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European Futures for Energy Efficiency

Multi-scale integrated comparison of the metabolic pattern of EU28 and China in time

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Deliverable 4.4

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History of changes

HISTORY OF CHANGES		
Version	**Publication date**	**Change**
1.0		Initial version
2.0	April, 2019	Revision in response to project review - Short executive summary section has been introduced addressing key issues about the report. - Boxes explaining MuSIASEM, Sudoku effect and End use Matrix have been introduced reinforcing the independency of deliverables among them. - Sections has been reorganized - Correction of typos

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Executive Summary

I. The issue to be explored

This deliverable builds on the research line of Work Package 4: exploring the potentialities of the approach of the *end use matrix* to characterize the metabolic pattern of social-ecological systems in terms of energy performance, rather than in terms of efficiency. Within this line, this deliverable addresses three new research questions: (1) when moving the analysis based on the end use matrix to very large Social-Ecological Systems such as the comparison of the metabolic pattern of China and EU28, do we still get a meaningful integrated representation?; (2) can we carry out a comparison in time (2000-2016) of two metabolic patterns of social ecological systems while observing it simultaneously at different levels and scales of analysis across non-equivalent descriptive domains? What types of problems are encountered with this analysis across levels? What type of insights can be obtained developing a decomposition analysis of metabolic indicators from multi-scale fund-flow approach?; (3) can we explore the implications of externalization on the stabilization of the metabolic pattern of social-ecological systems and on how does it affect its overall performance? Put in another way, can we identify the factors determining the stability of societal metabolism in relation to the terms of trade?

II. What was done to investigate it

This study required addressing and solving a few methodological and practical problems:
#1 - solve the problem generated by the different categorization of data used for the accounting when using data sources from Europe and China;
#2 - solve the problem of lack of consistency of data across the historic series (2000-2016) – not all the data were available for the chosen set of years, so we had to interpolate a few data in order to have three complete datasets over the three chosen years;
#3 - decide how to visualize the very rich dataset obtained as result of our analysis: data referring to different years, different social-ecological systems observed at different levels – e.g. whole economy, individual sectors, sub-sectors (the deliverable has 99 figures and 23 tables!);
#4 - develop a method of decomposition analysis (multi-scale fund-flow decomposition analysis – described in Section 2.1.3) to study the factors explaining the differences and the changes in the metabolic characteristics of EU and China over the considered period of time, when observing their functional elements across different levels;
#5 - develop and apply a method for assessing the effect of externalization on the metabolic pattern of EU27 and China.

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 differences and changes of the metabolic pattern of China and EU27 in the period 2000-2016 observed at different levels of analysis. A multi-scale fund-flow decomposition analysis and externalization have been developed and applied within the MuSIASEM rationale. Some visualization of the relational analysis compressed in the EUM over time have been made using Gapminder Tools Offline (www.gapminder.org).

IV. The data and sources

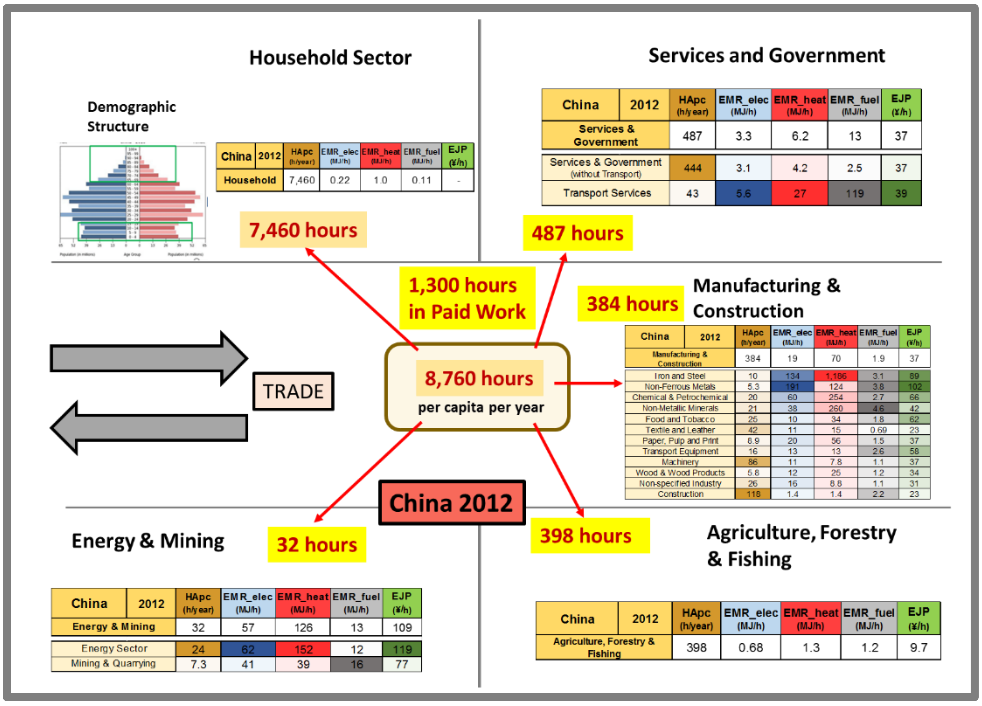
European data: *European Energy Balances* (Eurostat, 2018a); EUROSTAT *National accounts employment data by industry (up to NACE A*64)*; EUROSTAT *National accounts aggregated by industry (up to NACE A*64);*
Chinese data: *Census of the People's Republic of China*; *China Statistical Yearbook*; *China Labour Statistical yearbook*; *China Energy Statistical Yearbook*.
Embodied resources in trade were calculated using the EORA 26 v199.82 database for the year 2012 (Lenzen et al., 2013, 2012).

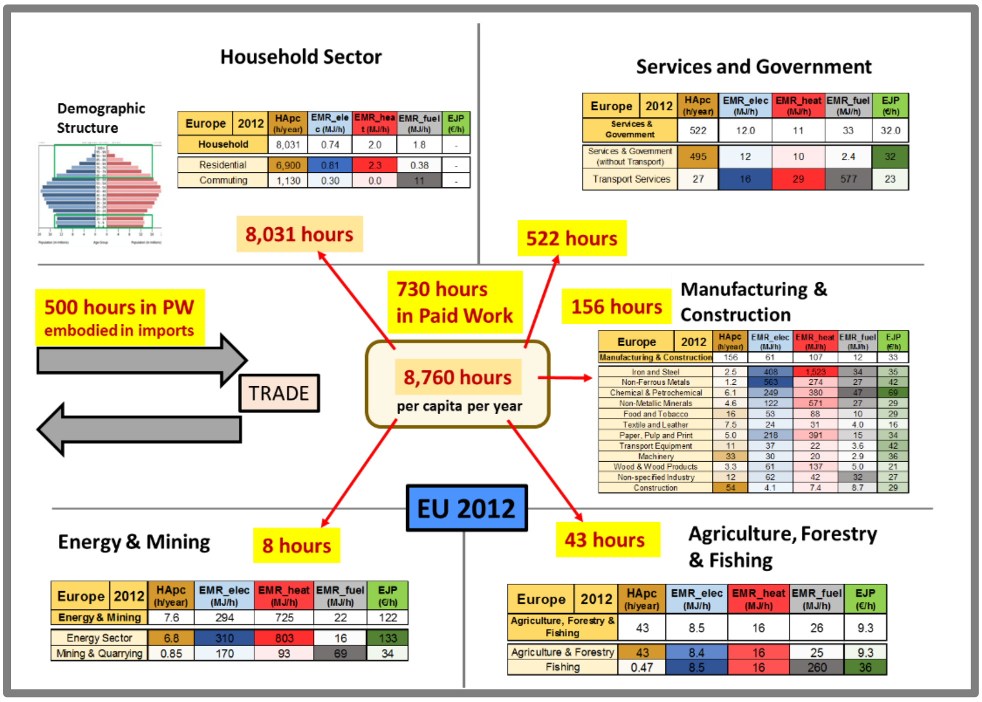
V. The results

When adopting a metabolic narrative, differences in energy uses at the level of the whole society can be explained not only in terms of: (i) differences in the technologies adopted; and (ii) differences in the economic mix, the relative importance of the service and industrial sectors. Two other key factors must be considered: (iii) differences in the metabolic phase of the trajectory of evolution of the economy. That is, this narrative makes it possible to contextualize the performance of the whole economy inside an expected evolutionary path. Using the analogy with the actual metabolism of human beings, in order to assess the energy performance of a given organ of a person, e.g. the heart, we have to know whether the organ is operating in an adolescent (e.g. an economic sector operating in China in the comparison) still building body mass (industries and infrastructures), or in an elderly person (e.g. an economic sector operating in EU, a post-industrial society); (iv) difference in the level of openness – keeping the analogy with human metabolism, a woman that is pregnant producing body mass for another human being will consume more than an old woman. In this study we have shown how the flow of industrial imports from China helps the EU28 to keep an economy mainly based on the service sector.

China and EU28 are two quite different economic systems operating in a different stage of their evolutionary trajectory as economies. By using a metabolic narrative we can identify the factors determining their differences: (i) a different size and structure of the population; (ii) different values in the benchmarks describing the metabolic pace of their different organs, with EU28 having consistently much higher values across the set of organs; (iii) a different profile of the relative size of their organs, China having a much larger industrial sector and a much smaller final consumption sector; (iv) a different level of externalization: EU28 externalizes industrial activities to China through imports. On the contrary China has a large industrial sector not only because of the need of further capitalizing its own economy and generating the required infrastructures of a modern country, but also because it exports goods to the rest of the world.

