifies the major determinants of energy performance – the overview given by the matrix makes it possible to identify the sectors, subsectors, specific processes using more or less energy and compare their performance with the analogous sectors, subsectors and specific processes in other countries. In this way it allows the framing of the discussion over the identity and robustness of the external referent of observed characteristics. Is the level of disaggregation of the data describing a sector or a subsector providing the required discrimination power to make a distinction between "technical energy efficiency" (determined by the characteristics of specific process) vs "effect of difference in economic structure" (determined by the different energy intensity of the mix of different technical processes)?

5. It makes evident the need of checking the level of openness of the considered sector/sub-sector/industry. Are the assessments of the energetic performance of sectors or subsectors referring to elements: (a) producing their output by using local primary sources?; (b) producing their output by importing raw materials?; (c) producing their output by importing semi-finished products as input; (d) just assembling finished components into the output they produce?

The deliverable provides an assessment of the performance of EU28 - as a whole, sectors per individual country and countries per individual sectors using end use matrices (45 tables and 34 figures).

VI. The significance of results for policy-makers (usefulness for governance)

According to the 2015 *Energy Efficiency Directive implementation progress report*, EU Member States struggled to achieve their energy efficiency objectives. This led the Commission to lay down the 2015 'Energy Union Roadmap', aimed at reviewing the energy efficiency directives. However, the strategies are still based on targets considered one at the time, at their own scale of analysis without considering the broader (societal) context. No explicit relation has been established between the effects that changes in specific processes taking place inside specific parts of the whole economic process will have on the national or EU economy as a whole. By embedding the discussion of targets and policies within the general framework of the end use matrix is becomes possible to get the "big picture" of the context, the existence of unavoidable trade-offs and of biophysical constraints on the changes that can be done inside the matrix. In that sense, the end use matrix represents a transparent and useful scientific tool for deliberative policy making, recognizing and relating quantitative information linked to concerns of different actors that all deserve to be considered in democratic political debates. Last but not least, the end use matrix presented here is just an example of the potentiality of MuSIASEM the same approach can be adopted for dealing with other relevant issues such as the nexus of water, food or land use (for examples of this type of application see the MAGIC project).

VII. The significance of results for stakeholders

The analysis of the energy performance of a society has to be based on the integration of a heterogeneous information space addressing the co-existence of multiple dimensions and multiple scales of analysis, all relevant when discussing energy policies. Stakeholders must ask both decision makers and scientists the adoption of more effective tools to be used to inform the debate on energy policies.

VIII. The significance of results for other researchers (plausibility of scientific inquiry)

An effective characterization of the national energy metabolism has to:

1. Address four issues: (i) what type of energy is used; (ii) how is used; (iii) by which sectors is used; and (iv) why is used. The evaluation of energy efficiency policies should be based on the concept of multi-level energy performance;
2. Characterize the *openness* of the various economic sectors and sub-sectors for assessing the effects of externalization on local performance. This require that data about the energetic performance of sub-sectors should be coupled to their level of imports;
3. Identify the various factors determining the overall energy consumption of economic sectors. This task does require a re-organization of the categories used by official statistical accounting. That is, the assessments of inputs – i.e. energy carriers, labor and imports - and outputs – i.e. type of products – have to be organized over a classification of economic activities that should map as much as possible onto homogeneous production processes.

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D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

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Abbreviations

AF – Agriculture, forestry and fishing

AFO - Agriculture and Forestry

AS – Average Society

Co - Construction

CP - Chemicals and Petrochemicals

EC - Energy Carriers

EEI - Economic Energy Intensity

EJP – Economic Job Productivity

Elec – Electricity

EM – Energy and Mining sector

ES – Energy Sector

EU – End Use

FI - Fishing

FT - Food and Tobacco

GVA – Gross Value Added

HA – Human Activity

HH – Household Sector

IS - Iron and Steel

Ma - Machinery

MC – Manufacturing and Construction sector

MQ - Mining and Quarrying for non-energy use

MuSIASEM - Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism

NF - Non-ferrous Metals

NM – Non-metallic Minerals

NS - Non-Specified Industry

PES - Primary Energy Sources

PPP - Pulp, Paper and Print

SG_nTS - Services and Government without Transport Sector

TL – Textiles and leather

TET – Total Energy Throughput

TE - Transport Equipment

TS - Transport Sector

WWP - Wood and Wood Products

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

EU-27 Member States include: 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.

EU-22 Member States include: the member countries of the European Union, with the exception of Cyprus, Denmark, Estonia, France, Luxembourg, Malta

Units and key concepts

PJ – Peta Joules (*10^{15})

TJ – Tera Joules (*10^{12})

GJ – Giga Joules (*10^{9})

MJ – Mega Joules (*10^{6})

The MuSIASEM approach

MuSIASEM or **Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism** is a transdisciplinary approach developed for studying sustainability issues building on energetics, biophysical economics using insights from complexity such as relational analysis, cybernetics, semiotics, hierarchy theory and general systems theory. The approach was introduced by Mario Giampietro and Kozo Mayumi at the end of the 90s and it is under continuous development.

The multiscale and transdisciplinary approach proposed by MuSIASEM uses relational analysis for the quantitative assessments considering diverse potentially relevant types of expertise, legitimate interest and concern when informing policy making. MuSIASEM can be used as a decision support tool for diagnostic evaluation or option space exploration in a transparent way. Sustainability of social-ecological systems can be evaluated in relation to three complementary key aspects:

(i) Feasibility - the compatibility with processes outside human control taking place in the biosphere (external biophysical constraints);

(ii) Viability - the compatibility with process under human control in the technosphere as available technologies or the existence of adequate social practices;

(iii) Desirability – the compatibility with normative values and institutions such as cultural traditions, established social practices or preferences.

MuSIASEM has been used in the EUFORIE project to provide a critical appraisal of the actual framing of the concept of efficiency in political and scientific arenas from a conceptual and practical point of view. We propose an alternative conceptual tool: the End Use Matrix, which breaks down silos and prevents the most powerful actors from cherry picking the specific output/input ratios, among the many possible indicators of energy efficiency, that best matches their agenda. To achieve the goals of saving energy and associated environmental impacts such as emissions of GHG, efficiency policies should be based on effective indicators establishing a clear relation between the local performance of energy uses and absolute energy consumption, i.e. global performance of the whole network of energy conversions. Establishing this relation requires developing a system of accounting capable of maintaining coherence across scales and dimensions of analysis while combining different metrics.

For more about MuSIASEM, see:

Giampietro, M. and Mayumi, K. 1997. A dynamic model of socioeconomic systems based on hierarchy theory and its application to sustainability. Struct. Chang. Econ. Dyn. 8, 453–469. https://doi.org/10.1016/S0954-349X(97)00017-9

Giampietro, M., Mayumi, K., Sorman, A., 2012. The Metabolic Pattern of Societies: Where Economists Fall Short. Routledge, New York.

Giampietro, M., Mayumi, K., Sorman, A.H., 2013. Energy analysis for a sustainable future: multi-scale integrated analysis of societal and ecosystem metabolism. Routledge, New York.

The End Use Matrix

The end use matrix is a MuSIASEM tool that integrates information on where, how, how much, which type, who and why biophysical funds and flows are used in a socio-economic system. The analysis is not deterministic but still it makes it possible to generate contingent evaluation of the viability of alternative profiles of allocation of human time or other resources, in relation to a set of functions to be expressed by society. It organizes quantitative information referring to different end uses described across different levels of analysis (whole society, sectors, sub-sectors). It follows the fund-flow scheme of Geoergescu-Roegen, where flows are quantities appearing or disappearing over the period of the analysis: energy, money, water, etc., and funds are structural elements preserving their identity: workers, technical capital, land use.
An *end use* is defined as the specific profile of inputs required to achieve a specific task. In the simplified definition adopted in this example, considering energy inputs only, the expected profile of inputs required for achieving a given task i can be represented using a vector:

$$[HA_i, EMR_{electricity i}, EMR_{heat i}, EMR_{fuel i}, ET_{electricity i}, ET_{heat i}, ET_{fuel i}]$$

where:

- **HA_i** - Human Activity allocated in hours/ year (h);
- **ET_{ji}** - Energy throughput metabolized in the form of energy carrier j. In this case the index j refers to electricity, heat or fuel, in joules/year (J);
- **EMR_{ji}** –Exosomatic Metabolic Rate: the amount of energy carriers metabolized per human activity, measured in joules of EC_j per hour of HA_i (J/h) for the different typologies of energy carrier. It is a proxy of use of technical capital.

The combination of extensive variables (HA_i and ET_i) and intensive variables (ET_i/HA_i – EMR_i) in different levels generates redundancy in the information space because of three basic congruence constraints, what is called a sudoku effect:

$$\#1\ (\Sigma ET_i)_{level\ n-1} = ET_{j\ level\ n}; \qquad \#2\ (\Sigma HA_i)_{level\ n-1} = HA_{j\ level\ n}; \qquad \#3\ HA_i \cdot EMR_i = ET_i$$

This entails impredicative relations. What society wants to satisfy human needs defines a downward causation, whereas the effects of the constraints determined by a limited amount of resources, technology or labor, generates an upward causation. This defines the option space within which political decisions can stir the metabolic pattern.

EU28 Year 2015	*Human Activity* HA (h p.c./year)	*power capacity* EMR_{elect} (MJ/h)	EMR_{heat} (MJ/h)	EMR_{fuel} (MJ/h)	*energy carriers* ET_{elect} (GJ/year)	ET_{heat} (GJ/year)	ET_{fuel} (GJ/year)
Whole society (*Level n*)	8,760	2.6	4.7	3.8	23	42	34
Household	8,028	0.7	1.8	1.8	6	15	14
Paid Work (*Level n-1*)	732	2.6	4.7	3.8	17	27	20
Services & Government	531	12	11	32	6.3	5.9	17.1
Manufacturing & Construction	161	42	91	5	6.7	14.7	0.8
Energy & Mining	7	485	785	29	3.4	5.5	0.2
Agriculture (*Level n-2*)	41	10	15	27	0.4	0.6	1.1

The definition of an end use matrix allows a non-deterministic analysis of the constraints affecting the allocation of human activity on a set of competing functional compartments of the society – i.e. there is a chicken-egg relation over the values taken by the numbers in the matrix. The analysis is not deterministic but still it makes it possible to generate contingent evaluation of the viability of alternative profiles of allocation of human time or other biophysical resources, in relation to a set of functions to be expressed by society.

For more about the End use Matrix see:

Velasco-Fernández, R., Giampietro, M., Bukkens, S.G.F., 2018. Analyzing the energy performance of manufacturing across levels using the end-use matrix. Energy 161, 559–572.

The Sudoku Effect

Sudoku is a logic-based number placement puzzle consisting in a 9x9 grid with digits so that each column, row and each of the nine 3x3 sub-grids that compose the grid, contains all the digits from 1 to 9. The column, row and block constraints generate mutual information within the information space of the sudoku grid. As a result, each time a number is introduced in the grid a path dependency is generated, and the option space of viable patterns is reduced. The sudoku game provides a very direct example of how relational analysis – the pre-analytical definition of expected relations over the values that will be taken by numbers in a specified grammar – can be used to generate an impredicative effect within an information space. A sub-critical Sudoku, in which the written numbers still does not fully define the missing ones, is an example of set of quantitative relations that is not deterministic, but still providing enough mutual information to generate expected patterns (Giampietro and Bukkens, 2015).

In MuSIASEM, the Sudoku effect refers to the mutual information generated when building a multi-scale and multi-dimensional set of relations over the quantitative assessments of flows and flow-fund relations. This mutual information generates constraints determined by the impredicative relation between top-down and bottom-up information. Therefore, aggregated data from statistical sources must be consistent with technical data about the processes described at lower hierarchical levels. The Sudoku effect makes it possible to apply systematically what is called triangulation in evaluation science, a "*research technique that facilitates the cross-verification using more than two sources. In particular, it refers to the application and combination of several research methodologies in the study of the same phenomenon […]. By combining multiple observers, theories, methods, and empirical data, researchers aim at overcoming the weaknesses, intrinsic biases and the problems that are often found in single method, single-observer and single-theory studies*." (Carugi, 2016).

When describing the metabolic pattern of a society with MuSIASEM we can characterize the various activities of both production and consumption in the form of a data array. The data are composed both of extensive variables – quantities of energy of different forms and quantities of human activity – and intensive variables – ratios of quantity of energy per unit of human activity. The need of reaching congruence across the values describing the metabolic pattern across different levels of analysis becomes extremely transparent in the organization of data in the end use matrix (see the box presenting the end use matrix).

For more about the Sudoku Effect see:

Giampietro, M., Bukkens, S.G.F., 2015. Analogy between Sudoku and the multi-scale integrated analysis of societal metabolism. Ecol. Inform. 26, 18–28.

Technical summary

The goals of this deliverable

Deliverable 4.2 is the second deliverable produced in the activities of Workpackage 4. In the previous deliverable (D4.1) we provided an analysis of the problematic use of concept of efficiency for characterizing the performance of the economic process. In D4.1 we suggested innovative solutions based on the concept of the multi-scale analysis of the metabolic pattern of social-ecological systems to be adopted to study the use of energy in modern economies. This second deliverable illustrates more in detail how the accounting framework of Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) can be used to provide an alternative set of input data for framing the issue of efficiency that at the moment is not available. We show in this deliverable D4.2 that this alternative organization of data could contribute substantially in having a better-informed debate about energy efficiency. In fact, adopting this organization of accounting it becomes possible to identify and study properly the set of technical and economic factors determining the profile of consumption of energy carriers in the different sectors of the socio-economic system, such as the service and government sector, the productive sectors and the household. More specifically the goals of Deliverable 4.2 are:

(1) it illustrates how the MuSIASEM accounting framework makes it possible to establish a bridge between assessments of the energy performance of functional elements of the economic sectors defined at different levels of analysis. In this way, the energetic performance of the whole economy (level n) can be characterized as being determined by the energetic performance of the various sectors making up the economy: households vs paid work (level n-1); and the main sectors of the paid work as agriculture, industry or service (level n-2). Then in cascade, the economic performance of each sector (level n-2) can be characterized as being determined by the energetic performance of the various sub-sectors (level n-3) making up it. This approach can be used to move to lower hierarchical levels of analysis, where finally it becomes possible to identify the specificity of processes of production (the energy required to produce steel is larger than the energy required to produce textile independently of the efficiency of the technology used). This approach can also be used to move to higher hierarchical level to establish benchmarks describing typologies of similar economies that can be used for comparison of the performance of sectors, sub-sectors or specific process of production. By adopting this accounting method, it becomes possible to characterize the economic performance in two non-equivalent ways: bottom-up and top-down. Therefore, this method can be used for “triangulating” quantitative information across different hierarchical levels of analysis: (i) by using extensive variables (data from statistics) one can describe the size of flows and fund elements; (ii) by using intensive variables (data from technical characteristics determining the quantities of consumed flows per unit of fund element) one can generate expected qualitative characteristics of the performance of different sectors.

(2) it provides a data set based on the MuSIASEM accounting framework that describes the metabolic pattern of EU countries in the form of an ***end use matrix*** – i.e. a description considering both the energy uses in production (in the Paid Work sector) and in consumption (in the Household sector). This description is carried out for the whole economy and its different sectors and its different subsectors. Key features of the end use matrix are: (i) it maintains a distinction between the different energy carriers consumed by the various compartments – electricity, fuels and process heat. Therefore, this accounting does not assess generic quantities of “energy” but the specified profile of energy carriers of different type which are required by each one of the sectors and sub-sectors considered; (ii) it includes also an assessment of the labor requirement associated with the consumption of energy carriers in the economic sector

(in the sectors and sub-sectors belonging to the paid-work sectors) and the "non-paid-work" time spent in the household. Therefore, this accounting makes it possible to use benchmarks (quantities of energy carrier per hour of labor) that can be used to scale the quantitative analysis across levels. Moreover, the accounting of requirement of labor makes it also possible to address the issue of job creation and employment; (iii) it includes also an assessment of monetary flows associated with the activity of different sectors and sub-sectors. This makes it possible to establish a bridge between the biophysical analysis of the flows of energy carriers and investment of hours of labor going into the various sectors and the associated economic analysis based on monetary variables.

(3) it provides a data set based on the MuSIASEM accounting framework that describes the ***end use matrix*** of the different subsectors within the industrial sectors of the EU countries. The generation of the end-use matrix at this level of analysis has been challenging because of an existing mismatch in the categorization used by different statistical sources in the definition of the taxonomy different labor and Gross Value Added across the different subsectors. Because of this problem we had to reconstruct the data across the different taxonomies of sub-sectors using different statistical sources. Despite the problem encountered with data sources, this additional movement of the analysis to a lower level is essential for making it possible an assessment of the technical performance (efficiency!) of the economy. In fact, it is only at a very local level of biophysical analysis that we can observe the actual characteristics of the various processes of production. It is only at this level that we can study the technological characteristics determining the relation between inputs and outputs. This detailed analysis of the metabolic process at the moment is not possible when using the available statistical sources!

(4) it presents examples of how to use a database of this type to study the factors determining the (i) feasibility - compatibility with external boundary conditions determined by processes outside human control; (ii) viability – compatibility with internal boundary conditions determined by processes under human control; (iii) desirability – compatibility with institutions and normative values.

(5) it identifies problems and missing information in relation to which more research is needed. More specifically our study shows the need of: (i) a better organization of the available data by the statistical offices; (ii) a complementation of the analysis based on end-use matrices with an analysis of the level of openness of the different sectors and subsectors determined by the imports and exports. In fact, as discussed in the Deliverable 4.1, in a globalized economy, the energy efficiency of functional elements – e.g. steel production – can be boosted by importing the supply of iron generated by structural elements (e.g. steel producing plants) operating outside the boundaries of the country under analysis. In this way the function required by the society is guaranteed but the relative burden of energy consumption is externalized to another society.

Policy summary

Introduction

According to the 2015 *Energy Efficiency Directive implementation progress report*, EU Member States struggled to achieve their energy efficiency objectives. This led the Commission to lay down the 2015 'Energy Union Roadmap', aimed at reviewing the energy efficiency directives and focusing on three main areas: heating and cooling, energy performance of buildings and energy efficiency of products. EU efforts have thus been focused on targets and policies that are relatively easy to frame and handle: efficiency of buildings, labelling of products, and defining efficiency targets for specific processes (e.g., heating and cooling). These targets are being considered one at the time, at their own scale of analysis without considering the broader (societal) context. No explicit relation has been established between the effects that changes in specific processes taking place inside specific parts of the whole economic process will have on the national or EU economy as a whole.

The Energy End-use Matrix as a Possible Solution

The energy end-use matrix (Fig. 1) represents a useful tool to tackle these obstacles and to evaluate the efficacy of policies aimed at achieving environmental targets, such as reduction of GHG emissions, and economic competitiveness in an integrated and transparent way as recommended in the Energy Efficiency Directive 2012/27/EU.

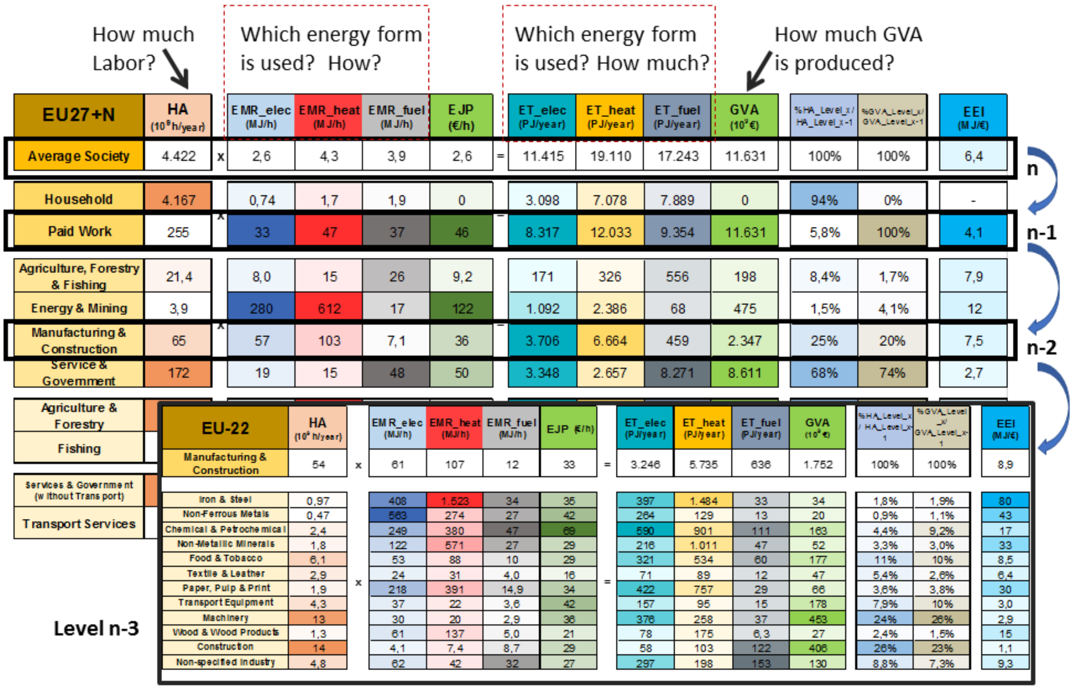


Figure 1: Example of energy end-use matrix describing patterns of energy uses across levels - n = national economy, n-1 = paid work, n-2 = economic sector, n-3 = sub-sectors (e.g. within manufacturing)

In particular:

(1) the energy end-use matrix makes it possible to study the energy performance of a country simultaneously at different levels and scales of analysis (national economy, sectors, sub-sectors, sub-sub-sectors) by keeping the distinction between "primary energy sources" and "energy carriers", and within the categories of energy carriers between electricity, fuels and process heat;

(2) it combines qualitative and quantitative variables into a multi-scale assessment obtained by keeping coherence in an integrated set of categories of accounting (fund vs flow elements) and data referring to different dimensions of analysis: biophysical, economic, socio-demographic data (it includes also hours of labor, gross added value, and economic energy intensity);

(3) it makes it possible to bridge top-down (national statistics) and bottom-up (technical coefficients) information into a coherent multi-level assessment. In fact, it can scale quantitative information across different levels of analysis by generating a "sudoku effect". Non-equivalent assessments based on intensive (bottom-up – unitary processors – technical coefficient coming from engineering analysis – e.g. quantities of energy carriers consumed per hour of labor or per

unit of output) and extensive (top-down – scaled processors – e.g. national and sectorial statistical data about the consumption of energy carriers per year) are integrated in the analytical accounting framework; and

(4) it readily identifies the major determinants of energy performance – the overview given by the matrix makes it possible to identify the sectors, subsectors, specific processes using more or less energy and compare their performance with the analogous sectors, subsectors and specific processes in other countries. In this way it makes it possible the framing of the discussion over the identity and robustness of the external referent of observed characteristics. Is the level of disaggregation of the data describing a sector or a subsector providing the required discrimination power to make a distinction between "technical energy efficiency" (determined by the characteristics of specific process) vs "effect of difference in economic structure" (determined by the different energy intensity of the mix of different technical processes)?

(5) it makes evident the need of checking the level of openness of the considered sector/sub-sector/industry. Are the assessments of the energetic performance of sectors or subsectors referring to elements: (a) producing their output by using local primary sources?; (b) producing their output by importing raw materials?; (c) producing their output by importing semi-finished products as input; (d) just assembling finished components into the output they produce?

The usefulness of the energy end-use matrix is validated in this deliverable in three sections. The first section illustrates the logic of the tool (concepts of relational analysis) and the mechanism of accounting. The second section illustrates a practical application of the end use matrix to generate a comparative analysis of the performance of the industrial sectors of Bulgaria, Finland & Spain (three different typologies of industrial sectors in EU). Finally, the third part provides a database organized in form of end use matrix describing: (i) the energy performance of the economy across levels in EU27 (+ Norway) – level n; n-1, n-2; (ii) economic performance of the industrial sector and sub-sectors in EU22 – level n-1, n-2, n-3. There a discussion about the importance of considering the implications of externalization (terms of trades) is based on the example of the pulp and paper industry.

Problems with statistical data

Available statistics (EUROSTAT) presently do not make it possible to integrate top-down with bottom-up information and to assess the performance (let alone the efficiency) of the various economic sectors. In fact, data referring to the chosen definition of sectors and subsectors are aggregating the characteristics of different typologies of biophysical transformations. For instance, industries that make pulp by cutting trees are mixed with industries making notebooks from imported paper into the same category of 'pulp and paper industry'. In this way the aggregate data are useless for drawing inferences about the efficiency of the technologies used in that sector. In addition, the current organization of statistical data ignores the significant role of imports in determining energy performance. It would be helpful if data on the energy consumption of the various sectors and subsectors were complemented with data on imports in these specific (sub)sectors. Although sectors that externalize the production of energy intensive products to other countries may result more 'efficient' in terms of reduced energy consumption, this 'better' performance is not due to more efficient technology but simply to externalization of the consumption elsewhere.

Policy Recommendations

* Targets used to define the expected energy performance of national economies or the EU economy should be based on insights derived from an integrated analysis of energy end-uses across different levels of organization of the economic process. This requires a robust identification of the various factors determining the overall energy consumption.

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

* An effective characterization of the national energy metabolism has to address four issues: (i) what type of energy is used; (ii) how is used; (iii) by which sectors is used; and (iv) why is used. The evaluation of energy efficiency policies should be based on the concept of multi-level energy performance;

* An effective characterization of the *openness* of the various economic sectors and sub-sectors has to assess also the effects of externalization on local performance. That is data about the energetic performance of sub-sectors should be coupled to their level of imports;

* A robust identification of the various factors determining the overall energy consumption of economic sectors requires a re-organization of the categories used by official statistical accounting. That is, the assessments of inputs – i.e. energy carriers, labor and imports - and outputs – i.e. type of products – have to be organized over the same classification of economic activities that should map as much as possible onto homogeneous production processes.

Key Message

The innovative features of the end use matrix integrate heterogeneous information inputs determined by the coexistence of multiple dimensions and multiple scales of analysis, all relevant for studying the energy performance, and therefore it represents an effective tool to inform energy policy.

Tasks of this deliverable related to WP4

Task 4.2. Internal view of energy systems

The MuSIASEM can provide insights for an informed debate about the technical and economic factors determining the profile of consumption of energy carriers over the different sub-sectors of the socio-economic system, such as the service and government sector, the productive sectors and the household. This view will provide information on energy services (energy end uses) that are needed in order to guarantee the functions to be expressed by the dissipative compartments of the society and therefore give options of improvement in terms of energy efficiency.

Task 4.3. Using the MuSIASEM as a decision-making tool for creating options in terms of feasibility, viability and desirability for energy systems

This multi-scale integrated analysis can be used as a tool for assessment and decision-making in understanding how different forms of energy carriers are used to perform different societal tasks, and to look into the external constraints limiting the supply of the required energy inputs. These can thereafter be used to elaborate upon options of feasibility and biophysical viability as well as desirability to take action in terms of energy efficiency.

1. Introduction – Theoretical Background

1.1 The impredicative relation between the "production side" and the "consumption side" of the economy

The problems experienced when trying to handle the challenges posed by the nexus between water-energy-food and the lack of efficacy of the policies that so far have been implemented to reduce emissions in relation to climate change are reasons of concern. The doubt is that the scientific state of the art of energy analysis is not capable of producing information useful to guide a transition to a low carbon economy.

The doubt becomes much stronger when adopting a metabolic narrative of how energy is used for reproducing the functional and structural elements of a social-ecological system. Within the narrative of energy metabolism, it becomes evident that a quantitative analysis based on the accounting input/output ratios referring to just a scale of analysis at the time is not what is needed for studying sustainability. In self-(re)producing systems the outputs of the internal process of self-organization – e.g. the supply of energy carriers produced by the energy sector and the supply of food items produced by the agricultural sector – are used as inputs by the other sectors of the economy. In turn the inputs used by the agricultural and energy sector are outputs produced by the other sectors of the economy. This entanglement of inputs and outputs across sectors implies that changing a metabolic pattern – i.e. a transition to a low carbon economy – will require changing not only to the set of sources of energy and associated technologies in the energy sectors. Many other features of the society will have to be changed within the metabolic pattern: the mix of products and services of the economy, the demographic structure of the population (affected by changes in life expectancy and immigration/emigration), the types of infrastructures required both for the economic activities and for residential purposes. To make things more difficult, in their energetic transitions to a low carbon economy, human societies will have to change their pattern of interaction with embedding ecosystems. Therefore, when considering Social-Ecological Systems we have to expect a co-dependence over the two sides: the natural environment will change, partly resulting from deliberate interventions of humans and partly as unintended side-effects of society's practices. Thus, predicting the evolution of phase-spaces in SESs is inherently beyond the capacity of the Newtonian paradigm (Giampietro and Mayumi, 2004).

The existing concern about future energy sources is natural since energy provides 'essential services' for human life - heat for warmth, cooking, manufacturing, or power for transport and mechanical work. However, the availability of the energy inputs required to provide these services - oil, gas, coal, nuclear, wood, and other primary sources (solar, wind, or water power) – is only a part of the story. Energy inputs are useless unless they can be converted into the different energy services needed to reproduce structural and functional elements of the society. For generating this conversion two additional elements are needed: (i) technical devices (or animal power) such as machines as stoves, turbines or motors generating a transformation of energy inputs into end uses (energy services); (ii) human control over the transformation. For this reason, in order to gain a useful understanding of the energetic metabolic pattern of a society is not sufficient to count "flows of energy". An effective analysis has to establish a relation between the various factors needed to stabilize the metabolic pattern: (i) the available mix of Primary Energy Sources (PES); (ii) the adopted mix of secondary energy - Energy Carriers (EC); (iii) the mix of technical devices needed for the conversions of energy carriers into end uses; (iv) the different categories of labor – i.e. jobs - or human activity controlling the processes in the household sector; (v) the set of functions to be expressed by the society to reproduce its identity.

As discussed in Deliverable 4.1 we can look at the metabolic pattern of energy of a society from two sides: i) the production side - referring to the activities taking place in the energy sector for gathering and transforming PES into a net supply of EC; ii) the consumption side - referring to the various uses of EC within the society to express the required functions associated with the reproduction and operation of the various sectors. In this way, we can define a profile of end uses for a sector (or a sub-sector) as a vector describing the quantities of energy carriers, human labor and technology, which is needed to express the functions associated with it. A combination of vectors of end uses (associated with specific sectors) represents an end use matrix. The various rows of the end use matrix (the number and the names of the sectors) map onto the set of functions that have to be expressed by the society to maintain its identity.

Having defined the *end uses matrix* we can characterize and study the two sides – production and consumption –within it. In this way, it becomes clear that the different functions expressed by the society are linked by an impredicative relation: 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. 2012; 2013; 2014). This metabolic narrative flags the obvious (but often ignored) fact that in any metabolic system the characteristics of the whole "affect/depend on" the characteristics of the parts and vice-versa (Giampietro and Mayumi, 2004). Impredicativity has to do with the familiar concept of chicken-egg problem: you have to assume the existence of a chicken to get the egg that will generate the chicken and vice-versa. Addressing the issue of impredicativity of the metabolic pattern of a society is essential in order to be able to study transitions. In fact, impredicativity shows that there are two types of relevant information for determining causality that have to be studied simultaneously: (i) given a mix of PES and a mix of End Uses we can calculate what type of technology and labor are required to express the given end use matrix (top-down causation); (ii) given the technology and the labor available in the different sectors we can calculated what mix of PES would be available to generate a mix of end uses or which mix of end use can be generated using the available mix of PES (bottom-up causation). In complex systems the relation of causality is not linear (top-down causality and bottom-up causality are co-existing and take over depending on the circumstances). In order to study impredicativity MuSIASEM uses relational analysis. Relational analysis does not establish a direct relation of causality over the characteristics of the metabolic process rather it defines a set of congruence constraints over a set of impredicative relations.

When coming to the analysis of the feasibility, viability and desirability of an energy transition: (1) the production side (the energy sector) is expected to supply a given quantity and mix of energy carriers reflecting the requirement of the consumption side – this supply is feasible if there are enough PES and sink capacity, is viable if there is enough technology, know-how and labor; (2) since the consumption side can only consume the given quantity and mix of energy carriers determined by the supply made available by the production side, the constraint of desirability implies checking whether or not the energy sectors can deliver what the rest of the society is expecting from it. If the supply is not enough, the consumption side can decide to reduce its consumption of factors of production in some subsector (reducing other functions) and use these production factors to boost the activity of the energy sector. In this way, the society can boost its supply of energy carriers by reducing its ability to consume energy carriers moving to another state of dynamic equilibrium. The existence of this dynamic equilibrium between production and consumption side within the end uses matrix implies that the characteristics of each one of the two sides do affect and do depend on the characteristics of the other. This impredicative relation between "what is produced and how" and "what is consumed and how" can be studied in quantitative terms by looking at the profiles (vectors) of "investments" and "returns" of the various sectors. Each sector (either on the supply or the consumption side) has to invest certain quantities of energy carriers, technological devices and labor for expressing its own function. All sectors compete for the same endowment of these resources, this implies that investments of energy carriers, technology and labor do have an "opportunity cost" for society.

When dealing with an impredicative relation it is simply not possible to adopt a substantive definition of what is an "input" and a resulting definition of the "output" defined as "what is the result obtained using that input" (this has been explained in the previous deliverable 4.1 when discussing the limited usefulness of the concept of efficiency). The two sides of the dynamic equilibrium always re-adjust simultaneously the profiles of inputs and outputs at each change! Moreover, the dynamic equilibrium is not referring to individual inputs/and outputs of flows, but to metabolic patterns – i.e. the vector of flow and fund elements required by the supply side (the energy sector) and the vector of flow and fund element required by the consumption side (the other sectors). The energy sector expresses activities that require energy carriers, labor and technology, and it produces a net supply of energy carries for the rest of the society. The consumption side (the rest of the society) expresses activities that require energy carriers, labor and technology, and it produces the required input of technology and labor for the energy sector. This implies that even if, in energy terms, the consumption side is not generating any net supply of energy carriers, the function it expresses is still essential because it guarantees the supply of the other inputs required for the reproduction of the society (food, materials, technology, labor) and for the proper operation of the energy sector.

The MuSIASEM accounting describes the dynamic equilibrium using two concepts: (i) the Bio-Economic Pressure (BEP) characterizing the metabolic requirement of the rest of the economy (the consumption side). BEP quantifies the fraction of the total quantity of energy flows, technology and human activity (labor) used by society, which is required by the sectors belonging to the consumption side; (ii) Strength of the Exosomatic Hypercycle [exosomatic energy = energy transformations taking place outside the human body but under human control] (SEH) characterizing the metabolic requirement of the Energy Sector (the production side). SEH quantifies the returns of the investments of technology, labor and other inputs that the rest of the economy has to invest in the energy sector to obtain the required net supply of energy carriers.

The surviving of a metabolic system obviously depends on its ability to stabilize the supply of the required inputs across the relations established across the different sectors. This implies the existence of biophysical constraints (to be added to the economic ones) on the feasibility and viability of a given metabolic budget in a society.

After having defined the relations between the characteristics of the two sides, that have to be congruent in the dynamic budget, we can discuss future scenarios: for example, we can start setting the characteristics (performance) of the energy sector and then discuss how the society should adapt to this, or, alternatively, we can start designing a (desirable) pattern for the society and then look at the technical characteristics of the energy sector that would be required to achieve the stabilization of this pattern.

In relation to this task, the grammar of MuSIASEM makes it possible to explore the severity of the biophysical constrains (the feasibility and viability domain) associated with this impredicative causality, by studying the forced congruence between the characteristics of the parts and the characteristics of the whole (Giampietro and Mayumi, 2004). The ability of defining an end use matrix – what is presented in this deliverable – both in theoretical and methodological terms and in the form of a data base covering the EU countries – is essential to improve our ability to study and visualize feasible, viable, and desirable pathways for a transition to low carbon economy.

1.2 The conundrum of how to characterize energy efficiency across scales

Impredicative loops (autocatalytic loop, chicken-egg paradoxes) can only be explored after explicitly acknowledging the fact that they are in general occurring across self-entailing processes operating simultaneously over different hierarchical levels. This implies that they can only be perceived and represented in parallel in non-equivalent way – e.g. we can use a model, defined at a given scale, to study how the number of predators determines the number of preys in a given ecosystem, but then we have to use another model, defined at another scale, to study how the number of preys determines the number of predators in the same ecosystem. A system is hierarchical when it operates on multiple space-time scales or when they are analyzable into successive sets of subsystems and when alternative methods of description exist for the same system (Giampietro *et al.*, 2006). That is, definitions based on impredicative loops refer to mechanisms of self-entailment operating across levels and which therefore require a set of representations of events referring to both parts and wholes in parallel over different scales. Exactly because of that they are out of the reach of reductionist analyses (Giampietro, Mayumi and Sorman, 2013).

The epistemological challenge faced when trying to analyze a system using simultaneously different scales is studied in the field of hierarchy theory (Giampietro and Sorman, 2012). In brief, hierarchy theory can be defined as "a theory of the observer's role in any formal study of complex systems". It explicitly acknowledges the unavoidable existence of multiple, non-equivalent identities for the same system when it is observed at different scales. As a matter of fact, the idea of a system having multiple-identities when observed at different scales has been proposed as the very definition of a hierarchical system: "a system is hierarchical when alternative methods of description exist for the same system" (Giampietro and Sorman, 2012).

As noted before a self-maintaining and self-reproducing system can only preserve its identity if it is capable of establishing a dynamic budget between the required flow of inputs (to sustain the consumption of the whole – at the level n) and the relative supply, which must be generated by specialized compartments (operating inside the black box – at the level n-*i*). In relation to this forced relation constraints can be detected when finding incongruence between the relative requirement and supply in the dynamic budgets of metabolized flows over different compartments at different levels. Biophysical constraints imply that if we find a compartment which is using a very large share of the total of a metabolized flow, in relation to its size (having a very high metabolic rate per unit of size), then we must find other compartment having a much lower metabolic rate per unit of size. This inverse relation in the relative value of throughputs is mediated by the relative size of the various compartments.

The analysis of congruence across different scales can be defined as a check on the congruence between the metabolic characteristics of the whole ("size" and "throughput" defined for the whole society) and the metabolic characteristics of lower level parts ("size" and "throughput" expected/established in each of the compartments making up the society). This forced congruence from what is expected by the whole, and what has to be delivered by the integrated set of parts is particularly relevant in the energy efficiency conundrum. However, this congruence refers to the inputs and outputs of entire sector or subsectors and not necessarily reflects what is going on at the level of local processes of energy conversions.

The Sustainable Energy For All 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 of how the energy carriers are consumed in the economy of a society 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, the results of this earlier research do not properly address the impact of heterogeneity in 'energy uses' in cross-sectional studies (differences in the internal functioning of different black-boxes), nor do they 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).

1.3 The need of an effective diagnostic tool for discussing energy transitions

Two points are crucial in a discussion over energy transitions:

#1 - establishing a clear link between the characteristics of the societal metabolism as a whole (referring to the entire loop – level n) and the characteristics referring to lower-level elements (referring to the activities of the parts – level n-1) and higher-level elements – (referring to the activities outside the control of the society – level n+1).

#2 – tracking the elements determining the autocatalytic loop of energy carriers when describing societal metabolism in energy terms. It is in fact well known that, in complex adaptive systems, the dissipation of useful energy must imply a feed-back, which has to be used to enhance the adaptability of their system of control. This implies that instead of using linear representations of energy flows in the economic process (e.g. as done with input/output analyses) we have to study how the flows are generated (by fund elements) and how flows are used to reproduce fund elements.

These points flag three essential features of the quantitative analysis of metabolic processes:

1. quantities that are observed at a given level of analysis – i.e. the metabolic characteristics of the whole household – are determined by the characteristics of processes taking place above (e.g. the availability of jobs) and below (e.g. the number of working hours of the elements of the household and the wages of the different jobs) the chosen level of analysis;
2. in order to be able to scale the information across levels one has to combine information referring to qualitative (intensive – metabolic rate per hour of labor) and quantitative (extensive – total quantity of energy and total quantity of labor) variables;
3. the relations established in this way across quantities defined at different levels is impredicative. In the sense that we can see the characteristics of the *level n* as: (i) ***determined*** by the characteristics found at lower level; or (ii) ***determining*** the characteristics found at lower level

To this extend, the MuSIASEM approach has been built as an alternative to the conventional approach of reductionism after acknowledging that it is impossible to generate quantitative analysis relevant for the sustainability of autocatalytic loops by using differential equations within a mono-scale analysis framework. For example, in a predator-prey relation some models will predict that the number of predator (the cause) is affecting the number of preys (the effect). But this conclusion is based on the adoption of a given scale for the analysis. However, other models based on the adoption of a different scale will define a different relation of causality – the number of preys is determining the number of predators (Giampietro et al. 2006). This implies that when considering possible adjustments taking place in a complex self-producing and self-maintaining system (such as a social-ecological system) we have to consider as relevant several processes that can only be observed at different scales (top-down and bottom-up causation). In this situation, it is impossible to establish a direct direction of causality using models: we are facing the predicament of "chicken-egg" paradoxes. The solution proposed by MuSIASEM is to look for sets of useful typologies of parts and wholes (characterized in terms of the relative size and specific throughputs), which can be used to generate a set of expected relations over fund and flow elements. After having decided to represent the metabolic pattern using a chosen set of typologies of fund and flow elements, then the resulting quantitative representation must guarantee the congruence of the flows across non-equivalent descriptive domains.

Essential and novel in our approach is the introduction of the concept of '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 and a given quantity of required labor. In this way 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 (or by making available data on the overall consumption of energy carriers described using extensive variables). This combination of information allows us to describe the energy consumption of a given (sub)sector or end-use simultaneously both in qualitative (e.g. the average value of kWh of electricity per hour of labor as average over a year) and in quantitative terms (e.g. the quantity of GWh consumed in a year and the hours of labor in a year). Therefore, the proposed framework provides practical criteria to define an identity for the various sectors and subsector across different hierarchical levels of analysis. When defining the name of the sub-sector or the sector in the taxonomy, we define the functional elements of the society to which it belongs. When defining the combination of extensive and intensive variables used for describing it, we are studying the characteristics of biophysical processes at a lower scale. This information is essential for studying the different levels of technological performance of the processes and the degree of openness at which these sectors and subsectors are operating.

By combining the information of the taxonomy of expected tasks/functions to be expressed by the various specialized compartments of society and the mix of end uses specific for each task and function we can study the nature and severity of internal constraints.

Afterwards, we need to calculate the profile of consumption of energy carriers (mix and amount of each of the carriers) per each one of the relevant compartment of the economy: household, agriculture, manufacturing and construction, service and government, including the energy sector in terms of a set of expected benchmarks.

For example, starting from the definition of the consumption patterns of the society, we can define what we called the Bio-Economic Pressure (BEP), that provides two types of information: (i) **how much** of each flow and fund elements is required to guarantee a desirable (adaptive, well maintained and well reproduced) dissipative sector (household-HH + services&government-SG); (ii) **what fraction of the total** use of flow and fund elements of the society has to be allocated to the dissipative sector. Again, this second information can be considered to be "depending on" or "affecting" the characteristics of the hypercyclic compartments (AF producing food, EM producing energy and MC producing the exosomatic inputs required for the stabilization of the metabolic pattern). The relation between BEP (Bio-Economic Pressure) and SEH (Strength of Exosomatic Hypercycle) is impredicative.

Building on the wisdom of George E.P. Box, "*all models are wrong, some are useful*", the results of this deliverable stress first the epistemological need to put aside mono-indicator energy accounting (reductionist approach), demonstrating that quantitative analysis of socio-ecological systems always demands the simultaneous consideration of multiple space-time scales and multiple dimensions of analysis (Munda, 2006). In this deliverable we illustrate the application of the MuSIASEM accounting scheme that addresses the challenge of how to deal with the fact that: (i) different societies uses different mixes of energy inputs to express different functions in different functional elements (economic sectors and sub-sectors); and (ii) these mixes may change over time within the dynamic equilibrium between BEP and SEH. This result is obtained by constructing an end use matrix providing the required data organized across different levels of analysis (whole, sectors, sub-sectors).