The four factors that can be used to explain differences in the energy performance of EU28 and China have been changing quite rapidly in the last two decades: (i) the population of EU28 is ageing and this is opening the door to immigration, the population of China has an extremely high share of adults in the work force, because of the legacy of the 1 child policy; (ii) the metabolic pace of energy consumption per hour is several times higher in EU28 than in China for many of the considered sectors (organs); (iii) whereas the industrial sector is getting smaller and smaller in EU28 both in terms of share of work force and GDP, it is very important in the Chinese economy; (iv) EU28 is dependent on imports for energy, food and a lot of industrial products, whereas China is an exporter of industrial products and its dependence on imports for food and energy is much smaller than EU28. Unless we adopt an analytical tool-kit capable of explaining how the overall performance of EU28 economy and China's economy are affected by the differences and ongoing changes in these four factors, it is very unlikely that we can get useful insights from the comparison. This is an option provided by the approach proposed here.





The two figures above illustrate the different patterns of energy uses and human time allocation on the different functional sectors of China and EU economy. In spite of having 1,300 hours of paid work per capita per year China has a lower number of working hours (488) in the service sector than EU28 (522). The large service sector in EU28 can be explained by its dependence of imports: 500 hours of paid work are embodied in the imports, allowing a dramatic reduction of labor allocation in the local primary sectors (AG and EM) and Manufacturing.

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

Decision makers should make an effort to: (i) improve the robustness of knowledge claims by differentiating the portfolio of approaches to modelling used to inform policy choices. Conventional CGE models of integrated assessment should be complemented by innovative models addressing the epistemological predicament associated with the existence of non-reducible descriptive domains, the co-existence of multiple scales and multiple dimensions of analysis. Talking of elephants missed when using existing indicators, China is using almost 1,300 hours of paid work per capita per year in its economy, whereas EU28 is using around 700 hours of paid work p.c. while the performance of these two economies is still studied and compared using aggregate economic indicators "per capita"; (ii) improve the transparence of models making it possible the co-generation of knowledge claims with the users of the results of the models. The transparency of both models and data was a hot issue discussed in the Energy Modelling Platform for Europe (EMP-E) 2018 that is gaining a growing attention both in the European Commission and in the community of practitioners – e.g. the open energy modeling initiative (https://forum.openmod-initiative.org/).

VII. The significance of results for stakeholders

The material presented in this deliverable suggests that an approach based on the analysis of the metabolic pattern can provide additional pieces of information to the discussion over sustainability. These additional pieces of information would allow an informed discussion of the proposed policies in terms of: (i) desirability, in relation to the material standard of living; (ii) viability, in relation to technical and economic aspects; and (iii) feasibility in relation to external constraints outside human control.

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

A multi-scale and multi-dimensional analysis can look simultaneously at the characteristics of the whole and at the characteristics of the various "organs" expected to operate inside social-ecological systems. In this metabolic narrative, differences in the performance of the different organs can be explained in two different ways: (1) because of the identity of the whole – i.e. the expected characteristics of the organs of a young economy still capitalizing vs an adult economy ageing; (2) because of the identity of the specific organs – after having defined an identity for a metabolic system (e.g. young and old people, men or women) we should expect different metabolic characteristics for different typologies of organs. In the analogy with the societal metabolism, when considering different typologies of economies, we can always expect to find that the metabolic characteristics of household sector are different from those of the energy and mining sector. This new narrative about the energy performance allowing the identification and quantification, across different dimension of analysis, of new aspects useful to explain the observed metabolic characteristics missed by conventional analysis.

Index

List of tables

List of figures

Abbreviations, units and key concepts

EC_j	Energy Carriers – the index j (1→ 3) refers to: electricity, heat and fuels.
EJP_i	Economic Job Productivity – GVA per hour of Human Activity in *i*
Elec	Electricity
EMR_{ij}	Energy Metabolic Rate – Quantity of Energy Carrier *j* per hour of Human Activity in *i*
ES	Energy Sector
ET_{ij}	Energy Throughput – Quantity of Energy Carrier *j* metabolized per year in *i*
EU_i	End Use$_i$ – A profile of quantities of Human Activity and Energy Carriers in *i*
GVA_i	Gross Value Added (average year) in the compartment *i*
HA_i	Human Activity (average year) in the compartment *i*
HH	Household Sector
MC	Manufacturing and Construction sector
MuSIASEM	Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism
PES	Primary Energy Sources
SG_nTS	Services and Government without Transport Sector
TET	Total Energy Throughput

MJ	Megajoule ($\times10^6$)
GJ	Gigajoule ($\times10^9$)
TJ	Terajoule ($\times10^{12}$)
PJ	Petajoule ($\times10^{15}$)

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:

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

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)	EMR_{elect} (MJ/h)	EMR_{heat} (MJ/h)	EMR_{fuel} (MJ/h)	ET_{elect} (GJ/year)	ET_{heat} (GJ/year)	ET_{fuel} (GJ/year)
		power capacity			energy carriers		
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.

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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)
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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

This is the last of a series of four deliverables having the goal to illustrate with practical examples the potentialities of an alternative approach to the analysis of energy efficiency. This alternative approach is based on the generation of an information space (the end use matrix) that can be used to generate an integrated multi-scale assessment of the factors determining the energy performance of modern economies. The various topics covered by the series can be resumed as follows:

* The first deliverable (D4.1) provides a critical appraisal of the use of the concept of efficiency. It exposes the impractical assumption that it is possible to generate useful indicators to be used for policy based on a single ratio between a single output and a single input. This approach entails a systemic problem – any chosen representation is meaningful only within a very specific context reflecting the pre-analytical identification of just one of many relevant aspects of an energy transformation in relation to a specific purpose. That is an efficiency indicator expressed as an output/input ratio refers to just one of the possible levels of analysis and just one of the possible criteria of performance that can be defined for a specific set of energy conversions. For this reason the deliverable suggests to move away from the concept of efficiency and to adopt the concept of performance. Performance has to be characterized using an integrated set of indicators referring to representations defined simultaneously across different scales and dimensions of analysis.

* The second deliverable (D4.2) presents the analytical tool – the end use matrix – that can be used to characterize the energetic performance of a society by generating an information space made up of quantitative assessments defined across different levels of analysis. The tool is illustrated by describing and comparing: (i) the energetic performance of EU28 considered as a whole (a single economy); and (ii) the energetic performance of the individual 28 countries and their economies. In both cases (EU28 and individual countries) the multilevel representation moves across levels of analysis from the whole economy, to the level of economic sectors and to the level of sub-economic sectors.

* The third deliverable (D4.3) illustrates a practical application of the end use matrix to the analysis of urban metabolism. Also in this case, the analytical tool is illustrated in conceptual and practical terms with a specific case study – the metabolism of the city of Barcelona. When comparing the results obtained with this approach with the state of the art in this field, we can conclude that the proposed tool has huge potentialities to help a more informed discussion about the energetic performance of cities.

* This fourth deliverable, the last of the series, illustrates the use of the end use matrix to compare the energetic performance of two large socio-ecological systems: EU28 and P.R. China over the period 2000-2016. Also in this case the results show the tremendous potentialities of the proposed analytical approach in providing a new typology of information associated with the adoption of the concept of the metabolic pattern of social-ecological systems. The new insights are determined by the existence of expected typologies of metabolic pattern that can be associated with different typologies of social-ecological systems. More specifically the multi-scale and multi-dimensional analysis can look simultaneously at the characteristics of the whole and at the characteristics of the various "organs" expected to operate inside social-ecological systems. In this metabolic narrative, differences in the performance of the different organs can be explained in two different ways: (1) in relation to the characteristics of the whole – i.e. we should expect a difference in the characteristics of the organs of a young economy still capitalizing vs an adult economy ageing; (2) in relation to the characteristics of the specific

organs – i.e. even when considering the organs inside different types of persons – e.g. young and old people, men or women, tall or short people, different types of societies in the metaphor - the metabolic pace of a given typology of organ (e.g. the household sector having the goal of producing and maintaining human activity for the whole society) is different from the metabolic pace of a different typology of organ (e.g. the energy and mining sector producing the energy carriers and the primary materials for the whole society). This new narrative about the energy performance makes it possible to identify and quantify, across different dimension of analysis, new aspects useful to explain the observed metabolic characteristics. These factors are missed by conventional analysis.