Particularly important is the multi-scale characterization of the metabolic pattern of the industrial sector (in relation to the metabolic pattern of sub-sectors) making it possible to make comparison within countries and across countries. Twenty-two EU countries are used to illustrate our approach. Another important result of this work has been the individuation of important gaps in current quantitative analysis. We urgently need not only better indicators and methods of analysis but also a better organization of data from statistical offices, avoiding mismatch of categorization over the taxonomy of definition of sectors.

2. Materials & Methods

2.1 The theoretical approach of MuSIASEM: the end-use matrix

When analyzing flows in a metabolic system to study the relation between 'the quantity of energy used' and 'the amount of GPD generated' (what is usually called as the Economic Energy Intensity and associated with the concept of "efficiency" – see Deliverable 4.1), we should not consider the two flows in isolation. Metabolic flows are meaningful only if they are contextualized in relation to the larger metabolic process in which the inputs are used as "useful inputs" and what is produced is considered as "useful output". In relation to this task the flow-fund model proposed by Georgescu-Roegen (Georgescu-Roegen, 1971) provides a solution by making 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). The fund elements preserve 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 of the size and the metabolic characteristics of the fund elements metabolizing 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) 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) to obtain the flow of food consumption (Giampietro *et al.*, 2014).

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, Mayumi and Dynamics, 1997; Giampietro and Mayumi, 2000a, 2000b; Pastore, Giampietro and Mayumi, 2000; Giampietro, 2003; Giampietro *et al.*, 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 include:

- Rather than reducing all energy forms into a semantically-void generic category of accounting, such as joules of energy commodities (as done by Eurostat and IEA), we respect the specificity of the main energy carriers - electricity, heat and fuel (that are specific metabolic inputs for specific *end uses*). This implies maintaining a separate accounting of them throughout the analysis.
- We map the consumption of this set of energy carriers for all sectors and subsectors of the system and also consider an additional production factor: human labor (fund element) - a necessary ingredient to stabilize the metabolism of energy flows by providing control on the transformations.
- For all sectors and subsectors of the system we map the allocation of fund and flow elements (biophysical inputs) onto the flows of value added generated.
- We define the size and hierarchical structure of the system on the basis of a taxonomy of functional elements mapping onto sectors and subsectors. Then the accounting of both the flow elements (energy carriers and added value) and the fund element human activity, defined in terms of time allocation (hours/year) can be done using the categorization referring to the various sectors and sub-sectors of the system. In this way we can characterize each (sub)sector of the system using an end-use vector describing flow elements (i.e., the different types of energy carriers and value added) and fund element (i.e. hours of human activity) allocated to it.
- The size of the social-ecological system (society) as a whole is defined using the fund element human activity calculated as: number of people × 8.760 (hours of human activity per capita in a year). The size of the different economic sectors and sub-sectors within society is defined as: 'number of paid hours worked per year in the given sector'. The choice of using human activity as scaling factor makes it possible to define the size of the flows of the various compartment in two different ways: (i) using extensive variables – the quantity of flows as resulting from statistics; (ii) using a combination of intensive variables (benchmark values – flow/fund ratio) scaled using the size of the fund element human activity. Knowing the energy flows per hours (the metabolic characteristics of the element) and the hours of work (scaling factor) we can calculate the overall flow.
- Therefore, we generate redundancy in our system of accounting by characterizing the metabolic pattern simultaneously using both extensive and intensive variables. Extensive variables assess the size of both 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). 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, the data array 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 the Energy and Mining sector (EM) – domestic production – and by imports.

Within this taxonomy we 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 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 has to be able to provide this 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 hypercycle 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 producing more exosomatic funds that they consume. For this reason, the primary and secondary sectors can provide net flows 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' (flow element)/'GDP' (flow element)'. Rather we propose the combined use of two sets of flow/fund ratios: 'quantity of energy carrier per hour of labor' (specified by energy carrier types and by job type) and '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*: the size of the fund human activity (labor hours) allocated to a given (sub)sector is used to scale its specific metabolic characteristics (defined by the flow/fund ratios). 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 efficiency (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 (EJP_i) – the amount of added value generated per hour of labor in a specific (sub)sector *i* –is an important feature of MuSIASEM. In fact, 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 it is no longer) competitive compared with other activities in the economic process (when it expresses a relatively low EJP_i), 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 EJP_i 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.

2.3 Selection of case studies

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, with the exception of Cyprus, Denmark, Estonia, France, Luxembourg, Malta and Slovenia (excluded because of lack of required data for our analysis) and the addition of Norway (included as an example of a "quasi-EU country" with a large production of oil).

2.4 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 have to 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 a functional compartment – the sub-sector producing iron and steel, or the agricultural sector – covers exactly the requirement of the country. Imports and exports are often used to handle 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 requires:

1. Defining the set of compartments (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 we define a taxonomy of function we select the national level as our focal level (level n). We 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 (TE), 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).

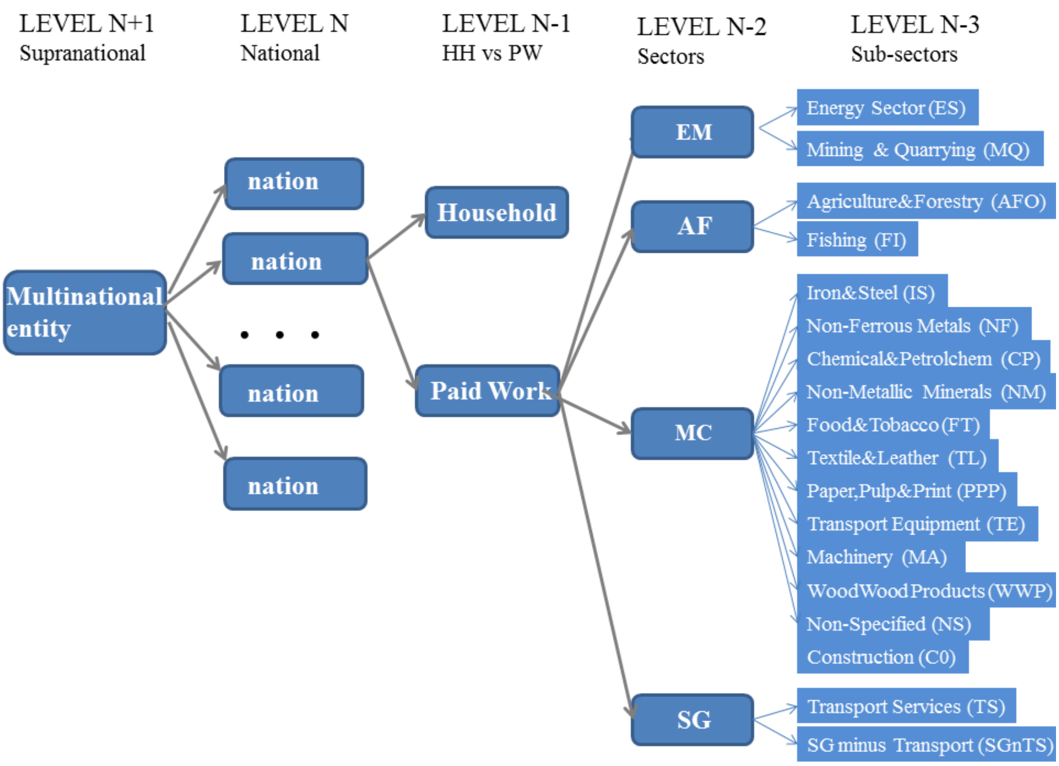


Figure 2-1 The different hierarchical levels of analysis at which metabolic elements are defined

Then this generic taxonomy based on a definition of functional levels of organization has to be applied to identify structural elements. As a matter of fact, for reasons of data availability, we will generate two distinct sets of multi-level end use matrices using the taxonomy illustrated in Fig. 2-0-1. In the first application we 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 we 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:

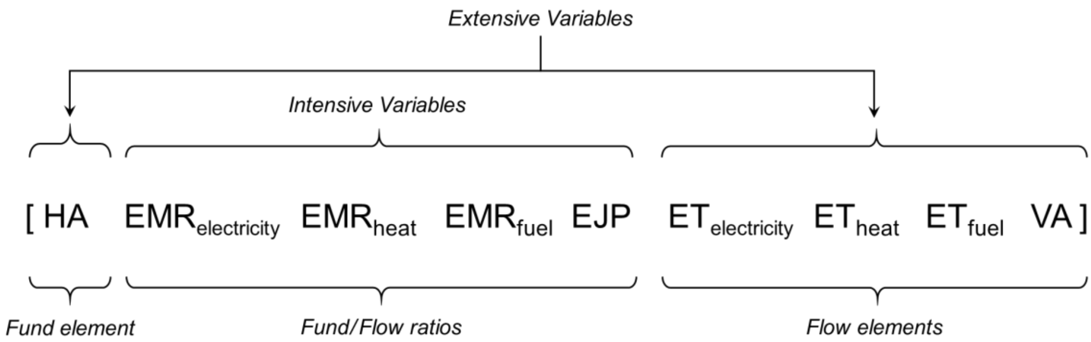
(i) the metabolic characteristics of the other compartments in the same country – how the metabolic characteristics of the Energy and Mining (or Textile and Leather) of France compare with the average metabolic characteristics of other sectors of France;

(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.

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

We 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);
- GVA – Gross Value Added generated by the end-use, measured in euros (€);
- EMR_i –Energy Metabolic Rate: 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;
- EJP –Economic Job Productivity: the gross value added (GVA) (at factor cost in SBS) generated per hour of work allocated to the end-use, measured in euros per hour of work (€/h).

2.5.1 Extensive Indicators: HA, ETs, GVA

In accordance with Georgescu-Roegen's flow-fund scheme (Georgescu-Roegen, 1975), human activity (HA) is defined as a fund element, whereas energy throughput (ETs) and gross value added (GVA) are flow elements. All three are extensive variables can be used to characterize the size (weight) of the end-use.

The relation of these extensive variables across the different levels of analysis could be expressed as follow (e.g. for Human Activity):

$$THA(n) = HA_{PW}(n-1) + HA_{HH}\ (n-1) \quad \text{(Eq. 1)}$$

$$HA_{PW} = HA_{AF}(n-2) + HA_{EM}\ (n-2) +\ HA_{MC}\ (n-2) +\ HA_{SG}\ (n-2) \quad \text{(Eq. 2)}$$

$$HA_{AF}(n-2) = HA_{AFO}(n-3) + HA_{FI}(n-3) \quad \text{(Eq. 3)}$$

$$HA_{EM}\ (n-2) = HA_{ES}\ (n-3) + HA_{MQ}\ (n-3) \quad \text{(Eq. 4)}$$

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

$$HA_{MC}\,(n-2) = HA_{IS}\,(n-3) + HA_{NF}\,(n-3) + HA_{CP}\,(n-3) + HA_{NM}\,(n-3) + HA_{FT}\,(n-3) + HA_{TL}\,(n-3) + HA_{PPP}\,(n-3) + HA_{TE}\,(n-3) + HA_{Ma}\,(n-3) + HA_{WWP}\,(n-3) + HA_{Co}\,(n-3) + HA_{NS}\,(n-3) \quad \text{(Eq. 5)}$$

$$HA_{SG}\,(n-2) = HA_{TS}\,(n-3) + HA_{SG\_nTS}\,(n-3) \quad \text{(Eq. 6)}$$

2.5.2 Intensive Indicators: EMR, EJP

Dividing flow by fund elements, we obtain the intensive variables EMR_i and EJP_i. Energy metabolic rates (EMR_i) are calculated for each of the energy carriers: electricity, heat and fuel. As explained above, this strategy permits to conserve valuable information about the quality and quantity of energy throughput in the form of different carriers metabolized in each end-use. The economic job productivity (EJP_i) represents the value added generated in a given end-use sector per hour of work required in that compartment. With the term 'economic *job* productivity' (rather than economic *labor* productivity used in previous MuSIASEM applications) we want to stress the qualitative aspect of human labor. Indeed, not all working hours are the same in the sense that they are complemented by different investment of energy carriers and technological capital in expressing their tasks implying a different requirement of know-how from the worker. For this reason, in a more refined analysis (not presented here) it is possible to introduce different categories of jobs (e.g., type of skills) in the same way as we have done for the 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.

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

$$EMR_{AS}(n) = \frac{TET(n)}{THA(n)} \quad \text{(Eq. 7)}$$

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 in the Introduction, 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 (Results & Discussion) a data-array for each analyzed country will be presented in each level.

The data array includes multiple indicators and it is organized as shown in Table 2-1:

Table 2-1 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)	GVA (€)	%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, a given subsector – e.g. paper, pulp and print;
- HA_j is the fund element 'Human Activity' expressed in hours per year;
- EMR_elec$_j$, EMR_heat$_j$, EMR_fuel$_j$, 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);
- GVA_j, expressed as € per year, is the flow element 'Gross Value Added in monetary terms';
- %(HA_sub-compartment/HA_supra-compartment) is the proportion of labor allocated in each sub-compartment;
- %(GVA_sub-compartment/GVA_supra-compartment) is the proportion of GVA allocated in each sub-compartment;
- EEI, expressed as MJ per € per 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.

2.6 Data sources and main assumptions

The definition of the sector and subsectors matches the Energy Balance Data (Eurostat, 2018a) categorization of Eurostat (nrg_110a). Data on hours worked (human activity – HA) and gross value added (GVA) have been obtained from the *National account employment data* (nama_10_a64_e) (Eurostat, 2015b). These data have been aggregated bottom-up-wise as shown in Table 1 to mostly match the categorization from the Energy Balances following the NACE Rev. 2 classification as its metadata establish (Eurostat, 2008).

Table 2-2 Correspondence between database categorization of economic activities for Energy Balance (IEA & EUROSTAT) (Eurostat and Commission, 2015) ***and hours of work (human activity) and value added (NACE Rev.2)*** (Eurostat, 2008)

Energy Balance Data Categorization (IEA & Eurostat)	Human Activity and Value-Added Data Categorization (NACE Rev. 2 Divisions)
Residential	Calculated in this study
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
Agriculture/Forestry	A1 - Crop and animal production, hunting and related service activities
	A2 - Forestry and logging
Fishing	A3 - Fishing and aquaculture
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
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
Chemical and Petrochemical	C20 - Manufacture of chemicals and chemical products
	C21 - Manufacture of basic pharmaceutical products and pharmaceutical preparations
Non-Metallic Minerals	C23 - Manufacture of other non-metallic mineral products
Mining and Quarrying	B7 - Mining of metal ores
	B8 - Other mining and quarrying
	B9.9 - Support activities for other mining and quarrying
Food and Tobacco	C10 - Manufacture of food products
	C11 - Manufacture of beverages
	C12 - Manufacture of tobacco products
Textile and Leather	C13 - Manufacture of textiles
	C14 - Manufacture of wearing apparel
	C15 - Manufacture of leather and related products
Paper, Pulp and Print	C17 - Manufacture of paper and paper products
	C18 - Printing and reproduction of recorded media
Transport Equipment	C29 - Manufacture of motor vehicles, trailers and semi-trailers
	C30 - Manufacture of other transport equipment
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.
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
Construction	F - Construction
Non-specified (Industry)	C22 - Manufacture of rubber and plastic products
	C31 - Manufacture of furniture
	C32 - Other manufacturing
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 and 99
Transport	H49 - Land transport and transport via pipelines
	H50 - Water transport
	H51 - Air transport

Human Activity and Gross Value Added

As said above, data on hours worked (human activity − HA) and value added (VA) have been obtained from the *National account employment data.* The Human Activity at HH (level n-1) are calculated as the difference between: (i) the total amount of hours of human activity for the whole society THA: number of people (Eurostat, 2018b) × 8.760 (hours of human activity in a year); and (ii) the working hours (PW) calculated from statistical data.

$$HA_{HH} = THA - HA_{PW} \qquad \text{(Eq. 8)}$$

The Human Activity- data on hours worked- at MC subsectors (level n-3) and value added (VA) have been obtained from the *Annual detailed enterprise statistics for industry* (sbs_na_ind_r2) (Eurostat, 2015b) and *construction* (sbs_na_con_r2) (Eurostat, 2015a).

As discussed below, the accounting of HA_i at lower hierarchical levels has proved to be problematic for some compartments because the accounting of HA within the data collections of Structural Business Statistics (SBS) and National Accounts (NA) is done using a different methodology of data sources, data collection and validation. This makes impossible a comparison across scales.

Missing data in human activity (e.g. in 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 worked hours in a year (working days/yr * full-time working hours/day). These values were further checked against the worked hours data available in the National Account.

NOTE: 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:

http://www.businessdictionary.com/definition/full-time-equivalent-FTE.html

Energy Throughput

The throughputs of the energy carriers (electricity, heat and fuel) are obtained by aggregating (bottom-up-wise) the different forms of each of these energy carriers provided in the Energy Balances of Eurostat (Eurostat, 2018a), as shown in Table 2-3.

Table 2-0-3 Aggregation of the different forms of the energy carriers electricity, heat, and fuel reported in the Energy Balances of Eurostat (Eurostat, 2018a)***.***

CODE	PRODUCT	EC
2100	Hard coal and derivatives	HEAT
2200	Lignite and Derivatives	HEAT
2410	Oil shale and oil sands	HEAT
3214	Refinery gas	HEAT
3215	Ethane	HEAT
3220	Liquified petroleum gas (LPG)	HEAT
3234	Gasoline (without bio components)	FUEL
3235	Aviation gasoline	FUEL
3244	Other kerosene	FUEL
3246	Gasoline type jet fuel	FUEL
3247	Kerosene type jet fuel (without bio components)	FUEL
3260	Gas/diesel oil (without bio components)	FUEL
3270A	Total fuel oil	HEAT
3285	Petroleum coke	HEAT
4000	Gas	HEAT
6000	Electrical energy	ELECTRICITY
5532	Solar thermal	HEAT
5541	Solid biofuels (excluding charcoal)	HEAT
5542	Biogas	HEAT
55431	Municipal waste (renewable)	HEAT
5544	Charcoal	HEAT
5545	Liquid biofuels	FUEL
5550	Geothermal Energy	HEAT
7200	Waste (non-renewable)	HEAT
7100	Industrial wastes	HEAT
55432	Municipal waste (non-renewable)	HEAT

Missing data in energy were imputed by extrapolation taking account time trends. Energy consumption in the household sector has been calculated by summing residential consumption (from the Eurostat Energy Balance) and fuel consumption by private cars (using the assumption of: 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, 2015c) 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 we simply assumed a consumption of 5 l/100km. After 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.

3. Results

3.1 Presentation of results

In this section we will present the results of our analysis aimed at illustrating the potentiality of the innovative approach of accounting based on MuSIASEM that makes 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 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.

Our results also flag the existence of problems with the existing organization of data in statistical sources – especially when moving the analysis at the level of the sub-sectors. Therefore, the analysis provided in this deliverable makes it possible to individuate what should be done by statistical offices to generate a more effective set of statistical data useful for analyzing the energetic metabolic pattern of modern societies.

As mentioned in the methodological section, a characterization of the pattern of consumption of 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, before presenting the various tables with the end-uses matrices across the levels n+1/n/n-1/n-2/ we present a pilot case study based on the analysis of only three countries – Bulgaria, Spain and Finland chosen for their different metabolic characteristics. After presenting the example of an analysis based on end-use matrices for these three countries, we will present the database on EU countries 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 (see Materials and Methods), the information required to generate the Energy End Use matrix.

In conclusion the presentation of the results is organized in three distinct sections:

- Section 1 – a pilot case study based on the analysis of only three countries (Bulgaria, Spain and Finland) used to illustrate the type of analysis that can be done using the end-uses matrices;
- 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 section we 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 present 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.

3.2 Section 1

Pilot case study based on the analysis of the metabolic pattern of three EU countries illustrating the potentialities of the end-use matrix

In this section we present the results of an analysis of the bioeconomic performance of the industrial sectors of Bulgaria, Finland and Spain. We remind the reader that the data presented here only serve to illustrate the methodology, and that an exhaustive comparison of the bio-economic performance of these countries is not a purpose of this pilot case study.

3.2.1 End-uses data representation using normalized chromatic intensity

Essential and novel to our approach is the introduction of the concept of '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.

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. We 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 we obtain chromatic visualization of the differences helping pattern recognition and detection of outliers in the data set.

3.2.2 Bioeconomic performance of national industrial sectors in the European context

In Table 3 we 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, we 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. As a result, we obtain the data array shown in Table 3-1 ([61 107 12] MJ/h and 33 €/h), which can be used for internal comparison with national industrial sectors (inside Europe) or for external comparisons with analogous data referring to other world regions.

As regards the internal comparison, we 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 3, 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 3-1 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 3-1 Metabolic characteristics of the industrial sector as whole of Bulgaria, Finland, Spain, and the EU22. The classic economic energy intensity (EEI) is listed for comparison only. Energy consumption for calculating EEI is expressed in joules equivalent

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_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%	15
Bulgaria	1,0	X	29	51	3,4	6,0	=	30	53	3,5	6,2	1,9%	0,35%	23
Finland	0,74		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 3-1 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 added value 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.

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

In this section we 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, we 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 ELP have to be done with extreme caution (a difference of around 30% may be found).

As can be seen from Tables 3-2, 3-3 and 3-4, Bulgaria, Finland and Spain display a similar metabolic pattern in that the energy sector has the highest metabolic rate of electricity (EMR_{elec}) and heat (EMR_{heat}), and the transport sector the highest metabolic rate of fuel (EMR_{fuel}). 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) that require more human control.

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 work hours). Electricity (EMR_{elec}) and heat (EMR_{heat}) 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 (EMR_{fuel}) 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 (EMR_{fuel}=2,8 MJ/h) with almost 0,6 cars per capita and more than 15,000 km/vehicle/year (Eurostat, 2015e). Regarding the metabolic rates of the productive sectors, Finland has again the highest values with the exception of EMR values in TS and EMR_{heat} 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 EMR_{heat} (82 MJ/h) due to the large amount of natural gas consumed in pipeline transport (Eurostat, 2018a).

As regards the economic job productivity (EJP)[1] 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.

Table 3-2 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		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	x	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%	-

[1] The VA and EJP data reported in this section are only comparable between Tables 3-2, 3-3 and 3-4, but not with the tables in other sections of the paper 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 3-3 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		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	x	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 3-4 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		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	x	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%	-

3.2.4 Bioeconomic performance of industrial subsectors

In this section we examine the industrial sector in detail. To this purpose, we construct a matrix formed by 13 data arrays that characterizes the metabolic pattern of the various sub-sectors (end-uses) for each country (Tables 3-5, 3-6, 3-7). 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 3-5 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, Tables 7-9 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.

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Table 3-5 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 3-6 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 3-7 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

In Tables 3-5, 3-6 and 3-7 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 3-8 for 'iron & steel' and in Table 3-9 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).

Table 3-8 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 3-9 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

As can be seen from Tables 3-8 and 3-9, 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. 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 import 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. 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.

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

In the introduction we discussed the peculiar characteristics associated with the metabolic pattern of social-ecological systems: the different functions expressed by the 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. 2012; 2013; 2014). 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 we 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 3-10 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.

Table 3-10 End-use matrix based on extensive variables – sectors/whole society

	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

	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	0,7	1	1,4	6	2
	Energy & Mining	0,10	26	14	0,0	2
	Manufacturing & Construction	0,9	26	55	1	7
	Service & Government	1	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	0,3	6	10	17	5
	Energy & Mining	0,04	19	45	1,7	5
	Manufacturing & Construction	0,9	133	228	21	35
	Service & Government	3	67	9	97	120
	Average Society	47	305	352	264	165

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 3-11.

Table 3-11 End-use matrix based on percentages of total – sectors/whole society

	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	0,044%	7%	23%	0,14%	3,4%
	Manufacturing & Construction	1,4%	28%	43%	2,2%	21%
	Service & Government	5,6%	33%	7%	63%	73%
	Average Society	100%	100%	100%	100%	100%

	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	95,2%	32%	30%	20%	-
	Agriculture, Forestry & Fishing	1,15%	0,8%	0,92%	5,1%	6,4%
	Energy & Mining	0,153%	21%	9,5%	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	0,079%	6%	13%	0,66%	3,2%
	Manufacturing & Construction	2,0%	43%	65%	7,9%	21%
	Service & Government	6,2%	22%	3%	37%	73%
	Average Society	100%	100%	100%	100%	100%

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) 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). The relative profiles of the fractions of the two sides are described in Table 3-12.

Table 3-12 The profiles of investments (labor, electricity, process heat, fuels) generating a dynamic equilibrium between dissipative and productive sectors (expresses in %)

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%	90,9%	74,2%	95,6%	94,1%
Primary Sectors	0,4%	9,1%	25,8%	4,4%	5,9%
Average Society	100%	100%	100%	100%	100%

Bulgaria	%HA/HA_AS	%ET_elec/ ET_elec_AS	%ET_heat/ ET_heat_AS	%ET_fuel/ ET_fuel_AS	% GVA/ GVA_AS
Dissipative Sectors	98,7%	78,3%	89,6%	94,8%	86,7%
Primary Sectors	1,3%	21,7%	10,4%	5,2%	13,3%
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	99,4%	91,8%	84,4%	92,9%	94%
Primary Sectors	0,6%	8,2%	15,6%	7,1%	6,0%
Average Society	100%	100%	100%	100%	100%

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 3-1.

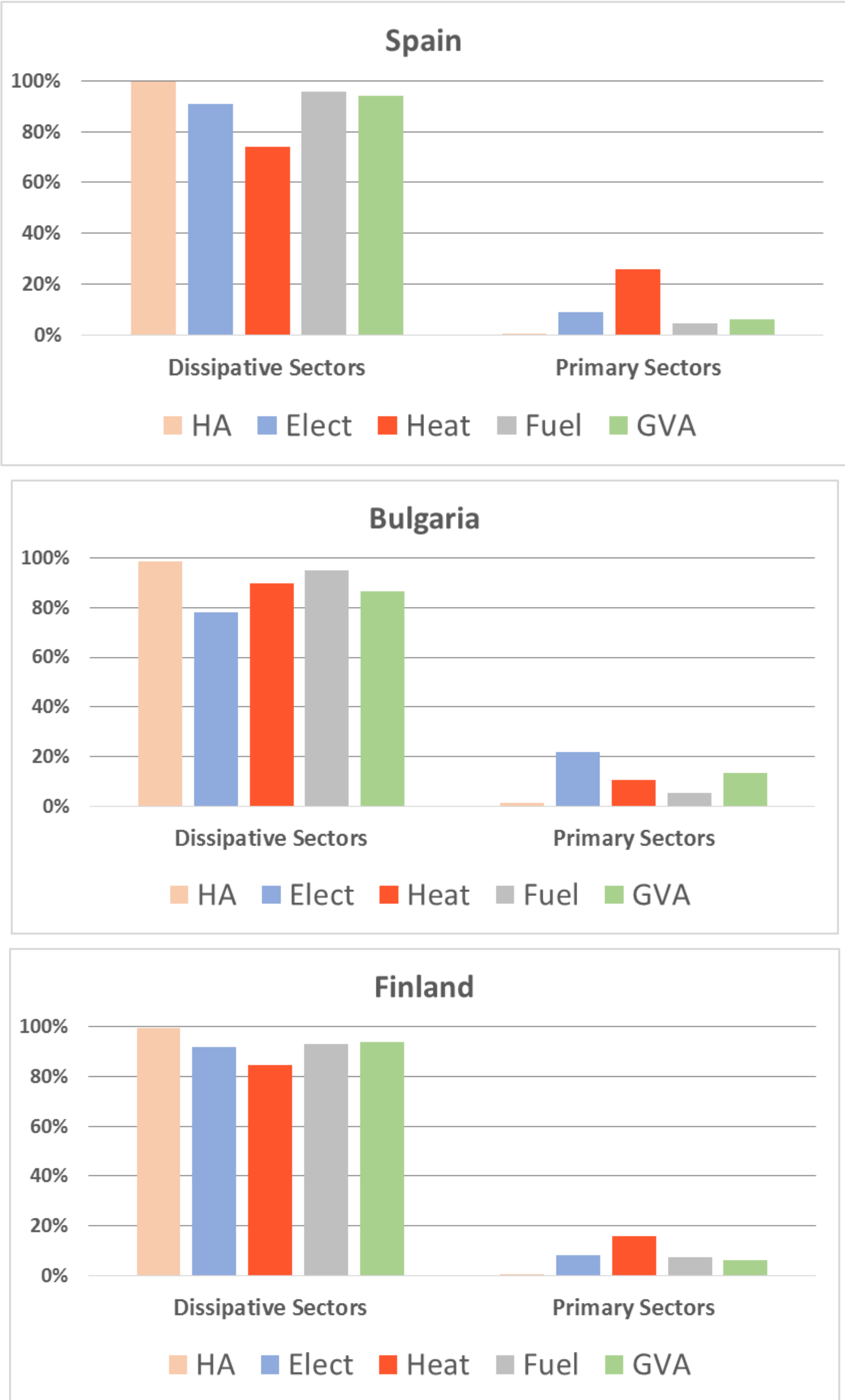


Figure 3-1 The profiles of investments (labor, electricity, process heat, fuels) generating a dynamic equilibrium between dissipative and productive sectors (in extensive variables)

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.

When looking at an end-use matrix quantified using “percentages of the total” (Fig. 3-2) 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 EU 27. Examples of blue prints generated in this way are illustrated in Figure 3-2.

The metabolic blue prints illustrated in Figure 3-2 shows, 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 EU 27. 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 we did not carried out analysis based on temporal series.

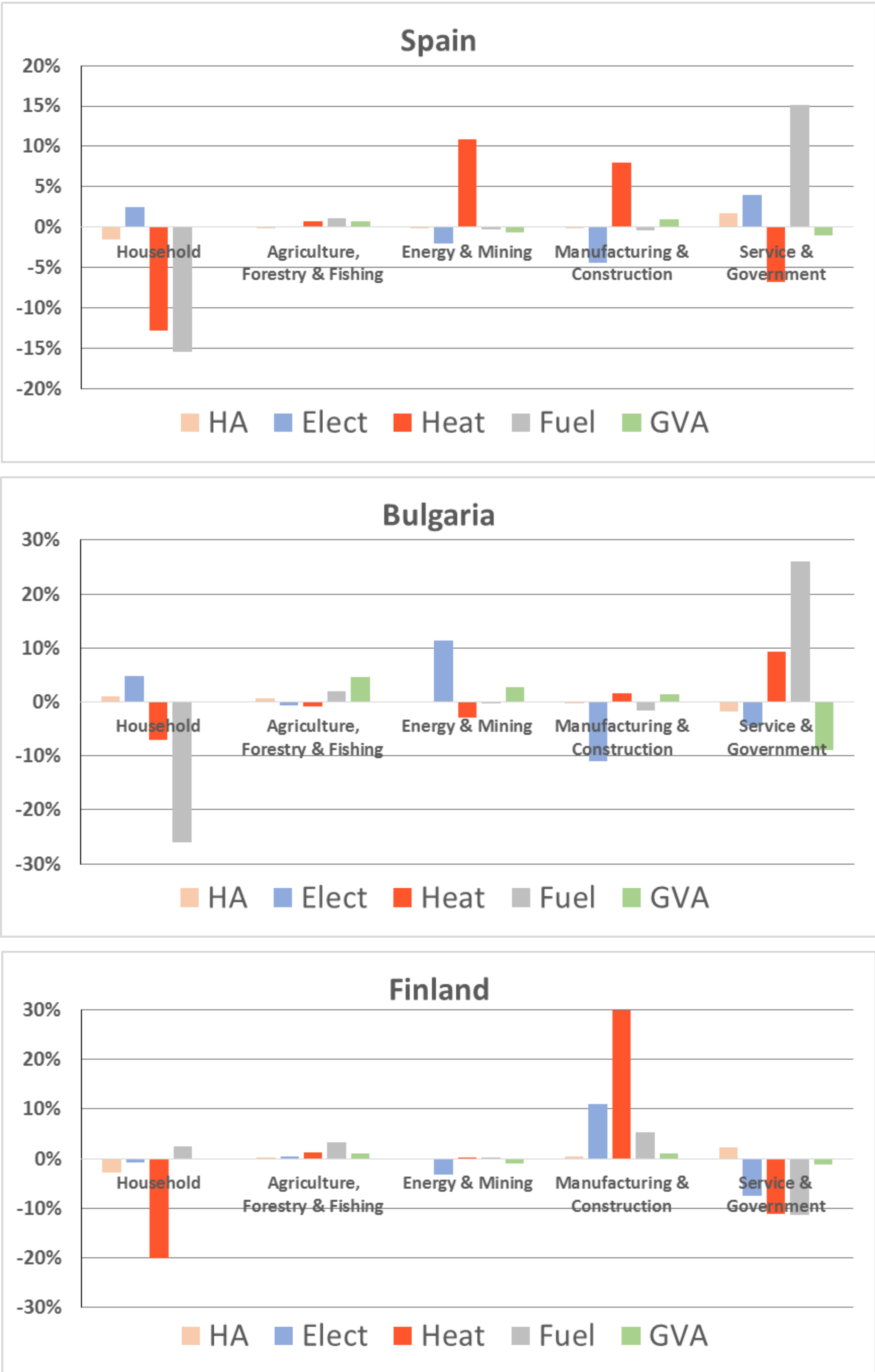


Figure 3-2 Blue prints of the metabolic pattern of EU countries based on the differences in the profiles of investments (expressed in percentage) over EU 27 averages (benchmarks)

3.3 Section 2

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

We 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. 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.

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 3-13 and Figure 3-3.

Table 3-13 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	x	2,6	4,3	3,9	2,6	=	11.415	19.110	17.243	11.631	100%	100%	6,4
Household	4.167	x	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	x	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	x	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	x	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.

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

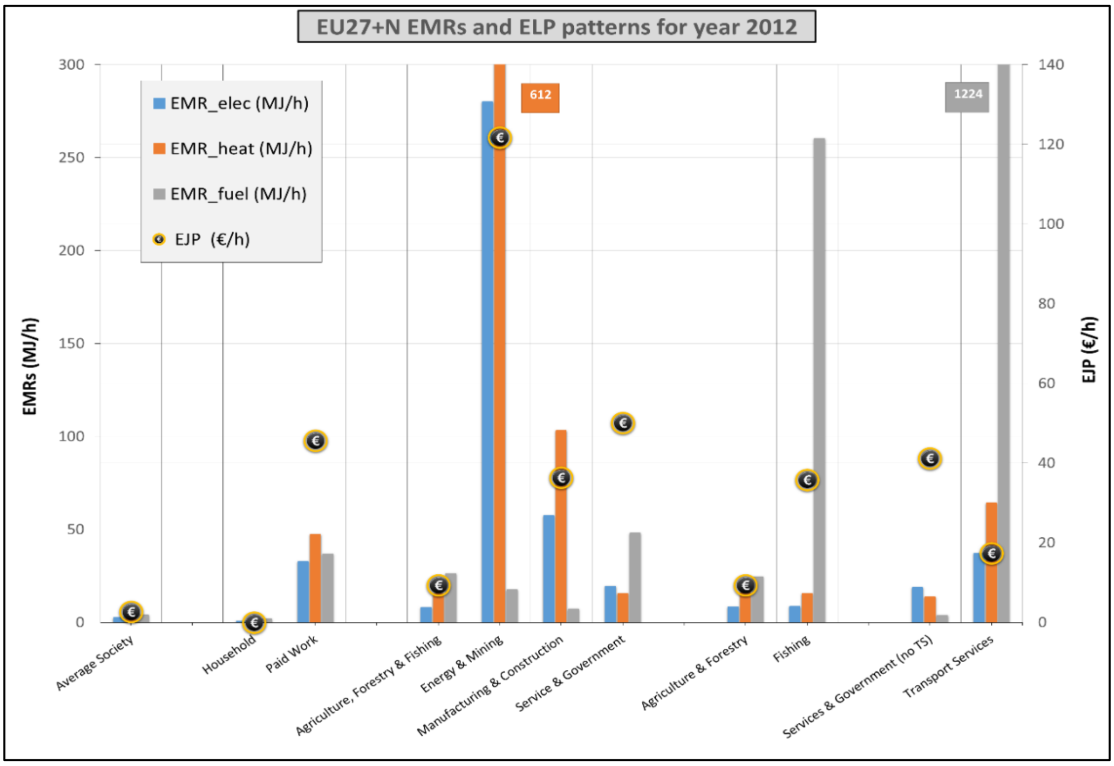


Figure 3-3 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n to Level n-3 of EU27+Norway for year 2012

When 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 3-13 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 3-3.

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 fraction of GVA) and not on the specific technological performance of local processes. 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 3-13.

When moving to national analysis we use the same set of levels as illustrated in Figure 3-4, but this time the values are calculated for data referring to processes taking place within the national boundaries.

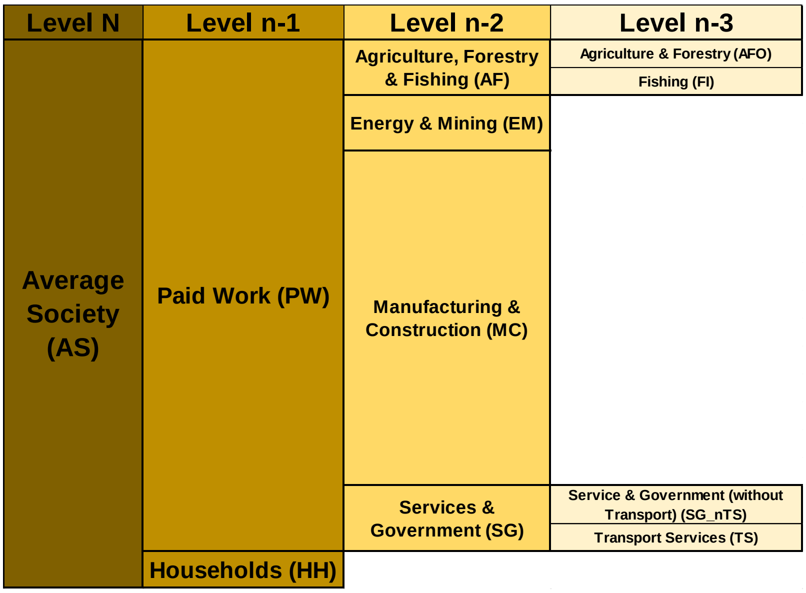


Figure 3-4 Dendrogram of the different levels and compartments of analysis

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 3-14 and in Figure 3-5.

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Table 3-14 Average Society End use matrix of EU27+Norway for the year 2012

AS	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	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

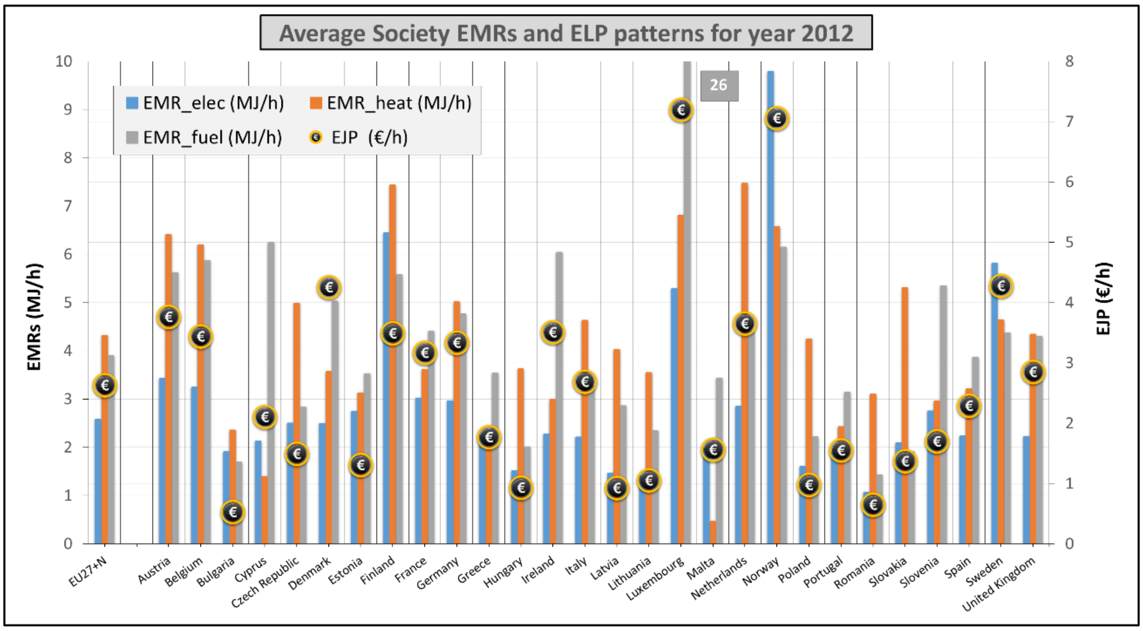


Figure 3-5 Average Society Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Sectors of national economies Level n-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 3-15 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) 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 3-15 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

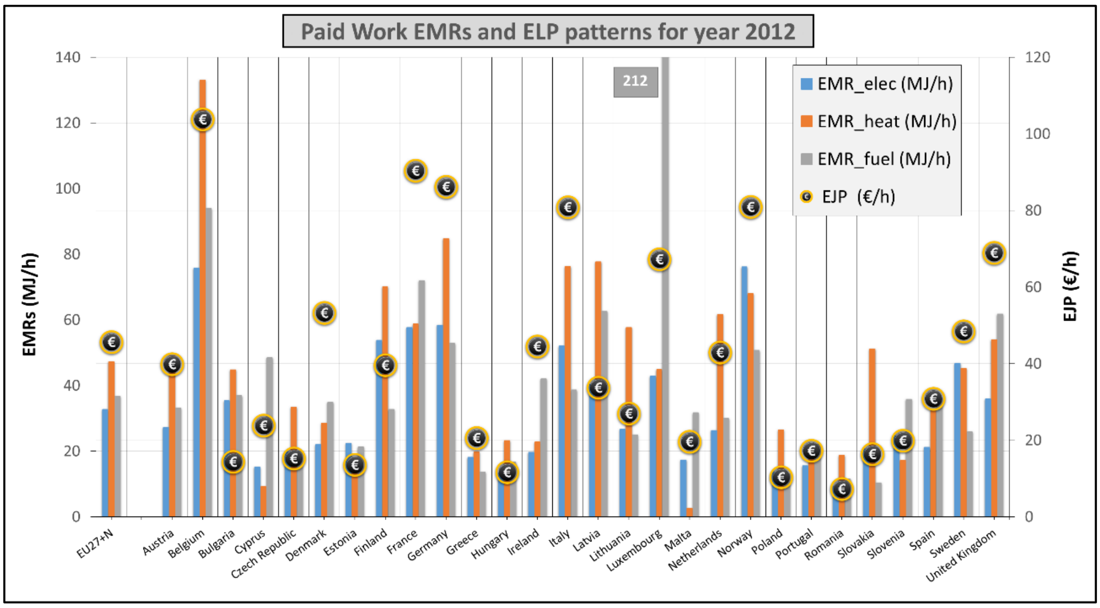


Figure 3-6 Paid Work Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Household

In the MuSIASEM accounting framework the Household sector by definition doesn't generate any value added, 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. Table 3-16 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) in terms of an average 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 3-16.