Policy summary

Potential developments based on the use of this tool

The compared analysis of the energy performance of China and EU28 based on the *End-Use Matrix* makes it possible to appreciate the originality and the potentiality of this analytical tool, capable of introducing new narratives about the energy performance of countries and economies. The concept of metabolic pattern of social-ecological systems assumes the existence of a common set of functional elements that can be defined at different levels of analysis: the whole is divided in constituent components (elements that are required to reproduce an economy – final consumption and the productive part of the economy) made up of "organs" – i.e. structural and functional elements expressing specific functions – represented by the economic sectors (made by lower level elements - subsectors). In the quantitative characterization these organs are: (i) the household sector maintaining and reproducing humans; (ii) service and government sector maintaining and reproducing institutions; (iii) manufacturing and construction sector maintaining and producing goods and infrastructures; (iv) agricultural sector producing food products; and (v) energy and mining producing energy carriers and minerals. These sectors/organs do express different functions and as result of this fact they have different expected metabolic characteristics (e.g. the energy sector consumes much more energy per hour of labour than the service sector). This means that their performance can be associated with benchmark values. Moreover, these organs do have different sizes when compared with the size of the whole and their relative size does change in relation to the type of society. For example: (i) a pre-industrial society has a huge agricultural sector (comprising the vast majority of the work force); (ii) an industrializing country has a growing and large industrial sector; and (iii) a post-industrial society can be associated with an anomalous expansion of the dissipative sectors (household sector and service sector) compared with the other sectors.

By adopting a biophysical analysis of the metabolic pattern of a socio-economic system it becomes possible to carry out a multi-scale and multi-dimensional analysis based on the characterization of the various "organs" in terms of their specific metabolic characteristics and their relative size. By adopting this metabolic narrative differences in energy use of the whole society can be explained not only in terms of: (i) differences in the technologies adopted; and (ii) differences in the economic mix, but also (iii) differences in the metabolic phase of the trajectory of evolution of the economy. That is this narrative makes it possible to contextualize the performance of the whole economy inside an expected evolutionary path. Using the analogy with the actual metabolism of people, in order to assess the energy performance of a given organ of a person – e.g. the heart - we have to know whether the organ is operating in an infant, an adult, or an elderly person.

Another crucial issue that can be considered when adopting metabolic analysis is the level of openness of the metabolic pattern. Using again the concept of metabolism we can see that in order to assess the energy performance of a given woman one has to know first of all whether the woman is pregnant or not. In fact, if a fraction of the metabolic activity of that woman goes in the production of body mass not belonging to her own body (e.g. in a pregnant woman a fraction of the metabolism is working to produce tissues in the unborn baby), it would be wrong to assess the woman as "not efficient" for her excessive consumption of food when comparing her metabolism with the metabolism of a non-pregnant woman. This is exactly the situation faced when comparing an economy – e.g. China - that has a large industrial sector dedicated to export (using energy to produce goods not used by its own economy but by other economies) and a country – e.g. EU28 – that heavily relies on imports for its energy and food security plus for the supply of a large fraction of the goods it consumes.

The end use matrix makes it possible to describe the energetic performance of the various organs of a society using a profile of inputs required by the various sectors and subsectors. The analysis of the inputs is not only limited to the mix of energy carriers required, but also to the hours of human activity (labor) and the associated monetary flows. In this way it makes it possible to establish a bridge between economic narratives and biophysical narratives. The combined use of extensive variables (defining the size of the whole economy, the specific economic sector, the sub-sector considered in the analysis) and intensive variables (the benchmarks providing the expected qualitative characteristics of the various organs) makes it possible to see relevant characteristics of the economic process generally missed by the conventional methods used right now based on economic narratives. For example: (i) the characteristics of the whole – e.g. the energy intensity of the economy – depends on the characteristics of the lower level constituent components – e.g. the energy intensity of the various organs of the economy – and not by "the level of technology" used in the economy; (ii) by looking at the individual organs it becomes possible to compare "apples with apples" and "oranges with oranges" within a coherent representation of the performance of the economy across different levels of analysis; (iii) the assessment of the performance of "apples and oranges" can be contextualized in relation to the evolutionary phase of the metabolic system - i.e. the metabolic characteristics of a liver of a youngster are different from the metabolic characteristics of a liver of an elderly person; (iv) it makes it possible to identify the performance of the various economic sectors considered and check their level of externalization (how much a specific sector or subsector of the economy is dependent on imports). This is another essential contextualization required to assess the performance of an economy within a metabolic narrative (i.e. the amount of food required by a pregnant woman is larger than the one consumed by a non-pregnant woman of the same age). Two views of the comparison of EU28 and China obtained using a metabolic narrative are shown in Figure 0-1.

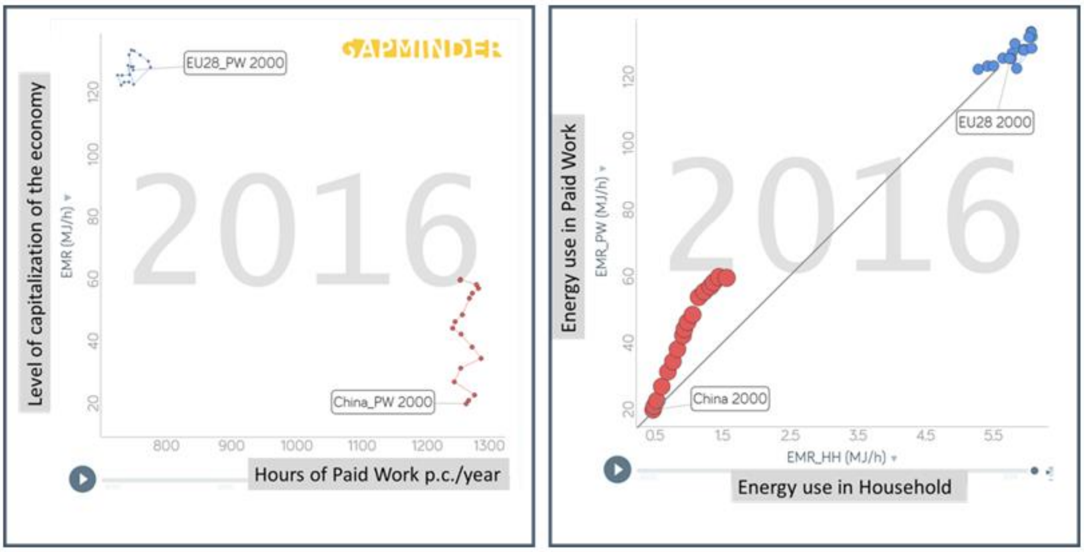

Figure 0-1 Examples of the innovative insights about how to compare economies

A detailed explanation of these two figures is provided in the rest of the deliverable, here we want only to focus on the different type of insights that a metabolic analysis can provide in relation to the existing ones. In the graph on the left of Figure 0-1 we can see two crucial differences between China and EU over the period 2000-2016: (i) the level of capitalization of the economy (the proxy here is "energy use per work hour") is stable in EU, whereas is growing through economic cycles in China; (ii) the number of hours in paid work in China is 1.8 times larger than in Europe (almost the double!) due to a dramatic difference in the distribution of the population over age classes and work load per year. These two points indicate that the metabolic pattern of China is typical of a fast industrializing country (young economy in the maximum phase of growth), whereas the metabolic pattern of EU28 is typical of a post-industrial country (an ageing economy).

In the graph on the right of Figure 0-1, we can see another important systemic difference between the two economies. Looking at the intensity of the end uses of energy in the paid work sector and the household sector (final consumption), we can see again two important differences: (i) the benchmarks of energy uses per hour of human activity in EU28 are much higher than in China. EU28 is already at a high level of capitalization, whereas China has still to invest in its own development; and (ii) so far the investments aimed at increasing end-uses of energy in China have been aimed at increasing the technical capital in the Paid Work sector of the economy (production) rather than increasing the end uses in the Household sector (final consumption). On the contrary EU28 has been increasing the intensity of end uses of energy balancing between the Paid Work and the Household sector. Also in this case these differences are due to the different evolutionary phase of the two economies. These examples show that a metabolic analysis makes it possible to integrate economic and biophysical narratives in a coherent representation. This integration helps the generation of an effective analysis of the factors determining energy performance.

Policy Recommendations

There is a growing criticism about the use of existing energy models developed according the CGE rationale. For this reason, the European Commission has launched in 2017 a Competence center on modelling (https://ec.europa.eu/jrc/en/modelling) having the goal to *"promote a responsible, coherent and transparent use of modelling" and "further strengthening the credibility of the Commission's policy analysis*". A recent workshop organized by the Energy Modelling Platform for Europe (EMP-E) 2018 – *Modelling Clean Energy Pathways* 25 -26 September 2018 (http://www.energymodellingplatform.eu/home-emp-e-2018.html) has hosted a serious discussion about the need of enlarging the portfolio of models in order to complement the information generated by existing models based on the adoption of economic narratives for the pre-analytical framing of the analysis with biophysical narratives.