Table 3-16 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 3-7

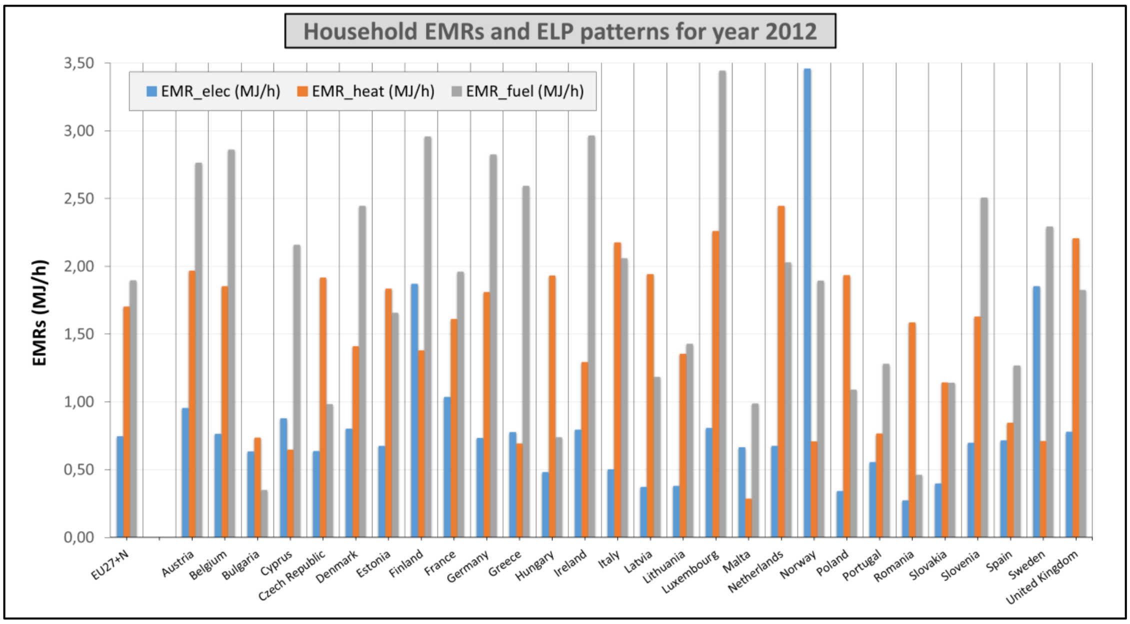


Figure 3-7 Household Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Level n-2 – economic sectors

In this section we open the Paid Work splitting it into four big 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.

Energy & Mining

The characteristics of the end uses in the Energy & Mining sector varies a lot from one country to another – Table 3-17 and Fig. 3-8. 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 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).

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Table 3-17 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

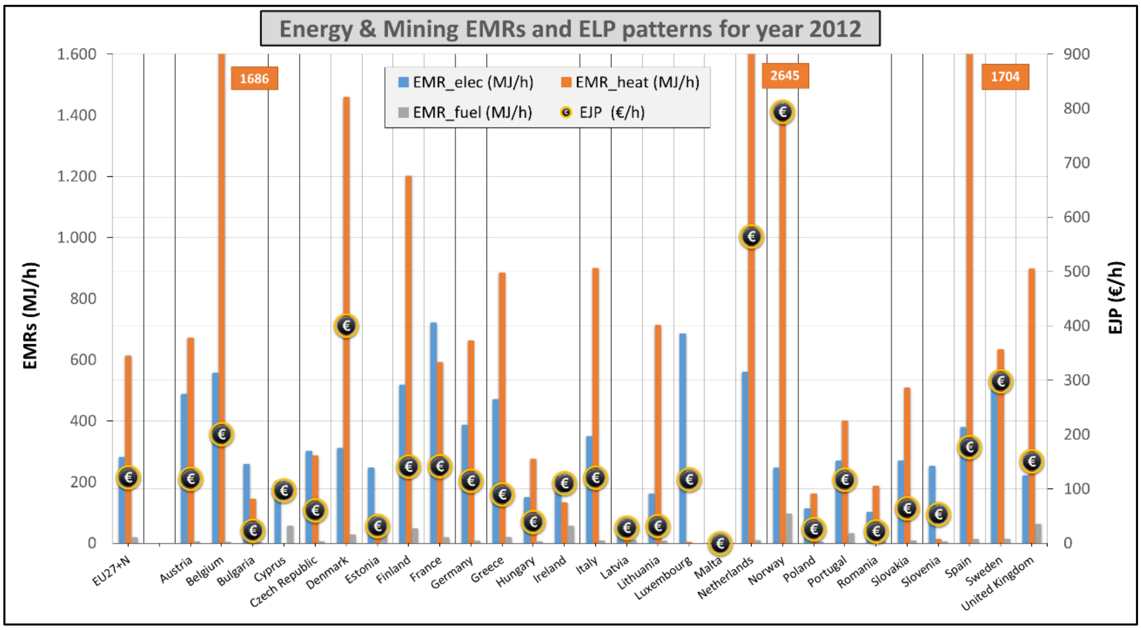


Figure 3-8 Energy & Mining Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Agriculture, Forestry & Fishing

Agriculture, Forestry & Fishing (AF) sector presents the lowest Energy Metabolic Rates, as well as the lowest Economic Job Productivity – Tab. 3-18 and Fig. 3-9. 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 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 3-18 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	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	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

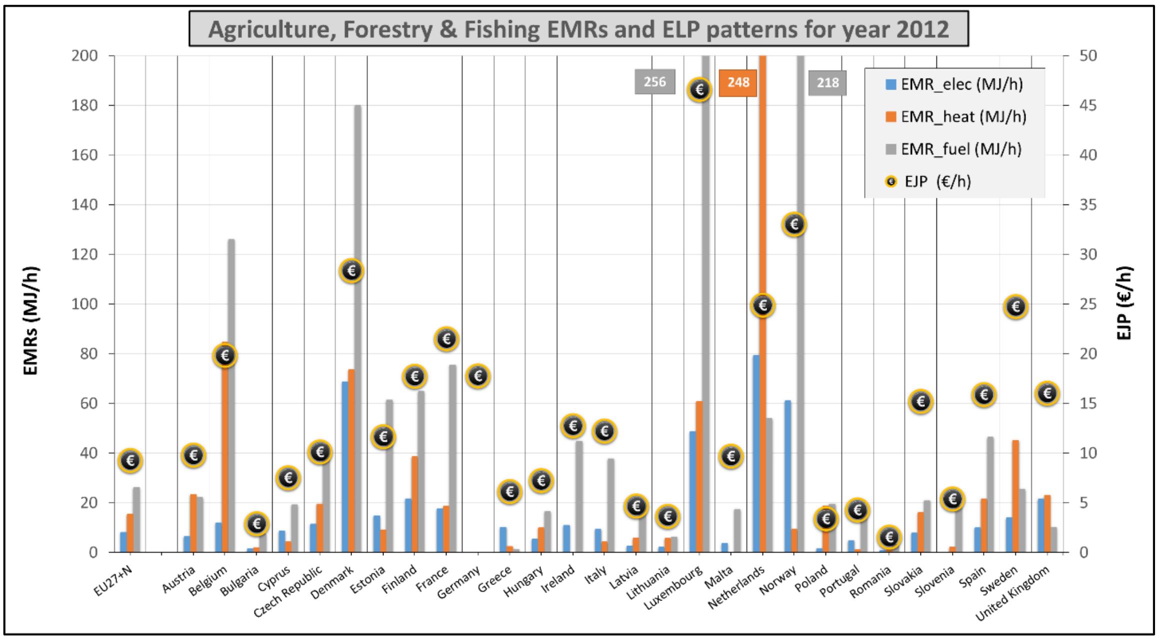


Figure 3-9 Agriculture, Forestry & Fishing Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Manufacturing & Construction

The metabolic pattern of the industrial sector for the EU27+N countries is shown in Table 3-18 and Fig 3-10. Here we can see the relation between the level of EMR 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 Section 3 when opening this sector and when 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 efficiency.

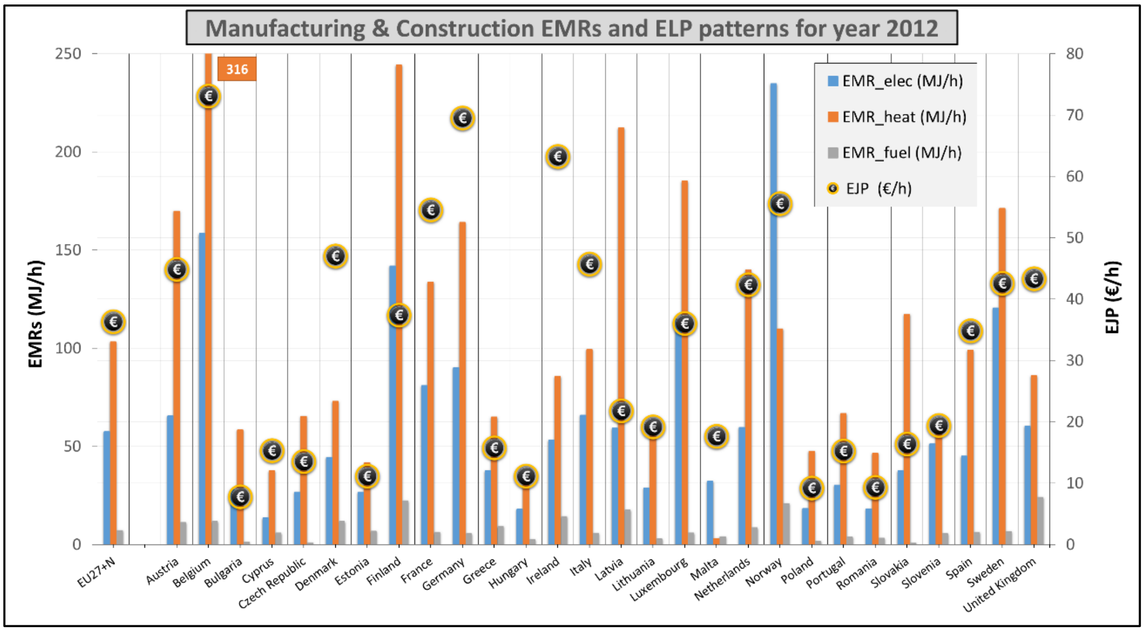


Figure 3-10 Manufacturing & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Table 3-19 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

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. Looking at Figure 3-11 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 3-20 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	0,2%	0,1%	6,0
Lithuania	0,64		18	22	35	29		11	14	22	19	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	12		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

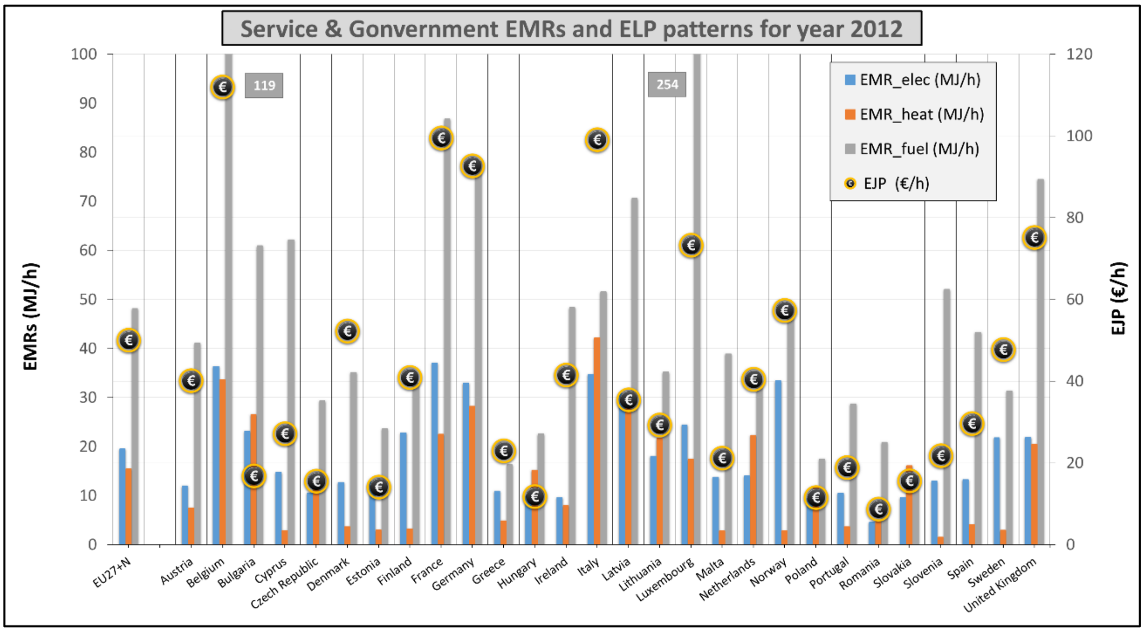


Figure 3-11 Service & Government Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Level n-3

At this level of analysis, we split the agricultural sector in two: (i) Agriculture & Forestry; and (ii) Fishing; and we split the service and government sector in two: (i) Transport Service; and (ii) Service & Government. We 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.

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 3-21 and Figure 3-12 shows, high Economic Job Productivity is clearly obtained when Energy Metabolic Rate are high (e.g. Denmark [71, 76, 140] MJ/h and 29 €/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 16 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).

Table 3-21 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

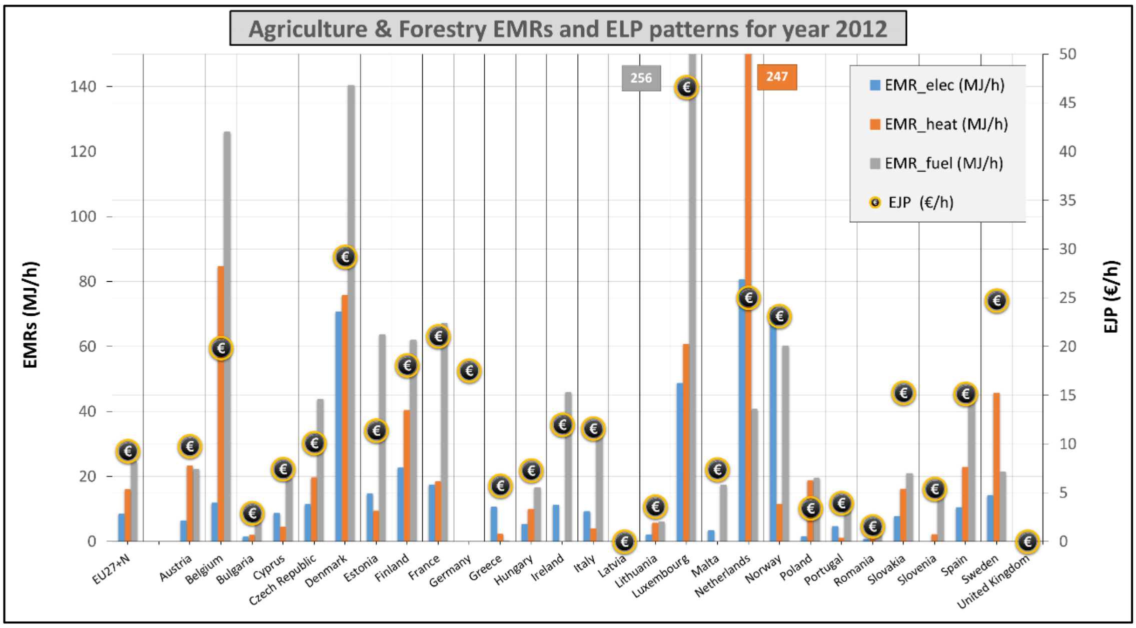


Figure 3-12 Agriculture & Forestry Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

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 3-22 and Fig. 3-13. 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 3-22 Fishing End use matrix of EU27+Norway for the year 2012

UNRELIABLE – MISSING DATA

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	[illegible]	0,3%	4,2
Denmark	3,0		0	0	1.567	99		0	0	4.654	[illegible]	4%	22
Estonia	1,9		17	0	0	19		[illegible]	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	[illegible]	24	13		0	212	1.115	20%	7%	2,9
Hungary	25		10	6	0	5		25	14	0	1,1%	0,1%	6,8
Ireland	[illegible]		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%	-

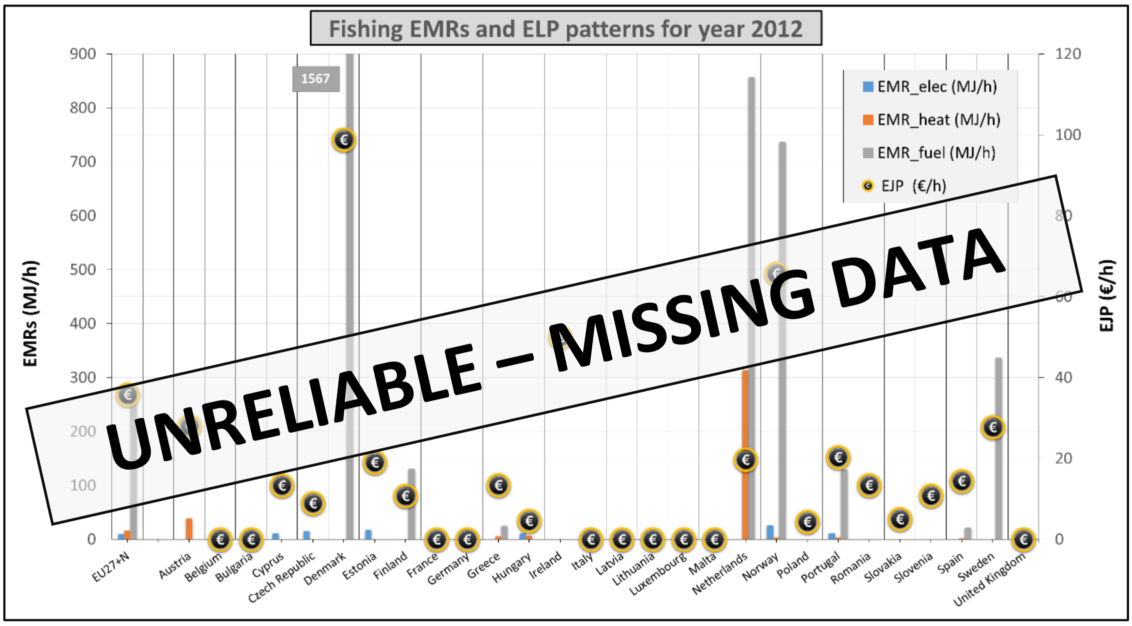


Figure 3-13 Fishing Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

Transport Service

The vast 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 has to add trains running on electricity and vehicles running on gas. However, in spite of 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.

Table 3-23 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	[illegible]	0,5%	45
Finland	189		14	15	458	32		2,7	2,9	[illegible]	3,0%	3,5%	21
France	-		-	-	-	-		45	[illegible]	[illegible]	-	44%	37
Germany	-		-	-	-	-		[illegible]	[illegible]	1.088	-	-	-
Greece	353		1,9	50	279	[illegible]		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	[illegible]	888	36		0,16	0,85	99	1,8%	3,7%	34
Italy	[illegible]		-	-	-	-	=	39	113	533	-	-	-
Latvia	[illegible]		-	-	-	-		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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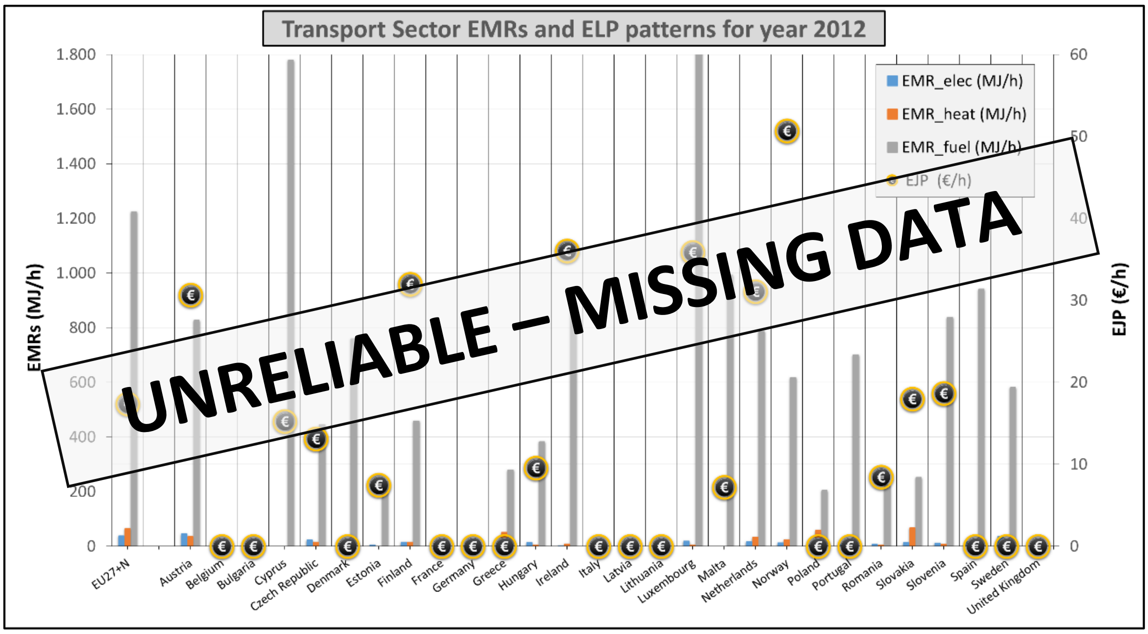

Figure 3-14 Transport Sector Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

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 3-24 and Figure 3-15. 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. However, 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, but not for energy.

Better information about the metabolic characteristics of the Service and Government service would be very valuable in the European context. In fact the Service & Government sector (minus Transport) generates almost 60% of the Gross Value Added and they requires 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 3-24 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%	-	-

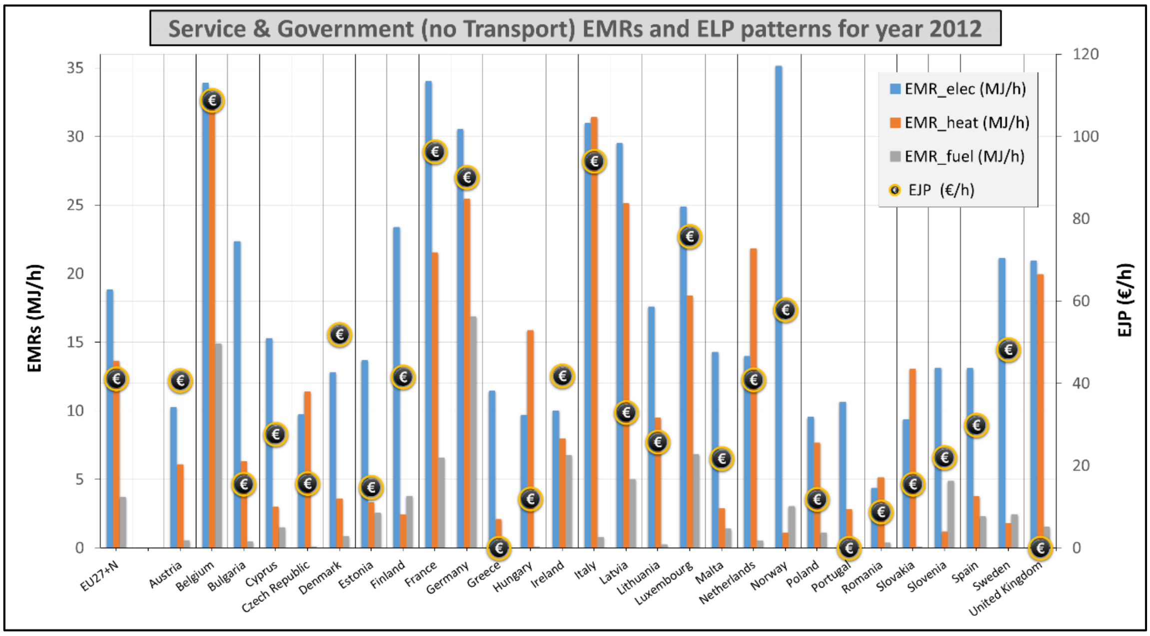

Figure 3-15 Service & Government without Transport Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU27+Norway for year 2012

3.4 Section 3

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

Moving the analysis of end uses down to lower hierarchical levels is essential for the study of efficiency. 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, we 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 an exploratory study, 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 Section 2. 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 gross 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. 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 processes 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 gross value added that can be obtained by using different mixes of energy carriers (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. We 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 3-16): (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 3-16 Dendrogram of the different levels and compartment analyzed with SBS database

We 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 Table 3-25. 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, we 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, we 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, we 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 an electricity (62 MJ/h) and fuel (32 MJ/h) EMRs, whereas Wood & Wood Products have a heat EMR of 137 MJ/h and Transport Equipment with a 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 we must highlight that Machinery and Construction generate the vast majority of working hours (jobs) in Manufacturing & Construction sector representing 24% and 26% of the total generating 26% and 23% of the Gross 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, one can realize the fragility of this kind of indicators for measuring energy efficiency. The low EEI of the construction sector depends on (is determined by) the high EEI of the iron & steel sectors.

Table 3-25 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

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

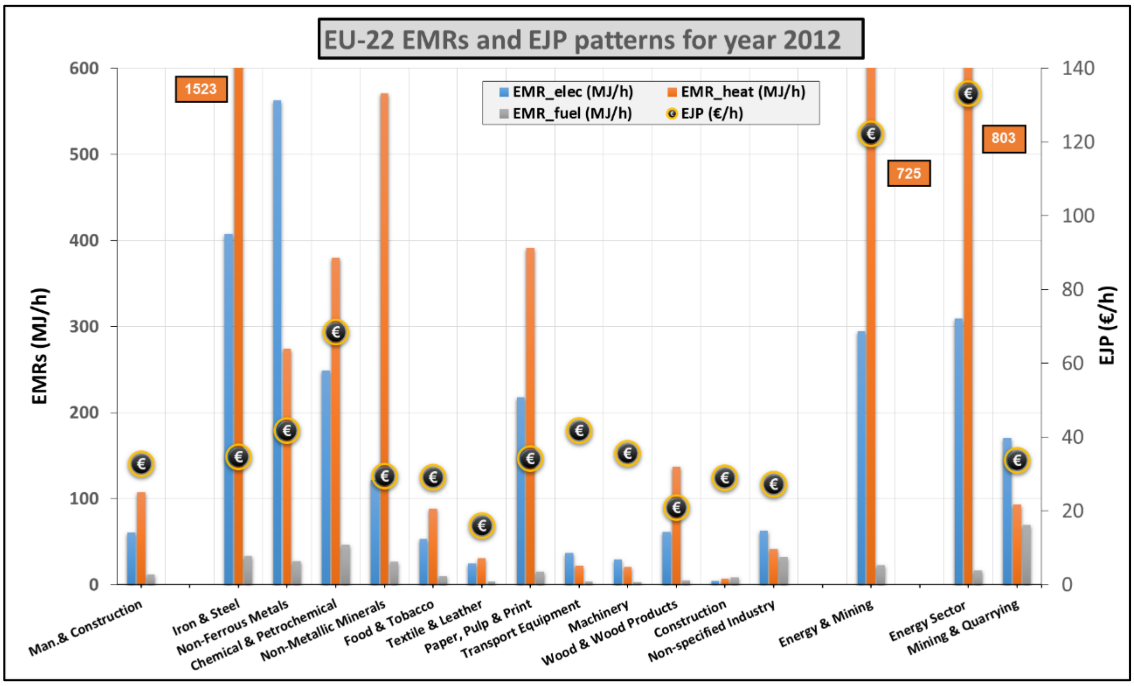

Figure 3-17 Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity for all sectors from Level n-2 to Level n-3 of EU22 for year 2012

Energy & Mining

Opening the Energy & Mining sector for all the EU-22 countries we can see – Table 3-26 - 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%). Norway produces 25% of the Value Added using only 4,6% of the working hours, followed by UK (16%) and Germany (15%).

Table 3-26 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

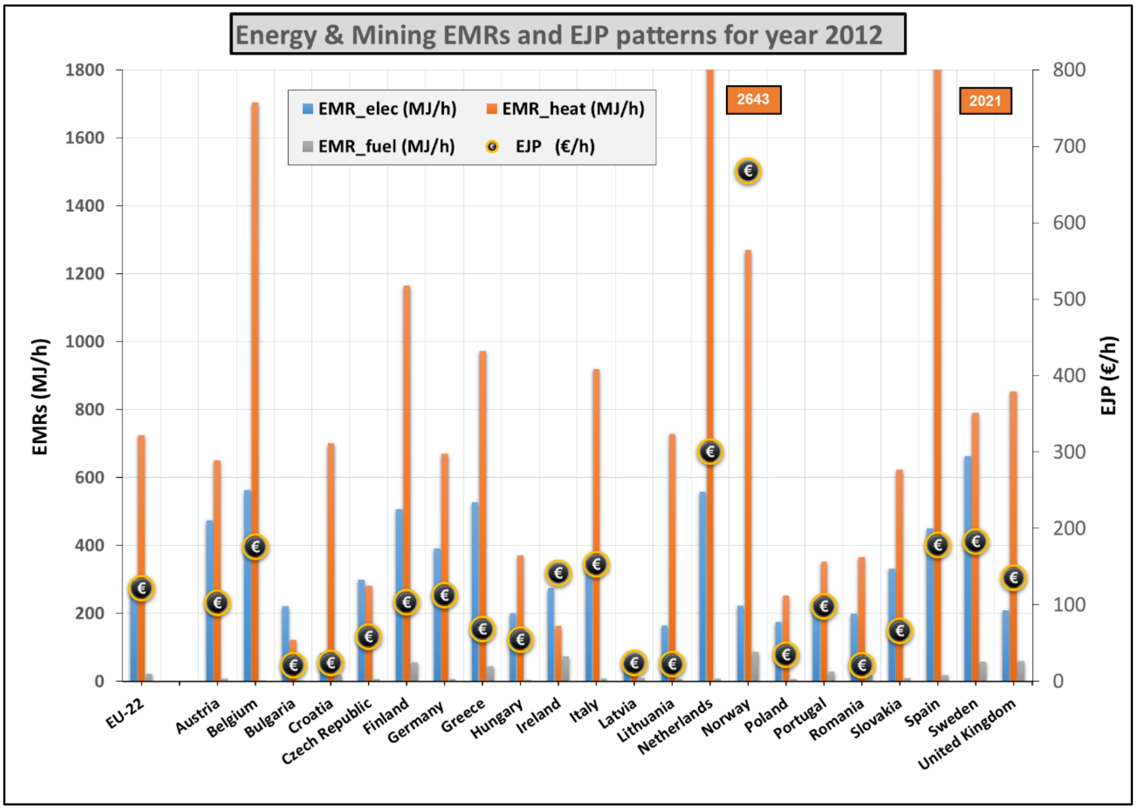

Figure 3-18 Energy & Mining Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Manufacturing & Construction

This end use matrix has already been presented in section 3.2 but the one presented in Table 3-27 and Fig. 3-19 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 3-27 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 (109 €)	%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

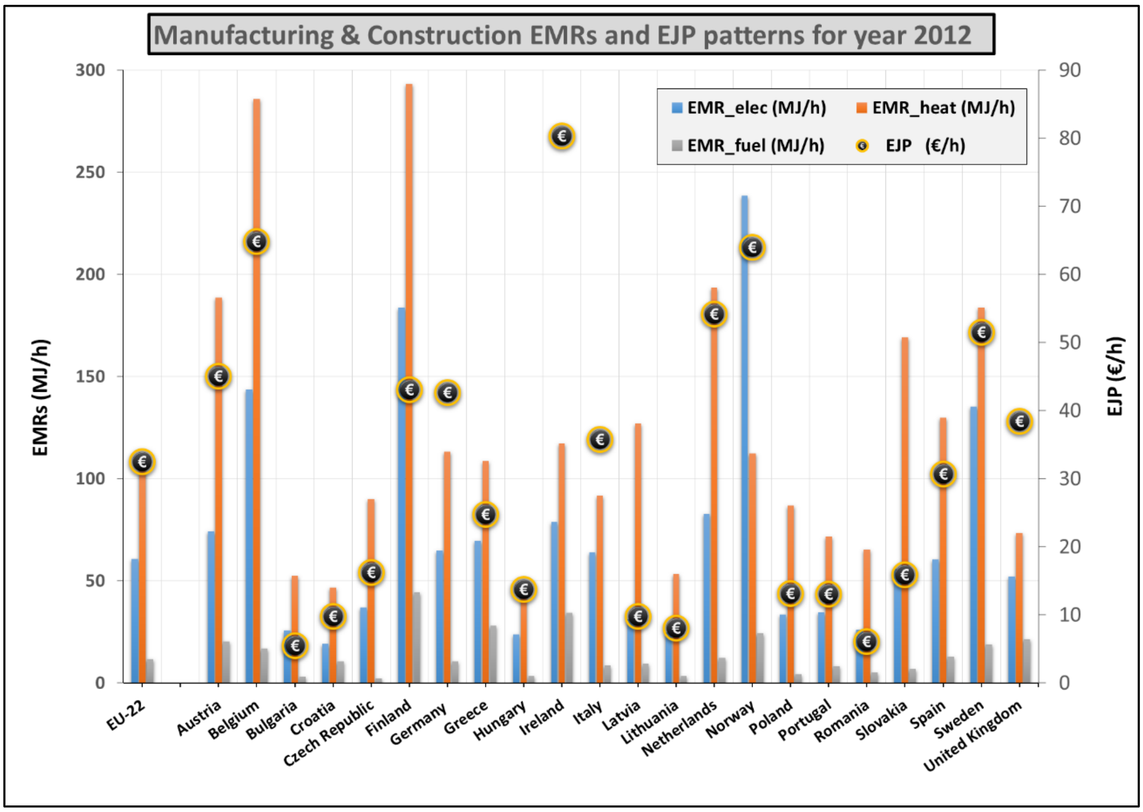

Figure 3-19 Manufacturing & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Level n-3 (using the SBS database)

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.

Table 3-28 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	x	389	1.026	4,5	168	=	82	215	0,94	35	7,7%	9,7%	13
Latvia	23		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

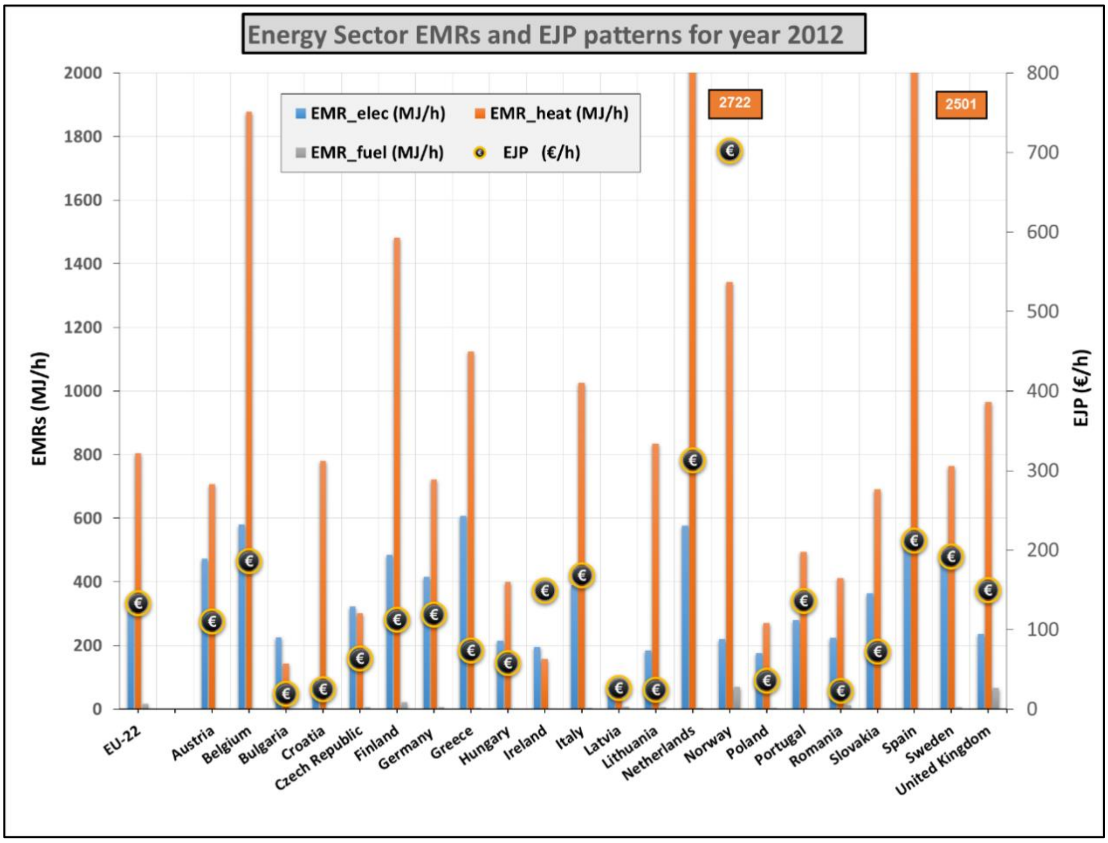

Figure 3-20 Energy Sector Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Mining & Quarrying

From Table 3-29 we can see how Sweden presents really high EMRs [2.889, 1.100, 723] MJ/h, much higher than the other. 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.

Table 3-29 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

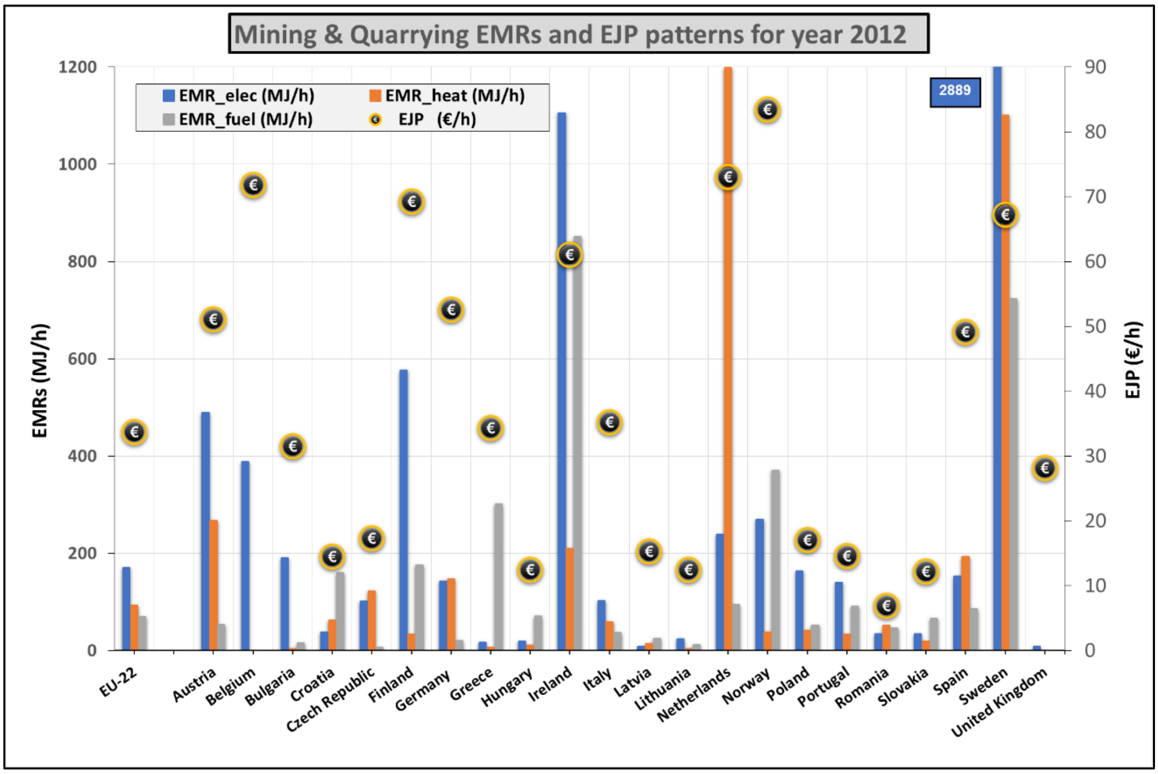

Figure 3-21 Mining & Quarrying Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Iron & steel

Table 3-30 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 GVA 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 type of products and quantity.

Table 3-30 Iron & Steel End use matrix of EU27+Norway for the year 2012

Iron and Steel	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	974	x	408	1523	34	35	=	397	1.484	33	34	100%	100%	80
Austria	37	x	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		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

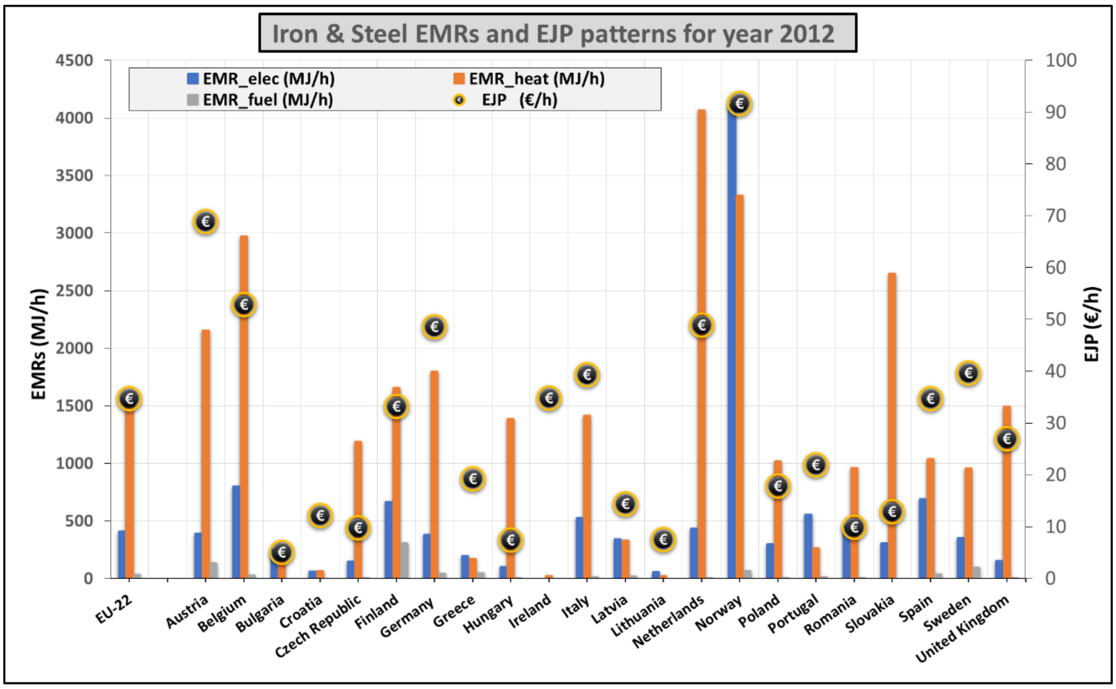

Figure 3-22 Iron & Steel Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Non-Ferrous Metals

Table 3-31 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); and Germany the largest proportion of HA (31%) and VA (34%) in the cluster studied.