In relation to this point, the material presented in this and the previous deliverables shows that it is possible to complement the conventional approach to energy models with innovative tools based on complexity theory (relational analysis, multiscale analysis, the analysis of social-ecological metabolic patterns). Therefore the policy recommendations based on the results of this deliverable are the following ones:

1. *improving the robustness of knowledge claims by differentiating the portfolio of approaches to modelling*. Conventional CGE models of integrated assessment should be complemented by innovative models addressing the epistemological predicament associated with the existence of non-reducible descriptive domains (the co-existence of multiple scales and multiple dimensions of analysis). In this way, it would become easier to avoid the missing of elephants in the room, a problem at times experienced when adopting existing energy models and indicators. We provided examples in Deliverable 4.1 of a series of elephant missed when using existing indicators. Going back to the examples given earlier in Figure 0-1, it is easy to see that indicators based on quantities per capita per year (e.g. GDP pc, or Energy consumption per capita, or CO_2 emissions per capita) are meaningless when comparing two economies, such as China and EU28. China is using almost 1,300 hours of paid work per capita per year, whereas EU28 is using around 700 hours of paid work p.c. Moreover, these quantities will change in the next years due to demographic adjustments. This problem can be solved by developing indicators of the performance of economies based on quantities per hour of paid work per capita/year. In the same way, an excessive aggregation of quantities used to assess efficiency implies hiding the relevant factors determining differences. The same ration of GDP over energy use can be referring to both a country having 1000 units of GDP produced using 500 units of energy use and

a country having 10 units of GDP and 5 units of energy use. An analysis of world countries has shown this paradox (Fiorito, 2013). The Economic Energy Intensity indicator provides the same value when describing countries completely different in their biophysical realities. Additional problems exposed by this deliverable are associated with the capital sin of using aggregated indicators. Then we can no longer see: (i) the effects of changes in the production mix; (ii) the effects of externalization of energy intensive production through imports; and last but certainly not least, (iii) the effects of credit leverage (quantitative easing) – on the overall GDP output/energy input. A country can reduce its energy intensity by buying goods using printed money, rather than producing them or produce the equivalent added value used to buy the imports. The examples presented below in the comparison between EU28 and China clearly illustrate the importance to complement economic analysis with an effective characterization of the biophysical performance of the various constituent components of an economy, described at different level and scales.

2. *improving the transparence of models making it possible the co-generation of knowledge claims with the users of the results of the models*. The transparency of both models and data was another hot issue discussed in the Energy Modelling Platform for Europe (EMP-E) 2018 that is gaining a growing attention both in the European Commission and in the community of practitioners – e.g. the open energy modeling initiative (https://forum.openmod-initiative.org/). The problem is generated by the fact that very often policy advice comes from complicated models that are totally obscure (no open source software and no open source data) to the user. On the contrary, the analytical method proposed here (relational analysis of the metabolic pattern of social-ecological systems) and the analytical tool of the end-use matrix is completely transparent in terms of assumptions, analysis of relations and data. Therefore, the incorporation of the analytical tool-kit presented here in the larger set of models used right now to describe changes in the energy end uses in the economy of EU could represent an important step in the desired direction.

3. *adopting a different approach when checking the quality of the production and use of scientific information for governance*. When using scientific inputs for governance it is wise to abandon the Cartesian dream – i.e. science can predict and control, implying the possibility of using just a piece of information to identify the best course of action obtained by the application of "evidence based policies". Rather we should move to the paradigm of post-normal science and complexity – i.e. several perspectives and several scientific narratives referring to different scales and dimensions should be considered simultaneously to generate a quantitative story-telling about relevant aspects of the problem. The methodology and the tool-kit proposed in this deliverable have been developed within the philosophy of quantitative story-telling.

Key Messages

* There are problems of credibility and transparency with the energy models used at the moment, the approach proposed here represents a viable alternative to reduce some of these problems.

* China and EU28 are two quite different economic systems operating in a different stage of their evolutionary trajectory as economies. By using a metabolic narrative we can identify the factors determining their differences: (i) a different size and structure of the population; (ii) different values in the benchmarks describing the metabolic pace of their different organs (with EU28 having consistently much higher values across the set of organs); (iii) a different profile of the relative size of their organs (China having a much larger industrial sector and a much smaller final consumption sector); (iv) a different level of externalization: EU28 externalizes industrial activities to China through imports. On the contrary China has a large industrial sector not only because of the need of capitalize its own economy and generate the required infrastructures of a modern country, but also because it exports goods to the rest of the world.

* The four factors that can be used to explain differences in the energy performance of EU28 and China have been changing quite rapidly in the last two decades: (i) the population of EU28 is ageing and this is opening the door to immigration, the population of China has an extremely high share of adults in the work force, because of the legacy of the 1 child policy; (ii) the metabolic pace of energy consumption per hour is several times higher in EU28 than in China for many of the considered organs; (iii) whereas the industrial sector is getting smaller and smaller in EU28 (both in terms of share of the work force and share of the GDP) it is very important in the Chinese economy; (iv) EU28 is dependent on imports for energy, food and a lot of industrial products, whereas China is an exporter of industrial products and its dependence on imports for food and energy is much smaller than EU28. Unless we develop an analytical tool-kit capable of explaining how the overall performance of EU28 economy and China's economy are affected by the differences and ongoing changes in these four factors, it is very unlikely that we can get useful insights from the comparison.

* The adoption of a narrative based on the metabolic pattern of socio-economic systems makes it possible to contextualize the differences in energy performance between EU28 and China considering simultaneously two levels: (i) the whole – identifying the evolutionary phase of the whole economy – industrializing vs post-industrial; and (ii) the functional elements – studying the different benchmarks of the different organs at different levels – constituent components, economic sectors, sub-sectors. This makes it possible to compare "apples with apples and oranges with oranges" both at a given point in time and over an evolutionary trajectory.

* The combination of extensive variables (defining the size of the various elements) and intensive variables (the benchmarks defining the level of end use of energy) makes it possible to generate: (i) for each lower level component - a decomposition of the factors determining changes in the overall consumption of energy (changes in the size of hours of work in the element vs changes in the metabolic pace per unit of size); (ii) for the whole economy - a set of relations explaining how changes in the metabolic characteristics of lower level compartments are reflected in changes in the metabolic characteristics of the whole. This makes it possible to identify: (i) what are the components using the different types of energy carriers (who is using energy); (ii) what is the functional role played by the various components (why are they using energy); (iii) the quantities of each type of energy carrier consumed by the various components (how much energy is used); (iv) the quantity of labor invested in the various components (how much labor/employment is associated with this consumption of energy); (v) the quantity of added value generated in the various components (the economic relevance of the specific consumption of energy); (vi) a qualitative characterization of how energy is used in the various components (in terms of the level of capitalization measured in terms of end use of energy per hour of labor).

* The proposed approach makes also possible to identify inside the end use matrix the level of externalization sector by sector. This can be measured by assessing the reduction of end uses in the various economic sectors due to the replacement of local supply with imports. As a matter of fact, one surprising result we obtained is illustrated in Figure 0-2. When correcting the metabolic characteristics of EU28 economy including the "virtual quantities of work and energy embodied in the imports", the difference between EU28 and China tends to disappear. That is, when summing to the hours of work in PW in EU28 (700 p.c./year), the hours of work embodied in the imports from the rest of the world (about 500 p.c./year) we can calculate that the overall input of hours of work to the EU28 economy is 1,200 hours p.c./year, pretty close to the quantity used by the economy in China! A more detailed explanation of this calculation is given in Section 5 of this deliverable.

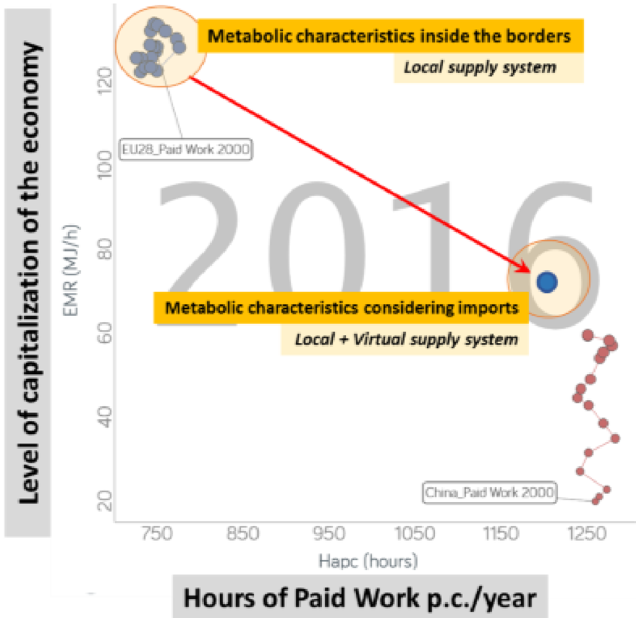

Figure 0-2 The difference in the metabolic characteristics of the PW sector of EU28 and China, considering and not considering the effect of imports

* The analysis suggests also new explanations for the reduction of energy consumption in EU28. Looking at the changes taking place in the period 2000-2015 we can see a progressive reduction of the hours of work in the Paid Work sector in absolute number. That is not only the work hours in the industrial sector have been almost entirely liquidated and replaced by hours of work in the service sector, but also the entire Paid Work sector has been shrinking. This reduction has been coupled to a concomitant **increase of the energy use per hour of work across all the economic sectors of the economy**. Therefore, this empirical evidence calls for a more careful evaluation of this phenomenon. In fact, this evidence squarely contradicts the official explanations about the role that technological innovations promoting efficiency play in reducing the energy use in the economies of developed countries.

Tasks of this deliverable in relation to WP4

WP4 in the EUFORIE project has the goal of exploring possible applications of the MuSIASEM accounting method (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism) in relation to the analysis of efficiency.

Task 4.2. Internal view of energy systems

MuSIASEM can provide insights for an informed debate about the energy performance of an economy. It does so by identifying and characterizing 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 energy sector, the agricultural sector, manufacturing and construction, service and government sector and the household. This information on energy services (energy *end uses*) is organized in an *end use matrix* making it possible to understand the dynamic equilibrium between the consumption of energy carriers going either to the dissipative compartments of the society or to the productive sectors.