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

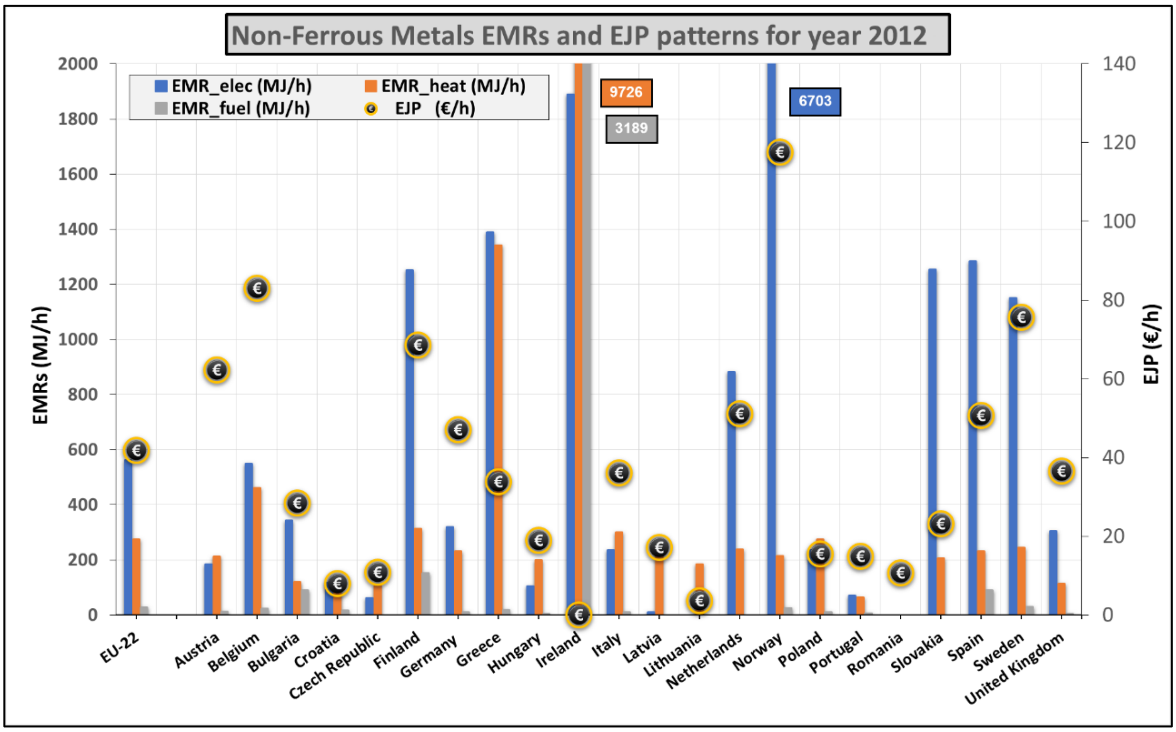

Figure 3-23 Non-Ferrous Metals Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Chemical & Petrochemical

When looking at the end use matrix of the Chemical & Petrochemical sector we can find a clear anomaly for Ireland. The country has a really low profile of values of EMRs [139, 61, 24] MJ/h - by far much higher 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 the Gross 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 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 3-32 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

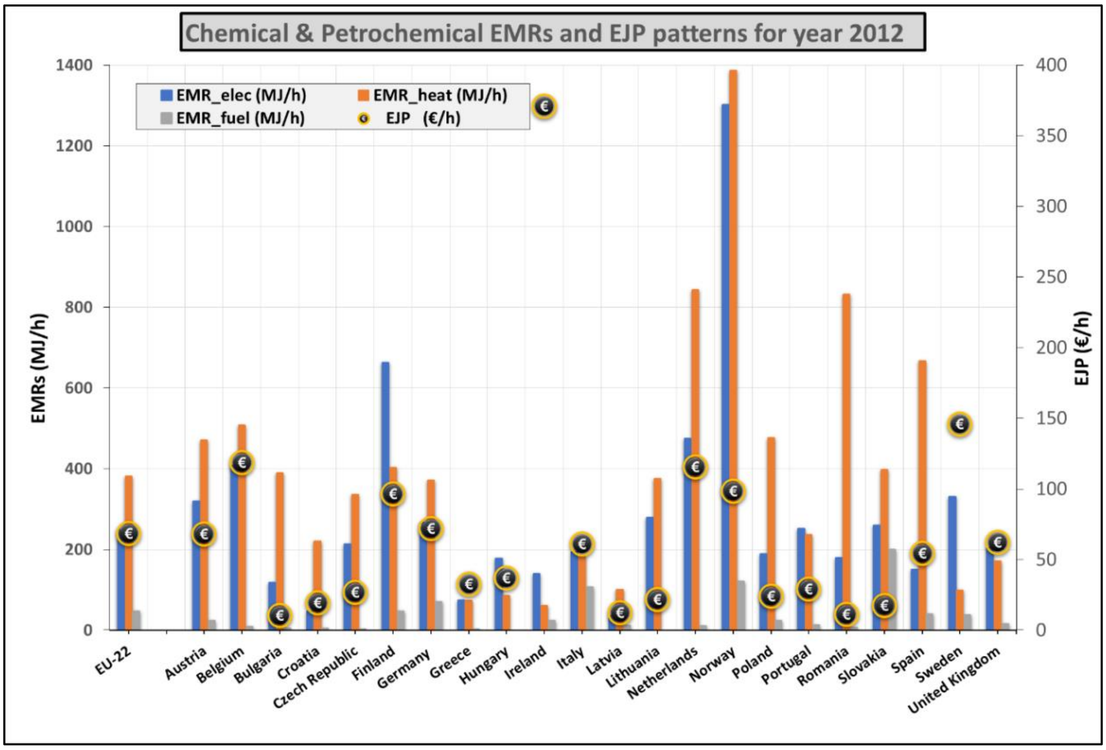

Figure 3-24 Chemical & Petrochemical Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Non-Metallic Minerals

In the case of Non-Metallic Minerals – Table 3-33 and Fig. 3-25 - 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 3-33 Non-Metallic Minerals End use matrix of EU27+Norway for the year 2012

Non-Metallic Minerals	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	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%	0,54%	96
Croatia	20		92	542	14,0	14		1,9	11	0,29	0,28	1,2%	0,53%	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	0,87	1,1	1,4%	2,1%	15
Germany	354		125	585	28	40		44	207	10	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	0,66%	1%	62,6
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	0,42%	0,23%	78
Lithuania	13		62	517	19	10		0,80	6,6	0,25	0,13	0,73%	0,25%	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	1,04%	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	1,12	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	0,042	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

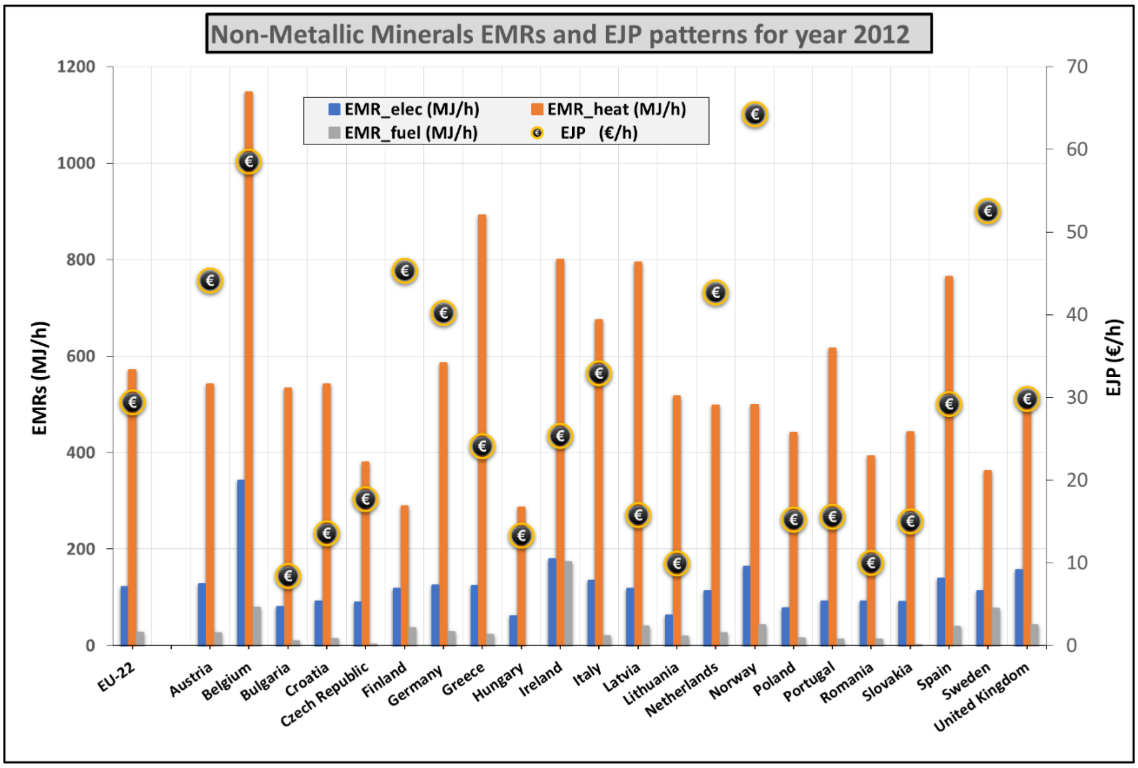

Figure 3-25 Non-Metallic Minerals Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

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 Gross Value Added than Agriculture and Forestry (43 vs 9.3 €/h) while consuming less energy. This fact reinforces our argument of the crucial importance of carrying out an integrated analysis of the end use matrix across levels and dimension of analysis. Looking at the data in table 22, 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 3-34 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

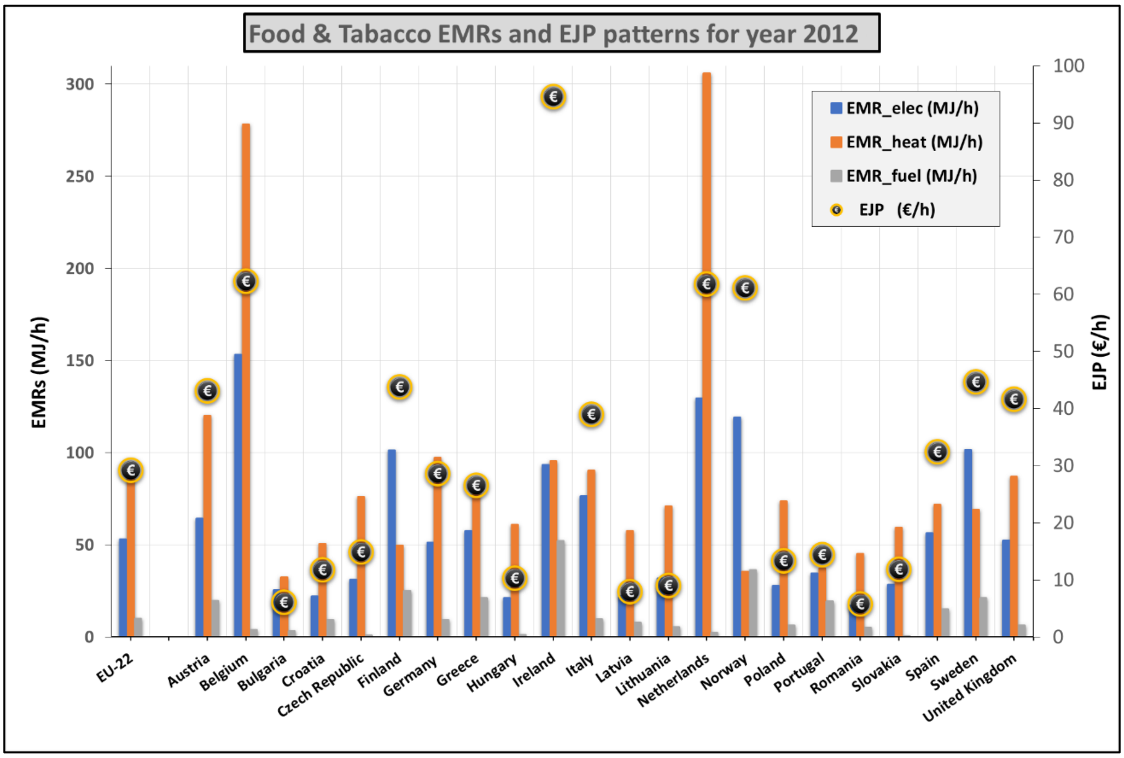

Figure 3-26 Food & Tobacco Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Textile & Leather

Textile & Leather represents a sector with very low values of EJP. Data are presented in Table 3-35 and in Fig. 2-27. It presents some interesting peculiarities like Germany with a small proportion of HA (7%) but generating 40% of the Gross 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).

Table 3-35 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

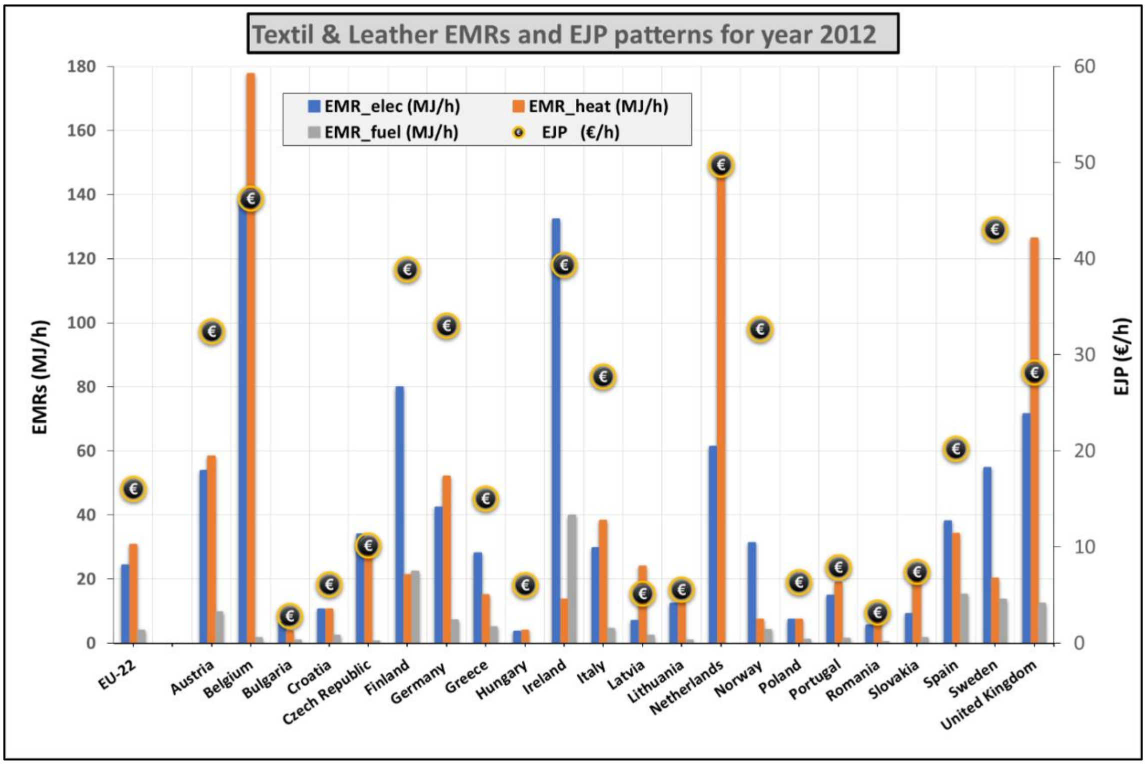

Figure 3-27 Textile & Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Paper, Pulp & Print

Paper, Pulp & Print have been already extensively commented in the pilot case study. Nevertheless, we can mention again in the values given in Table 3-36 and Fig. 2-28, 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. Some other countries like Austria (57 €/h) and Belgium (60 €/h) do have remarkably high EJPs.

Table 3-36 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

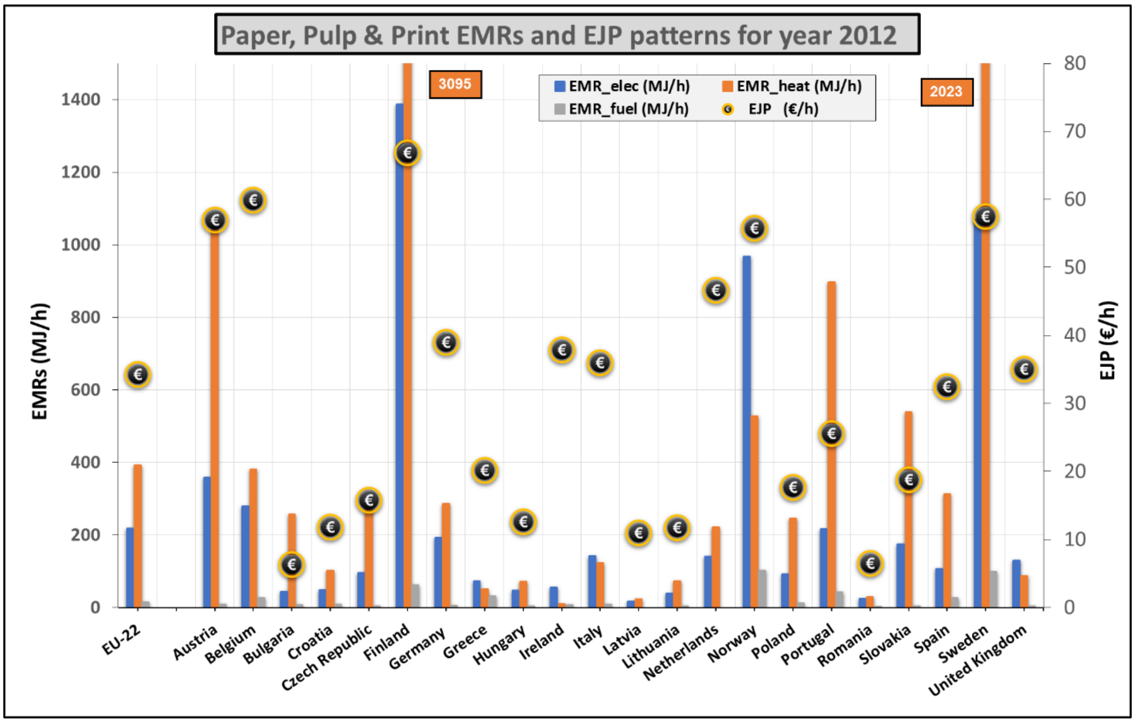

Figure 3-28 Paper, Pulp & Print Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

D.4.2 Characterizing energy efficiency from the matrix of consumption of energy carriers at the national level

Transport Equipment

Data for this sector are illustrated in Table 3-37 and Fig. 3-29. Germany draws attention in the Transport Equipment subsector because it represents 33% of the HA and produce almost 50% of the GVA 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 3-37 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	x	31	0	0,11	35	=	12	0	0,043	14	9,2%	7,7%	2,3
Latvia	6,3		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

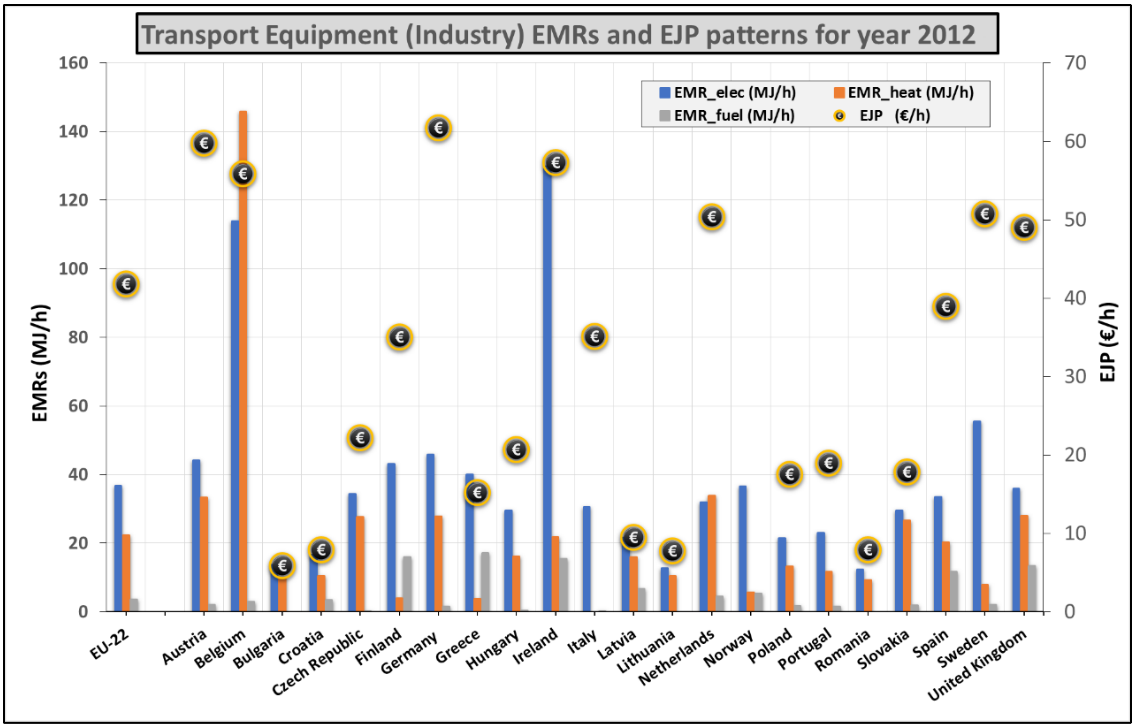

Figure 3-29 Transport Equipment Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Machinery

In this subsector – illustrated in Table 3-38 and Fig. 3-30 - Germany has again a really high percentage of both HA (32%) and GVA (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 3-38 Machinery End use matrix of EU27+Norway for the year 2012

Machinery	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	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

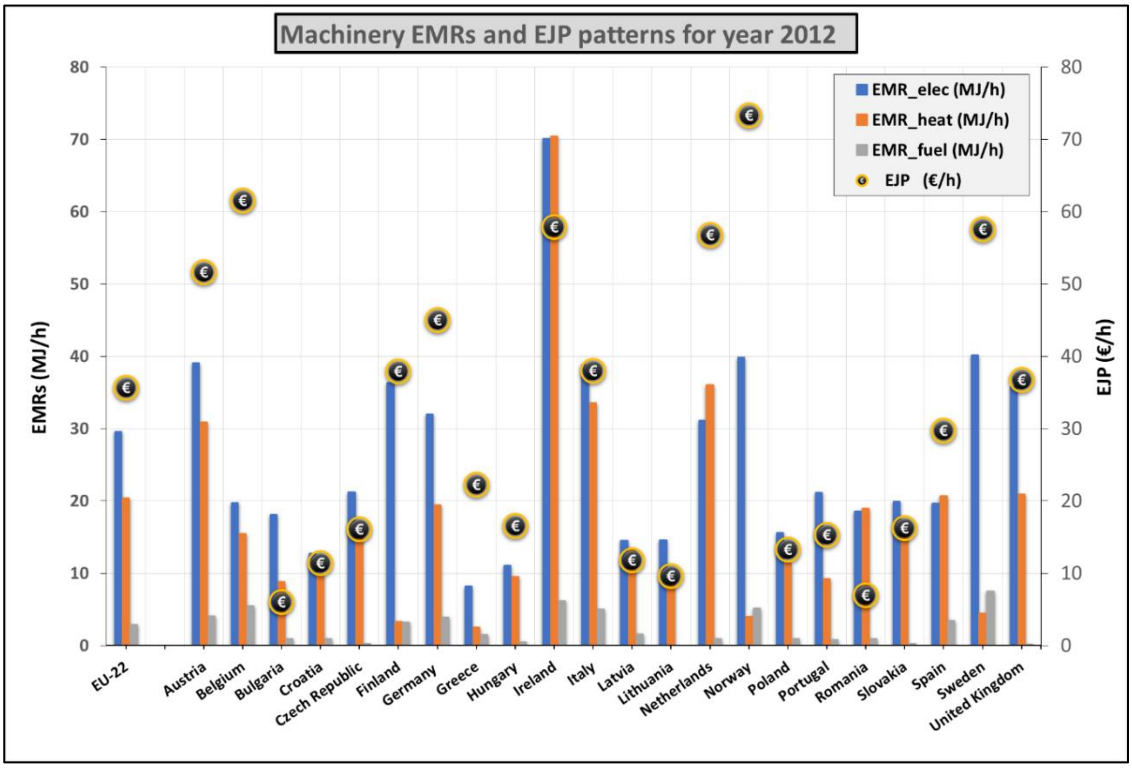

Figure 3-30 Machinery Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Wood & Wood Products

Data for this subsector are illustrated in Table 3-39 and Fig. 3-31. 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).