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

The end use matrix is a tool for assessment and decision-making identifying how different forms of energy carriers (electricity, fuels, process heat) are used to perform different societal tasks – who is using them, how much of them, how, and for doing what. The information provided by the end-use matrix can also be used to look into the external constraints limiting the supply of the required energy inputs.

In D 4.1 we provide a critical appraisal of the use of the concept of efficiency - a simplistic representation of energy performance considering just one of the relevant factors at the time. Then we show that it is possible to move from simplistic indicators of efficiency to a set of more effective indicators of performance.

In D 4.2 we illustrate the features of the end-use matrix by providing a multilevel analysis EU28 – i.e. the whole EU 28 analyzed at different levels (economic sectors and subsectors) and the individual EU countries at different levels.

In D4.3 we illustrate an application of the end-use matrix for the analysis of the energetic performance of urban metabolism, using Barcelona as case study.

In this deliverable - D 4.4 - we present an application of the end-use matrix for the comparison of the energy performance of EU and China over a given period of time (2000-2017). The analysis: (i) identifies key factors and drivers of change; (ii) provides new insights about the differences in energy end-uses observed across different levels and dimensions of analysis; and (iii) individuates knowledge gaps in existing analysis.

Introduction

This summer (July 2018) "*the EU and China reaffirmed their commitment to advance the implementation of the Paris Agreement and intensify their cooperation on climate change and clean energy*" (European Commission, 2018a). This cooperation between two giant emitters became crucial after the announced withdrawal of the United States on 1st of June 2017 from the 2015 Paris Agreement (Bocse, 2018). Taking seriously this goal would require a good understanding of: (i) how the two countries are using energy; and (ii) how their specific patterns of energy end uses are affected by their commercial relations. Adopting a metabolic narrative about the functioning of modern economies, we consider policies having the goal of reducing emissions and re-adjusting the activities generating them, such as efforts aimed at re-adjusting the dietary habits and lifestyles. In the metabolic analogy new diets and new lifestyles would have to be established in order to improve (or at least preserve) their health while reducing their direct and indirect emissions.

If we adopt this analogy there are two obvious consequences on the type of analysis that would be required to inform this decision: (i) when discussing of changes in the diet we cannot use information referring to generic quantities of food (measured either in kg or kcal). Rather we have to make a careful distinction between different types of nutrient carriers – we have to consider kcal of carbohydrates, kcal of proteins, kcal of fats, and grams of fibers. In the analogy this would indicate the need of adopting a variety of categories of accounting of energy carriers to better study the set of end uses – i.e. airplanes do not fly on kWh of electricity, the vehicles used right now for road transportation use liquid fuels. We need to specify which type of energy carriers are used, where in the economy, to do what; (ii) when discussing of changes in the diet we have to know the age and the size of the organs fed by the chosen diet. This information is needed because different organs of different age and different characteristics do require different types and mixes of nutrients.

In the comparison presented in this deliverable we will provide a type of analysis based on a metabolic narrative organized in the following chapters:

Chapter 3 - a historical analysis of the changes in the metabolic pattern of EU28 and China over two periods 2000-2007 and 2007-2016 across different levels of analysis: (i) level n – the whole economy; (ii) level n-1 - the constituent components (final consumption vs Paid Work); (iii) level n-2 – the economic sectors; and (iv) level n-3 – the subsectors of the economic sectors;

Chapter 4- a decomposition analysis of the changes in the elements of the metabolic patterns of EU28 and China to study, element by element, the relative importance of changes in: (i) hours of work (number of employed people) and (ii) energy intensity per hour of work (level of technical capitalization) on the overall quantity of energy end uses.

Chapter 5 – an analysis of the embodied quantities of labor and energy uses associated with the trade between EU28 and China and EU28 and the rest of the world. This is a preliminary analysis carried out using input/output economic tables. An alternative approach is developed in another EU project (MAGIC) for producing the same estimation from biophysical analysis.

Chapter 6 – Provides a reflection on the lessons learned from this exercise. The insights gained with the adoption of a biophysical narrative based on the concept of the metabolic pattern of social-ecological systems makes it possible to get a different picture of the knowledge economy in relation to potential future troubles.

Data and methods

1.1 Methods

The analytical framework used for this deliverable is the same used in previous deliverables of WP4, the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) (Giampietro et al., 2013, 2012). The metabolic pattern analysis of Europe and China have been developed through different MuSIASEM tools:

1. The End-Use Matrix (EUM)
2. Historical analysis of relational analysis compressed in the EUM
3. The multiscale fund-flow decomposition analysis
4. The embodied resources trade balance.

In this section we will briefly present the basics of these different methods used in this deliverable.

1.1.1 The End-Use Matrix (EUM)

The End-use Matrix (EUM) is a MuSIASEM tool generating quantitative congruence between fund-flow indicators across scales, dimensions and levels (Velasco-Fernández et al., 2018). Some of these indicators used in the current analysis are: energy carrier's throughputs (ET) and monetary value added (GVA) as flows; human activity (HA) as fund; and Energy Metabolic Rates (EMRs, calculated for each energy carrier) and Economic Job Productivity (EJP) as flow/fund indicators. By organizing these indicators in a vector we generate a biophysical production function for each end-use. These indicators could be complemented with others as water, food as input flows; CO_2, NOx, SO_2 as output flows; additional fund elements, such as land use, power capacity, can also be added. In this way it becomes possible to generate a multidimensional nexus spaces that characterize in quantitative terms key factors of the biophysical performance of a country across scales and levels (see the Magic Nexus EU project: http://magic-nexus.eu).

The EUM presented in this study focus only on energy carriers (ET_electricity, ET_heat and ET_fuel), human time (HA) and monetary value added (GVA). It makes it possible to identify at different levels *who* is using energy for doing *what* (end-uses across levels, see dendrogram in Figure 0-2), *how* energy is used in technical terms (EMR_electricity, EMR_heat and EMR_fuel), *how* energy is used in relation to the generation of value added (EJP_i). The distinction between different types of energy carriers and different tasks makes it possible to have an integrated view of which type and how much energy is used (electricity, heat and fuel), how much value added (GVA_i) and how much human activity is allocated in each end-use (HA) (see Figure 0-1). To make easier the comparison between Europe's and China's metabolic patterns, we have extended the traditional EUM with indicators per capita, as well as express the energy consumption and energy metabolic rates in Joules of thermal equivalent of Gross Energy Requirement (ET_GER and EMR_GER).

The Exosomatic energy Metabolic Rate (EMRs) is an innovative indicator of MuSIASEM approach that defines the exosomatic energy under human control used to do a task or end-use. It is built on the distinction proposed by Lotka (1956) between endosomatic energy (energy under human control converted inside the human body) and exosomatic energy (energy under human control converted outside the human body). Georgescu-Roegen (1971) introduced the idea of identifying exosomatic instruments produced and used in the economic process. A further elaboration of these concepts was introduced by Giampietro and Mayumi, associating exosomatic energy with the applied power generated by machines and/or animals outside the human body (Giampietro et al., 2013). In this study we will focus just on the exosomatic energy carriers under human control when using power generated by machines.

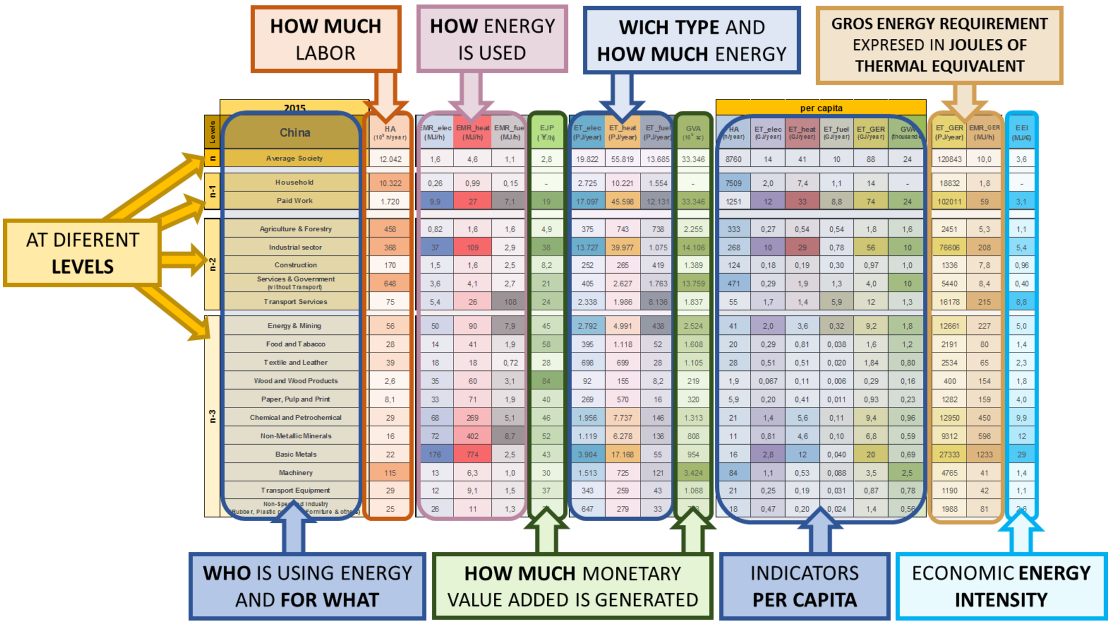

Figure 0-1 The information space generated by the End-use Matrix

In the MuSIASEM approach we distinguish between different forms of exosomatic energy (Giampietro et al., 2013):

1- Primary Energy Sources (PES) refer to the available biophysical gradients out of human control associated with the possibility of generating energy flows under human control.
2- Gross Energy Requirement (GER) refers to the total amount of energy under human control, defined at the level of the whole country, which is required to produce and consume the energy carriers used to express the various functions.
3- Energy carriers (EC) refer to the local supply of energy carriers used at the level of individual compartments or individual energy converters to express functions, in this deliverable we will group them in three categories: electricity, heat and fuel.
4- End uses, (EU) refers to the practical results (final causes) achieved because of the utilization of energy carriers in relation to pre-established tasks. An end use requires the combination of quantities of flows and fund elements included in the vectors of the matrix.