Table 3-39 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%	-

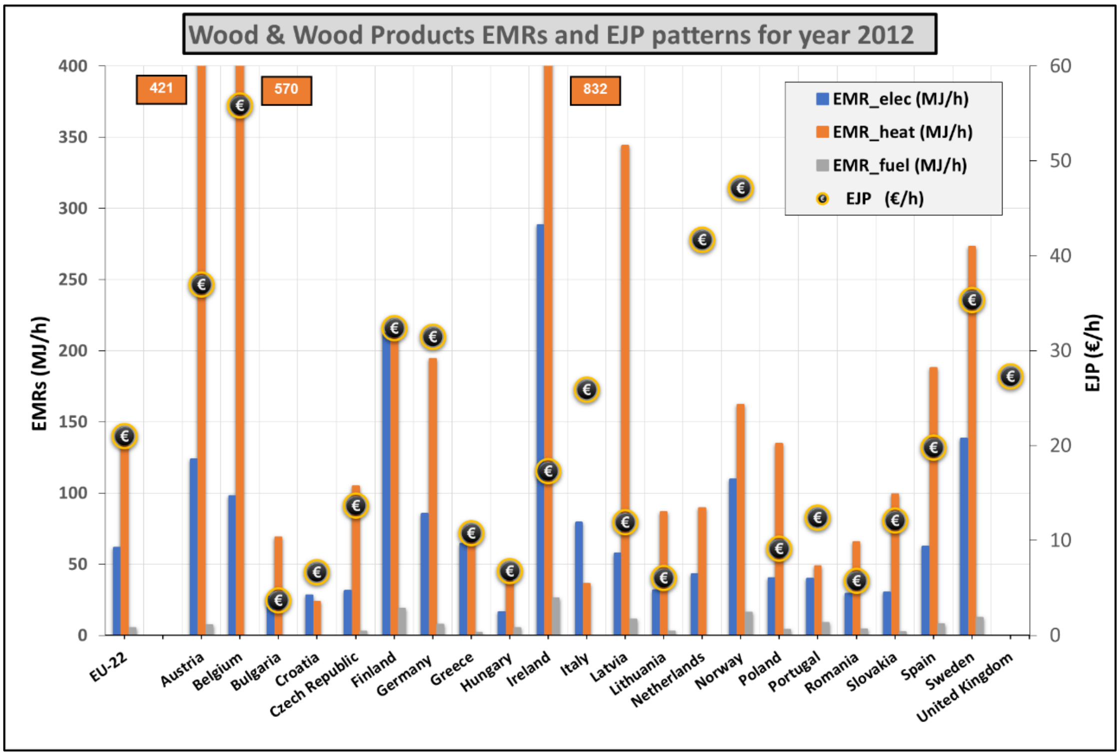

Figure 3-31 Wood & Wood Products Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

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 3-40 and Fig. 3-32. 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 3-40 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	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	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

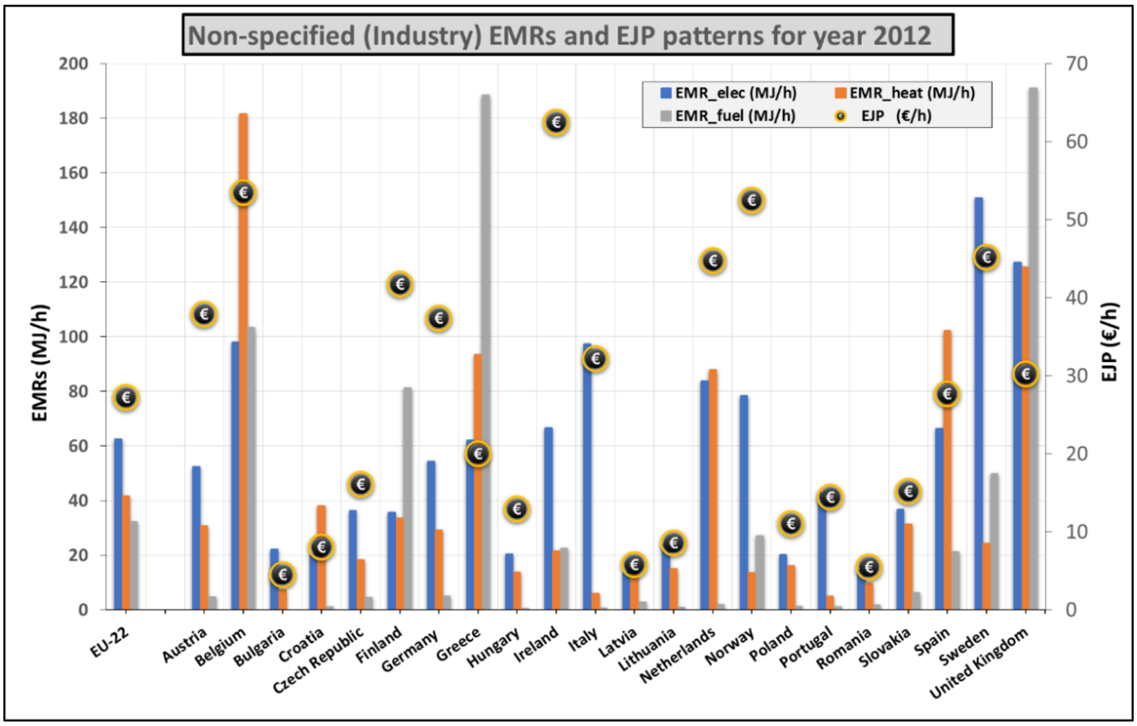

Figure 3-32 Non-specified (Industry) Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

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 3-41 and Fig. 3-32. 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). In regard to EJP, Norway (62 €/h) and Belgium (57 €/h) do have the largest values.

Table 3-41 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	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	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

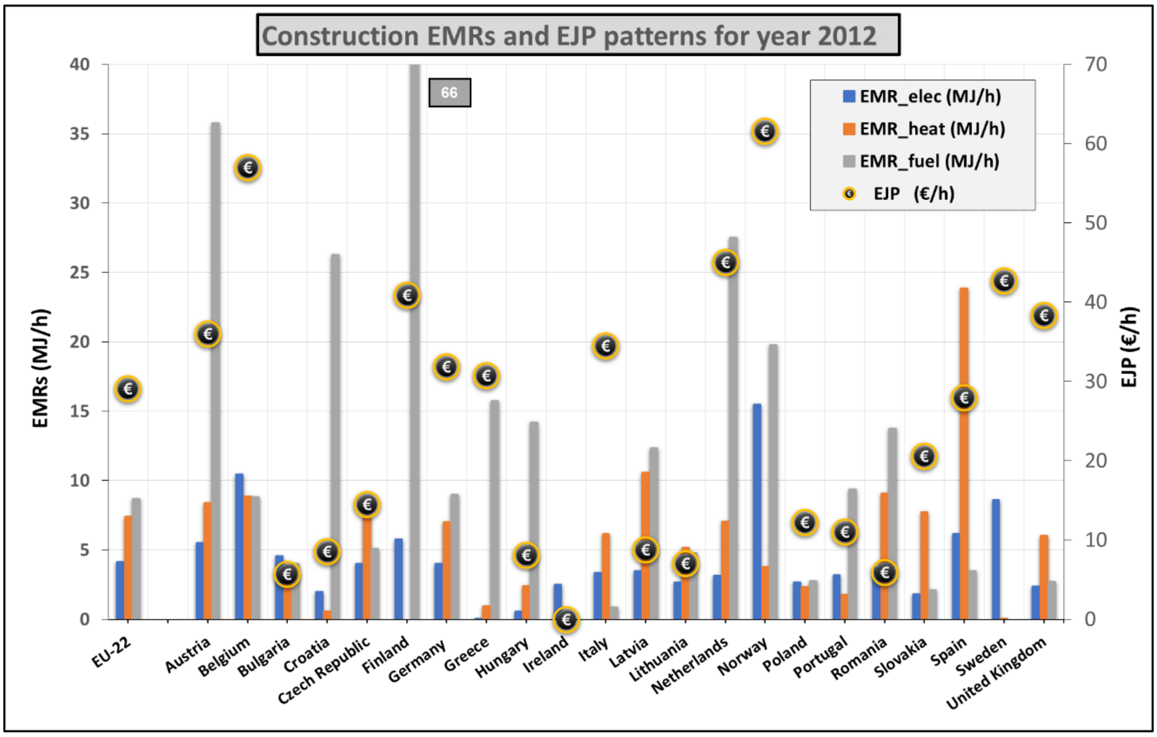

Figure 3-33 Construction Electricity, Heat and Fuel Metabolic Rates vs Economic Job Productivity of EU22 for year 2012

Human Activity allocation matrix for Manufacturing & Construction

After presenting the detailed End Use matrices of the subsectors, we can present the end use matrix of the Manufacturing and Construction assessed in a bottom-up way using the different data source (SBS). The results are presented in Table 3-42.

In this table, we have calculated the EMR in just a single numerical assessment (converting the electricity, heat and fuel consumption in a virtual Primary Energy Source equivalent, what is done when using Tons of Oil Equivalent) expressed in Joules of Primary Equivalent Gross Energy Requirement. This has been done for all the subsectors of MC and for all the EU-22 countries. These values are shown in the table together with the values of EJP. The cells of the box indicate the % of the HA allocated in each subsector per each country and the intensity of the red color shows which country that have higher proportion of his HA in that sector. With this table, we want to show that countries having higher values of EMR (or high values of the indicator economic energy intensities) not necessarily are less efficient. The value of EEI simply reflects the mix of economic activities requiring the allocation of HA (labor) and determining the generation of GVA (the mix of EJP) on economic processes that require different levels of consumption of energy carriers.

Table 3-42 Allocation of Human Activity by MC subsector and Country organized by EMR in Gross Energy Requirement and with Society End use matrix of EU27+Norway for the year 2012

	% OF HA_subsector OVER HA_Manufacturing & Construction														
	IS	NF	CP	PPP	NM	MQ	WWP	NS	FT	TE	Ma	TL	Co		
	Iron and Steel	Non-Ferrous Metals	Chemical and Petrochemical	Paper, Pulp and Print	Non-Metallic Minerals	Mining and Quarrying	Wood and Wood Products	Non-specified Industry	Food and Tobacco	Transport Equipment	Machinery	Textile and Leather	Construction		
EU22	1,8%	0,9%	4,4%	3,6%	3,3%	0,6%	2,4%	8,8%	11%	7,9%	24%	5,4%	26%		
Finland	2,5%	0,7%	3,5%	6,8%	3,3%	1,1%	4,6%	5,2%	7,6%	3,2%	29%	1,3%	31%	528	44
Belgium	2,7%	1,3%	11%	4,1%	4,2%	0,4%	1,5%	6,3%	12%	6,5%	17%	3,0%	30%	443	65
Norway	0,7%	1,6%	3,1%	2,4%	2,9%	1,2%	3,4%	3,5%	12%	7,6%	16%	1,6%	45%	382	65
Sweden	3,4%	0,7%	3,7%	5,7%	2,4%	0,3%	3,7%	5,8%	6,4%	9,3%	24%	0,7%	34%	348	52
Netherlands	1,5%	0,8%	6,2%	4,3%	2,6%	0,2%	1,3%	6,5%	12%	3,9%	22%	1,4%	37%	293	54
Austria	2,7%	1,4%	3,6%	3,5%	3,8%	0,6%	3,9%	8,4%	8,8%	4,6%	26%	2,2%	31%	276	45
Slovakia	4,0%	0,9%	2,6%	2,7%	3,5%	0,5%	2,5%	10%	8,6%	15%	27%	6,5%	16%	234	16
Ireland	0,5%	0,4%	11%	3,5%	2,9%	0,5%	1,2%	16%	19%	1,3%	17%	0,8%	26%	229	81
Greece	2,8%	2,0%	5%	4,4%	4,6%	1,4%	1,9%	7,7%	23%	2,1%	14%	6,8%	25%	209	25
Spain	1,6%	0,7%	4,7%	4,1%	3,9%	0,7%	1,9%	7,0%	14%	6,7%	16%	4,4%	34%	204	31
Germany	2,0%	1,1%	5,5%	3,5%	2,8%	0,4%	1,4%	9,1%	9,9%	11%	32%	1,6%	19%	188	43
Italy	2,0%	0,9%	4,1%	3,4%	3,9%	0,4%	2,1%	8,9%	8,4%	5,7%	28%	9,9%	23%	165	36
United Kingdom	1,2%	0,9%	4,5%	4,5%	2,3%	0,8%	1,8%	8,8%	11%	7,6%	20%	2,2%	34%	149	39
Latvia	1,9%	0,3%	2,8%	2,8%	2,8%	1,9%	13%	6,0%	16%	2,4%	10%	7,0%	33%	133	10
Czech Republic	2,8%	0,5%	2,9%	2,9%	4,0%	0,6%	2,7%	10%	8,4%	12%	30%	3,5%	19%	129	16
Poland	1,6%	0,6%	3,5%	3,2%	4,4%	1,0%	3,6%	12%	15%	7,2%	19%	5,2%	23%	124	13
Portugal	0,5%	0,4%	2,0%	2,9%	4,4%	0,9%	3,0%	7,0%	11%	3,6%	13%	18%	32%	116	13
Romania	1,7%	0,5%	2,6%	2,1%	2,6%	0,8%	3,7%	8,7%	12%	10%	13%	17%	25%	97	6
Bulgaria	1,0%	0,9%	3,4%	2,8%	3,2%	1,7%	2,3%	8,2%	15%	2,8%	17%	20%	21%	83	6
Croatia	0,8%	0,5%	3,4%	3,7%	3,5%	0,7%	4,4%	7,1%	18%	4,1%	16%	9,1%	29%	79	10
Lithuania	0,4%	0,0%	2,4%	2,8%	3,0%	0,9%	7,3%	14%	16%	1,3%	10%	11%	31%	78	8
Hungary	1,1%	1,1%	3,9%	3,1%	2,9%	0,4%	1,9%	9,7%	13%	9,5%	28%	5,2%	20%	74	14
	2637	1793	1086	983	920	613	305	239	239	123	102	99	27	EMR (GER MJ/h)	
	35	42	69	34	29	34	21	27	29	42	36	16	29		EJP (€/h)

4. Conclusions

Ambitious targets for a quick transition to a low carbon economy put strong pressure on the evaluation of effective energy policies. For this reason, it is essential to analyze the implications of the chosen targets. Is the EU 20% energy efficiency target by 2020 (in three years from now) (European Parliament, 2012) achievable? What type of changes in the actual pattern of energy use in the society are required to achieve this goal? What are the priorities if we want to change the metabolic pattern of the industrial sector? What are the criteria to be used to prioritize the interventions? What would be the direct cost and the consequences of achieving the given targets?

In relation to the possibility of answering these questions, we observe that the discussion over energy policies tend to be framed using the narrative of economic energy (or carbon) intensity. As already discussed in Deliverable 4.1 we believe that this narrative, without a better understanding of the multi-scale metabolic pattern of society, does not provide the information that is required to answer these questions. This situation implies the risk of choosing policies on the basis of wishful thinking.

The approach presented in this deliverable is an attempt to characterize the bio-economic performance of the society and the industrial sector integrating information gathered across different hierarchical levels of organization. In particular the MuSIASEM approach makes it possible to study the complex set of relations between the consumption of energy carriers, requirement of human activity and ability of generating gross value added.

Our analysis: (i) characterizes the quantitative (size) and qualitative (rates/intensities of flows) energy metabolic characteristics of the various sectors and sub-sectors of the industrial sector; (ii) assesses the economic job productivity (€/hour of labor); and (iii) makes it possible to study the role that externalization (imports and exports) play in altering the economic energy intensity. In fact, by importing goods a society can guarantee the function (the supply of required goods) without having to build and operate the structural elements needed for such a production (the requirement of fund elements and inputs required for the supply of the imported goods).

A key feature of our approach is the use of 'end-uses data-arrays' filled by a mix 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. It should be noted that the handling of different variables reflecting different relevant attributed of the system in end use matrix does not imply an aggregation of the information into a single indicator (as done for example in the definition of an overall composite indicator). An end use matrix keeps separated the indications referring to different attributes of performance and therefore makes it possible to generate an integrated characterization on a multi-attribute performance space. This avoids the risk of camouflage of shortcoming across multiple-criteria of performance generated by too aggregated indicators – "*Building sustainability indices aggregating energy, water and waste issues pose the risk of camouflage: progress in one field can cover-up deficits in another*" (Pag. 18 Deliverable 5.2 (Spangenberg, 2016)).

The analysis carried out at the level of the industrial sub-sector shows that the differences in the values describing the various end-uses still depend on differences in specific processes taking place in the same sub-sector – e.g. 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 – looking at the characteristics of homogenous production processes carried out at the level of sub-sub-sectors. In this way, by describing the end-uses in terms of technical coefficients (or biophysical production functions) referring to homogenous typologies of processes one could finally focus on the specific role of technological improvement. At this level of analysis, one can establish a direct bridge between bottom-up information (expected characteristics of specific technologies) and top-down information (statistical data referring to the categories provided by statistical offices). 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).

In relation to this point, in this deliverable we have illustrated with practical examples that:

(1) the MuSIASEM accounting framework makes it possible to establish a bridge between assessments of the energy performance of functional elements of the economic sectors defined at different levels of analysis. In this way, the energetic performance of the whole economy (level n) can be characterized as being determined by the energetic performance of the various sectors making up the economy (level n-1). Then in cascade, the economic performance of each sector (level n-1) can be characterized as being determined by the energetic performance of the various sub-sectors (level n-2) making it up. This approach can be used to move to lower hierarchical levels of analysis, where finally it becomes possible to identify the specificity of processes of production (the energy required to produce steel is larger than the energy required to produce textile independently of the efficiency of the technology used). This approach can also be used to move to higher hierarchical level to establish benchmarks describing typologies of similar economies that can be used for comparison of the performance of sectors, sub-sectors or specific process of production. By adopting this accounting method, it becomes possible to characterize the economic performance in two non-equivalent ways – bottom-up and top-down. Therefore, this method can be used for "triangulating" quantitative information across different hierarchical levels of analysis: (i) by using extensive variables (data from statistics) one can describe the size of flows and fund elements; (ii) by using intensive variables (data from technical characteristics determining the quantities of consumed flows per unit of fund element) one can generate expected qualitative characteristics of the performance of different sectors.

(2) the concept of end use matrix – i.e. a description considering both the energy uses in production (in the Paid Work sector) and in consumption (in the Household sector) - provides important features for the organization of quantitative information: (i) it maintains a distinction between the different energy carriers consumed by the various compartments – electricity, fuels and process heat. Therefore, this accounting does not assess generic quantities of "energy" but the specified profile of energy carriers of different type which are required by each one of the sectors and sub-sectors considered; (ii) it includes also an assessment of the labor requirement associated with the consumption of energy carriers in the economic sector (in the sectors and sub-sectors belonging to the paid-work sectors) and the "non-paid-work" time spent in the household. Therefore, this accounting makes it possible to use benchmarks (quantities of energy carrier per hour of labor) that can be used to scale the quantitative analysis across levels. Moreover, the accounting of requirement of labor makes it also possible to address the issue of job creation and employment; (iii) it includes also an assessment of monetary flows associated with the activity of different sectors and sub-sectors. This makes it possible to establish a bridge between the biophysical analysis of the flows of energy carriers and investment of hours of labor going into the various sectors and the associated economic analysis based on monetary variables.

(3) the organization of quantitative information across different levels of organization makes it possible to study the factors determining the dynamic equilibrium between: (i) the Bio-Economic Pressure – BEP is a quantitative representation of the requirement of end uses of the society for the dissipative compartment; and (ii) the Strength of the Exosomatic Hypercycle – SEH is a

quantitative representation of the requirement of end uses of the society for the primary compartments. In turn this analysis makes it possible to study the factors determining the (i) feasibility - compatibility with external boundary conditions determined by processes outside human control. Do we have access to enough Primary Energy Sources to generate the gross supply of energy carriers (both in quantities and mix) required by society? What would be the impact on the environment when considering the aggregate effect of the conversion of these Primary Energy Sources into the required mix of Energy Carriers?; (ii) viability – compatibility with internal boundary conditions determined by processes under human control. Can the competition for finite endowment of energy carriers and labor between the dissipative compartment and the primary sectors be handled respecting the existing technical and economic constraints?; (iii) desirability – compatibility with institutions and normative values. Looking at the values found in the end use matrix of the whole society, is the resulting "material standard of living" – associated with the characteristics of end uses in the dissipative compartment – desirable enough to guarantee the stability of the social fabric? In fact, when the level of end use in the household sector – associated with the material standard of living at the household level - and in the service and government sector – associated with the characteristics of the welfare state - is considered to be too low and unfair, then it is very likely that the social fabric will collapse – e.g. emigration, brain drain, corruption, street violence, social unrest, etc.

(4) the attempt to organize available statistical information into a characterization of end uses across different levels has identified problems of reliability. Labor data coming from Structural Business Statistics (SBS) and National Accounts (NA) cannot be reliably compared due to: (i) the different methodology of data sources, data collection and validation; and (ii) the different categorization (labor statistics split service sector in many subsectors, while energy balance statistics just present one value for all services spite it represent about a third of the total).

A second crucial point is the need of complementing the analysis of the characteristics of the domestic supply generated by a given sub-compartment with its level of openness. In fact, when considering the end-use we can know how much a given sub-compartment consumes in terms of quantities of energy carriers and labor for expressing the domestic supply of a given type of good. However, this type of information needs to be complemented by an analysis of the level of openness of that subsectors determined by the imports and exports. In a globalized economy, the energy efficiency of functional elements – e.g. steel production – can be boosted by importing the supply of iron generated by structural elements - e.g. steel producing plants - operating outside the boundaries of the country under analysis. In this way the function required by the society is guaranteed but the relative burden of energy consumption and labor requirement is externalized to another society.

Also in this case, statistical sources referring to the material trade across industrial subsectors are already available. After this reorganization of classification, they could be finally used to assess the level of openness of sub-sectors.

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