In this deliverable we measure energy under human control of the different compartment of the society (end-uses) in the form of energy carriers (ECs) – a vector of three values – or in Gross Energy Requirement (GER) – just a single quantitative assessment. To facilitate the graphic representation of the ECs they are measured in Joules, but it is recommendable to express them in different units to reinforce the qualitative distinctions of these forms of energy (e.g. electricity in kWh, process heat in calories and fuel in joules). The energy carriers aggregation has been done following the protocol developed by Velasco-Fernández (2017). Gross Energy Requirement (GER) is expressed using the partial substitution method (Giampietro and Sorman, 2012). Specifically, we have calculated the virtual primary energy sources in thermal equivalent of the electricity consumed (Giampietro et al., 2013) by considering and equivalent of primary heat to generate the recorded electricity consumption assuming a conversion efficiency of 38,6% - following the world benchmark from nuclear and all other non-combustible renewable sources used by the World Economic Forum (International Energy Agency (IEA) and World Bank, 2014).

Previously to the indicators definition we need a dendrogram (Figure 0-2) defining the compartments of the society that we would like to characterize across levels: where the various end-uses take place. These compartments have been defined following available data for Europe and China, and the classification compatibility that make them comparable.

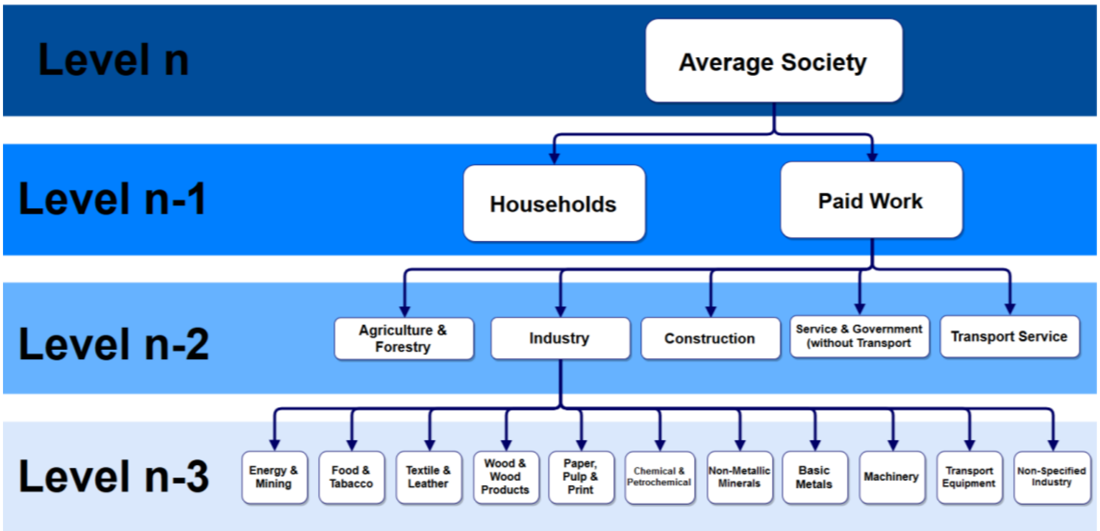

Figure 0-2 Dendrogram with the different hierarchical levels of analysis at which metabolic elements are defined.

As explained in previous deliverables, the indicators of MuSIASEM analyze the economy from a biophysical point of view. The Exosomatic Energy Metabolic Rate (EMR) characterizes the amount of exosomatic energy that a society manages per hour of human activity. Inside the paid work sector EMR is a proxy of the capitalization of the economy. In the household sector it is a proxy of the material standard of living, as it indicates the number of devices and appliances in the houses and used by private transport (e.g. car or motorcycles). As mention before, in this deliverable we identify three types of EMR reflecting the types of energy carrier considered: electricity, derived heat and fuel. EMRs give information about the types of devices that a society is using: more electricity or fuel powered. On the other hand, combining monetary value-added generation with human activity we get the Economic Job Productivity (EJP). As monetary indicators are based in local currencies (euros and yuan) they are just comparable inside each region analyzed and not among them. The ratio EMR_i/EJP_i represents a local indicator of energy intensity.

Human activity (HA) indicates the number of hours allocated in each compartment, the amount of labor required (or sustained) in each sector. Energy Throughput (ET) indicates the amount of energy carriers consumed in each sector and is a rough proxy of the environmental impact generated by each compartment (e.g. GHG emissions). To compare these indicators between the two study regions, they are expressed per capita (HApc and ETpc) – that is the overall quantity of either Human Activity or Energy Throughput is divided by the size of the population. More details on MuSIASEM indicators interpretation would be introduced in the analysis. For a further explanation of the academic discussion of these indicators see MuSIASEM foundation literature (Giampietro et al., 2013, 2012).

1.1.2 Historical analysis of relational analysis compressed in the EUM

MuSIASEM have been criticized recently by a supposed a-historicity of its analyzes (Gerber and Scheidel, 2018). However, some MuSIASEM historical analysis was previously developed comparing the metabolic pattern of EU14 countries between 1992 and 2005 (Giampietro et al., 2012) or of China and India between 1971 and 2010 (Velasco-Fernández et al., 2015). In the current report we improve these previous MuSIASEM historical analysis in two ways: (i) exploring lower levels of analysis by looking inside the manufacturing sector, what allows to get four hierarchical levels of description; and (ii) distinguishing three different types of energy carriers, which allows to get a better understanding of the energy metabolic patterns evolution in relation to energy qualities and machinery (power capacity) associated.

The visualization of the relational analysis compressed in the EUM over time have been made using Gapminder Tools Offline (www.gapminder.org) with elaborated secondary data (data sources are explained in the further section). Using its bubble charts, this visualization tool allows us to plot three indicators over time: two in the axis as Energy Metabolic Rate (EMR, MJ/h) vs Human Activity per capita per year (hours per year); and a third one associated with the size of the bubbles as Energy Throughput (energy carriers consumption expressed in thermal equivalent GER) or Human Activity (this time in extensive way for showing the total amount of labor associated). The labels indicate the first year of the historical representation to show the direction of the evolution of the pattern. However, a proper visualization would require a video and arrows have been introduced in some figures where the evolution is not easily deductible (see Figure 0-2).

Other plotting techniques have been used illustrating the metabolic pattern evolution of the regions as bar and line charts or the Normalized Chromatic Intensity of tables (Velasco-Fernández, 2017).

1.1.3 The multiscale fund-flow decomposition analysis

Decomposition analysis is used to explore the main factors driving the total energy consumption of an economy. It was initially introduced in the late 70s to study the impacts of structural changes of energy consumption by industry. This type of analysis tries to prevent misunderstandings and hasty inferences when analyzing the relation of energy intensity with total energy consumption of a system. In fact, MuSIASEM critiques to energy intensity indicator (Velasco-Fernández et al., 2018) share the epistemic concern of these analysis when claiming the relevance of considering that the relative size of the economic activities, the technology and the economic structure are key aspects to analyze the energy performance of an economy (Achão and Schaeffer, 2009). It should be noted that often traditional decomposition analysis does not distinguish between the different characteristics of the indicators analyzed.

The proposed decomposition analysis presented here takes advantage of the insights of Georgescu-Roegen and its fund-flow model (Georgescu-Roegen, 1971). In that sense, the relation between any two flow variables - e.g. energy (ET) and GDP - has to be explained through their relation to a given fund element (e.g. HA) that gives to the analyst an external reference. For example: (i) ET is written as EMR x HA, and (ii) a quantity of GVA is written as EJP x HA. Therefore, the explanation of the intensity (or technological) effect of a sector that is commonly inferred through the sectoral economic energy intensity (MJ/€) (Ang et al., 2015), would be substituted by the Energy Metabolic Rate (MJ/h) of that sector and by the Economic Labor Productivity (e.g. €/HA) of that sector. The activity effect (or the size of the economic activity of the sector) is traditionally associated to the value-added of the sector, in our method we will associate it to the size of the fund, it this case, the human activity in the sector (HA). Last but not least, the structure effect uses to be associated with relative coefficients to the analyzed context (e.g. proportion of value-added of a sector over the entire economy) or complicated mathematical relations. In our method, we avoid the need of tackling the structure effect, by generating a multilevel decomposition analysis giving to the reader an open and holistic understanding of the relation. The structure effect determined by the size of the fund elements (in our case just one, the human activity) can be analyzed looking at the relative size of the fund elements across levels.

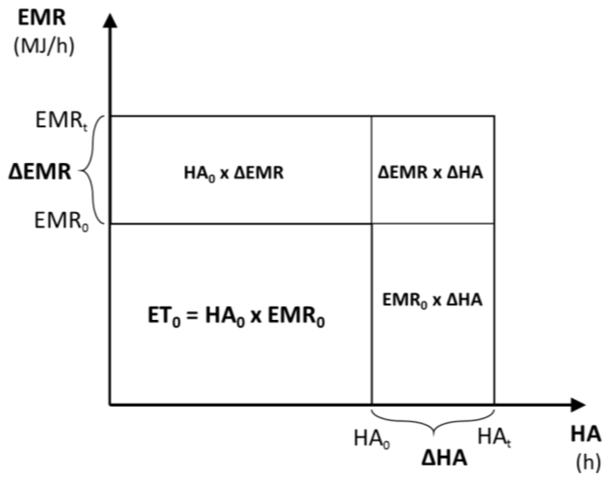

Figure 0-3 The main effect and contribution of the factors in a two-factor system. Adaptation from (Sun, 1998)

Regarding the allocation calculation, the proposed method avoids the use of logarithmic methods (Ang, 2005) following the relative insights on the topic of Mayumi and Giampietro (2010). Instead, it follows a traditional decomposition method (Sun, 1998) with a slight modification (see Figure 0-3). This difference basically affects the distribution of the residual component (ΔEMR x ΔHA in our case), if traditional decomposition model follows the principle of "jointly created and equally distributed" (Sun, 1996), here we opt for a "jointly created and proportionally distributed" principle. However, the proportionality is based in the direct effect of each variable for avoiding scaling problems (HA_0 x ΔEMR and EMR_0 x ΔHA).

Consequently, we can express the variation of the ET in relation to HA and EMR as follows:

$$\Delta \boldsymbol{ET}_{t\rightarrow t+i} = \underbrace{\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t}_{\text{Due to } \Delta HA} + \underbrace{\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t}_{\text{Due to } \Delta EMR} + \underbrace{\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \Delta \boldsymbol{EMR}_{t\rightarrow t+i}}_{\text{Due to } \Delta HA \,\&\, \Delta EMR}$$

And ΔET to ΔHA and ΔEMR is allocated as follows:

(i) <u>When (ΔHA>0 & ΔEMR>0) or (ΔHA<0 & ΔEMR<0):</u>

The effect of ΔHA over ΔET is:

$$\Delta \boldsymbol{ET}_{\Delta \boldsymbol{HA}_{t\rightarrow t+i}} = \Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t + \left[\left(\frac{(\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t)}{(\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t) + (\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t)}\right) \cdot \Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \Delta \boldsymbol{EMR}_{t\rightarrow t+i}\right]$$

$$\Delta \boldsymbol{ET}_{\Delta \boldsymbol{HA}_{t\rightarrow t+i}} = \Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t \cdot \left[\boldsymbol{1} + \left(\frac{\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \Delta \boldsymbol{EMR}_{t\rightarrow t+i}}{(\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t) + (\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t)}\right)\right]$$

and for ΔEMR:

$$\Delta \boldsymbol{ET}_{\Delta \boldsymbol{EMR}_{t\rightarrow t+i}} = \Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t + \left[\left(\frac{(\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t)}{(\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t) + (\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t)}\right) \cdot \Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \Delta \boldsymbol{EMR}_{t\rightarrow t+i}\right]$$

$$\Delta \boldsymbol{ET}_{\Delta \boldsymbol{EMR}_{t\rightarrow t+i}} = \Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t \cdot \left[\boldsymbol{1} + \left(\frac{\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \Delta \boldsymbol{HA}_{t\rightarrow t+i}}{(\Delta \boldsymbol{HA}_{t\rightarrow t+i} \cdot \boldsymbol{EMR}_t) + (\Delta \boldsymbol{EMR}_{t\rightarrow t+i} \cdot \boldsymbol{HA}_t)}\right)\right]$$

(ii) <u>When (ΔHA>0 & ΔEMR<0) or (ΔHA<0 & ΔEMR>0) the residual (ΔHAxΔEMR) is 0, then:</u>

The effect of ΔHA over ΔET is:

$$\Delta ET_{\Delta HA_{t\rightarrow t+i}} = \Delta HA_{t\rightarrow t+i} \cdot EMR_t$$

and for ΔEMR:

$$\Delta ET_{\Delta EMR_{t\rightarrow t+i}} = \Delta EMR_{t\rightarrow t+i} \cdot HA_t$$

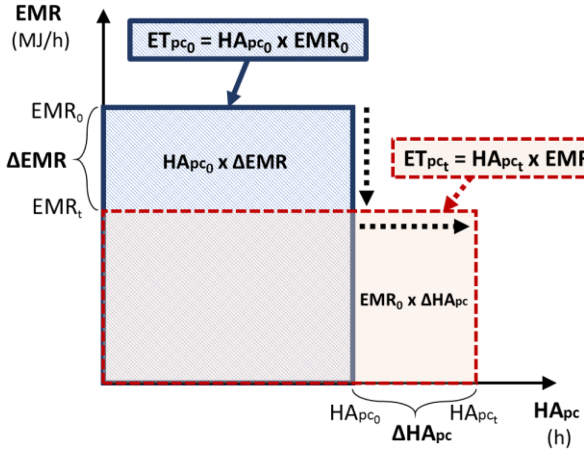

Figure 0-4 The main effect and contribution of the factors in a two-factor system, when (ΔHA>0 & ΔEMR<0) or (ΔHA<0 & ΔEMR>0).

Where:

- *t* is the initial year
- *t+i* the final year
- $\Delta x_{t\rightarrow t+i}$ is the variation of the x component between the years *t* and *t+i*, and
- $\Delta y_{\Delta x_{t\rightarrow t+i}}$ is the allocation of the variation of the y component to the variation of the x component between the years *t* and *t+i*.

1.1.4 The assessment of embodied resources in trade

Embodied resources in trade were calculated using the EORA 26 v199.82 database for the year 2012 (Lenzen et al., 2013, 2012). Information obtained from this source was combined with the data on human activity (HA) and energy throughput (ET) presented in the previous chapters. Data on HA for the 'rest of the world' (ROW) was taken from the Exiobase database. China data in the Exiobase include Hong Kong. This implies that that 'the rest of the world' does not include Hong Kong. However, we found that this does not substantially affect the results. Due to lack of data, only the virtual flows of Human Activity were assessed for worldwide trade, the assessment of virtual flows of Energy Throughput are limited to the trade between China and EU. The complete list of data sources used is listed in Section 1.3.

It must be pointed out that the data used in this chapter (EORA database) to assess value added (VA) is different from the data used in the previous sections. Also, because data on HA and ET were not derived from EORA and based on a different classification of categories of economic (sub)sectors, the two datasets had to be harmonized.

Table 0-1 Variables and data sources used for the construction of the information space of EU-China trade

DATA		Data source
T	Matrix intra-industry trade	EORA
FD	Final demand trade	EORA
VA	Value added vector	EORA
HA_{PW} - EU	Human activity PW for EU28	Eurostat
HA_{PW} – China	Human activity PW for China	Statistics book of China
HA_{PW} - ROW	Human activity PW for Rest of the World	Exiobase
ET - EU	Energy Carriers Throughput (electricity, heat and fuels) for EU28	China Statistical Yearbook
ET - China	Energy Carriers Throughput (electricity, heat and fuels) for China	Eurostat

The analysis was developed in several steps:

The first step consisted in calculating the part of domestic added value embodied in trade (DVA) (see Figure 0-5). This was done according to the method of Aslam et al (Aslam et al., 2017). Value Added data better captures the role of countries inside the worldwide Global Value Chain than Trade, by avoiding the double counting implicit in gross flows of trade (Koopman et al., 2014). Indeed, countries do not produce from cradle to gate. They are contributors in global processes where resources and intermediate products cross borders multiple times before getting to the final consumer. A clear example is the Global Value Chain of electronic products and cars (De Backer and Miroudot, 2013) or even Barbie dolls (Tempest, 1996). Some countries only serve as intermediate ports (not making any physical transformation of the product), because of lower tariffs or absence of sanctions, which is referred to as re-export or entrepot trade. For example, Hong Kong is an important re-exporter for China, the 9th exporter economy in the world. Hong Kong's role would have been hidden with an assessment based simply on Trade.

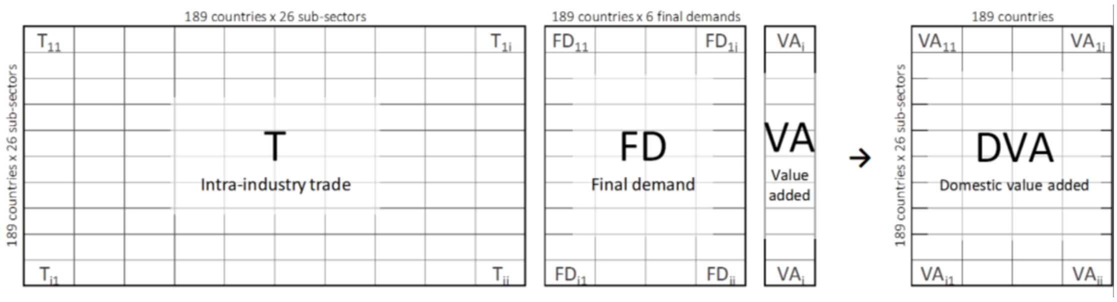

Figure 0-5 Data matrixes from EORA in the calculation of Domestic Value Added matrix with the Aslam et al. (2017) method, including their size

Table 0-2 Relation of countries included in the analysis of trade

30 Countries/Regions			
People's Republic of China	1	Latvia	16
Austria	2	Lithuania	17
Belgium	3	Luxembourg	18
Bulgaria	4	Malta	19
Cyprus	5	Netherlands	20
Czech Republic	6	Poland	21
Denmark	7	Portugal	22

Estonia	8	Romania	23
Finland	9	Slovakia	24
France	10	Slovenia	25
Germany	11	Spain	26
Greece	12	Sweden	27
Hungary	13	UK	28
Ireland	14	Croatia	29
Italy	15	Rest of the world	30

In a second step we aggregated the 189 countries and the 26 industries in the final categories. For the rows, we keep China and the 28 EU countries (Table 0-2), and aggregate the rest of countries in a Rest of the World region (RoW). We are going also to adapt to the classification of economic sectors that matches the two datasets for the end-use matrixes of China and EU, whose coordination to EORA is shown in Table 0-3. This way we are going to incorporate the differences by industries and countries inside the EU, even though the final analysis is made in the global EU28 terms. The classification of economic activities hides differences in both technical coefficients for the same activity and the mix of activities belonging to the same category. For example, in relation to the classification "Wood and Paper", Finland has an industry devoted to cut trees in the forest making pulp, very energy intensive, whereas Portugal do the same with a less capitalized pulp sector. In Italy this classification refers only to the manufacturing of paper products (Velasco-Fernández et al., 2018). This implies that in the case of RoW, the assessment for HA refers to a quite coarse aggregation of types of economic processes in the chosen categories. In relation to the columns, we consider only three regions to which the products are sold: People's Republic of China, EU28 and Rest of the world.

Table 0-3 Relation of economic classifications, from the one of the trade raw data to the one used for calculations

Economic classification from EORA	Economic classification calculations
1 Agriculture 2 Fishery	1 Agriculture and fishery
3 Mining and quarrying	2 Mining and quarrying
4 Food and beverages	3 Food and beverages
5 Textile and wearing apparel	4 Textile and leather
6 Wood and paper	5 Wood and paper
7 Petroleum, chemical and non-metallic mineral products	6 Petroleum, chemical and non-metallic mineral products
8 Metal products 9 Electrical and machinery	7 Metal products + machinery
10 Transport equipment	8 Transport equipment
11 Other manufacturing 12 Recycling	9 Other manufacturing
13 Electricity, gas and water	10 Electricity, gas and water
14 Construction	11 Construction
15 Maintenance and repair 16 Wholesale trade 17 Retail trade 18 Hotels and restaurants	12 Services
19 Transport	13 Transport
20 Post and telecommunications	12 Services

21 Financial intermediation & business act.	
22 Public administration	
23 Education, health and other services	
24 Private households	
25 Others	
26 Re-export and re-import	

After having generated this DVA matrix with the aggregated classification, we multiply the Economic Job Productivity of each country-industry (EJP_k) to the Domestic Value added of that industry due to the trade to each region (DVA_{kl}). An important hypothesis laying down the calculation is that we are considering that each monetary unit sold will have the same economical and technical characteristics no matter the country of destination. It is known that companies that export have different characteristics than those who import (Upward et al., 2013), but this fact was not addressed in this study.

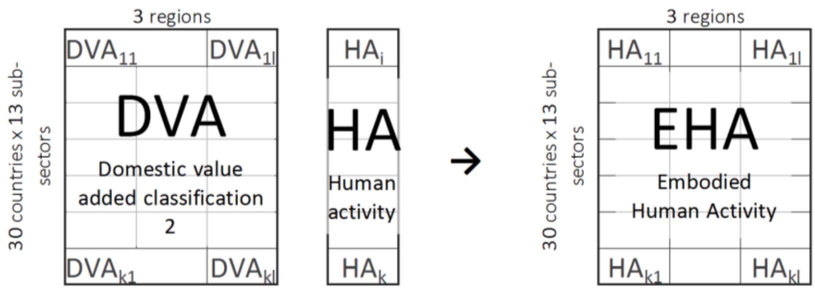

Figure 0-6 Data matrixes in the calculation of Embodied Human Activity matrix via EJP, including their sizes

$$\mathrm{EHA_{kl}} = \mathrm{DVA_{kl}} \cdot \mathrm{EJP_k} = \frac{\mathrm{HA_k}}{\sum_l \mathrm{DVA_{kl}}} \cdot \mathrm{DVA_{kl}}$$

k: country-industry (28 countries x 13 sub-sectors)
l: region (China, EU28 or Rest of the world)

Multiplying this EHA matrix to the 3 EMR vectors (electricity, heat and fuels), the 3 matrixes for embodied Energy Throughput can be calculated.

$$\mathrm{ET_{elec_{kl}}} = \mathrm{EMR_{elec_k}} \cdot \mathrm{EHA_{kl}}$$

$$\mathrm{ET_{heat_{kl}}} = \mathrm{EMR_{heat_k}} \cdot \mathrm{EHA_{kl}}$$

$$\mathrm{ET_{fuel_{kl}}} = \mathrm{EMR_{fuel_k}} \cdot \mathrm{EHA_{kl}}$$

With this data, we can analyze country-by-country. In order to see the data for the whole EU, the cells for EU countries for each industry in each column can be summed vertically, in order to have a 39x3 matrix (3 regions and 13 sub-sectors per 3 regions).

This data was organized for each country in relation to the consumption and the trade iinvolved on. Thus, countries produce products and services, part of which are consumed in the same country/region (*Domestic*) and the rest is exported, both to Rest of the World (*Exported ROW*) or to the other region of analysis (*Exported China* for EU and *Exported EU* for China). On the other hand, the needs of the country/region are partially fulfilled by Imports, from Rest of the World (Imported RoW) or from the other country/region of analysis (Imported China for EU and Imported EU for China).

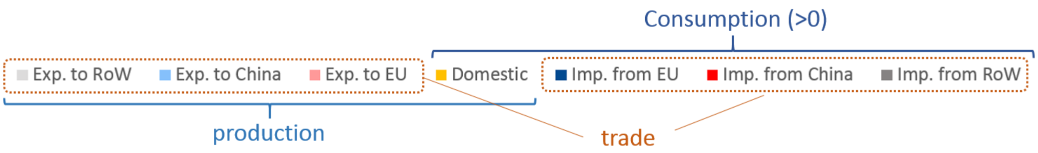

Figure 0-7 Divisions of HA and ETs in trade according to their relation to production, consumption and trade

- Exported to Rest of the World (from EU or China)
- Exported to China (from EU)
- Exported to EU (from China)
- Domestic: production and consumption in the same region
- Imported from EU (to China)
- Imported from China (to EU)
- Imported from Rest of the World (to China or EU)

In the graphs shown in the next sections, the positive numbers refer to Consumption of the country (Domestic + Imports) and negative numbers to Exports. In the case of HA, the whole picture could be constructed since there was data available for RoW. In the case of ET, there was no data available for RoW, and so only the relation between China and EU28 could be made.

Also, an assessment of the "consumed EMR" can be made. This is, instead of calculating EMR as usual (ET_i/HA_{PW}) we take into account the embodied ET and HA of the consumption, in this case only including China and EU28.

For some of the results and in order to ease the legibility of the graphs, an alternative classification has been used (Table 0-4) aggregating all categories related to industry.

Table 0-4 The alternative system of classification adopted in this study

Econ. class. calculations	Econ. class graphs
Agriculture and fishery	Agriculture and fishery
Mining and quarrying	Mining and quarrying
Food and beverages	Industry
Textile and leather	
Wood and paper	
Petroleum, chemical and non-metallic mineral products	
Metal products + machinery	
Transport equipment	
Other manufacturing	
Electricity, gas and water	Electricity, gas and water
Construction	Construction
Services	Services
Transport	Transport

1.2 Data sources and main assumptions

All data used in this deliverable is secondary data from the statistical offices of Europe and China. Since energy, labor and monetary value-added statistics are based on ISIC classifications, the comparison has not required large assumptions. In Table 0-5 and Table 0-6 we can see the main data sources used in this analysis.

In the case of Europe, human activity and monetary value-added data have been obtained from Annual National Accounts and Population on 1 January (Eurostat, 2018b).

The 2010 population census of the People's Republic of China (NBSC, 2018a) and China Labour Statistical yearbook (NBSC, 2018b). In relation to the energy throughputs data, it has been obtained from European Energy Balances (Eurostat, 2018a). For more details see Table 0-5.

Table 0-5 Main data sources used for the EU energy metabolic pattern analysis.

Data	Data inventories	Data sources	Brief descriptions
Human Activity	*Total employment domestic concept (*Hours worked)	*National accounts employment data by industry (up to NACE A*64)*	Employment covers all persons engaged in some productive activity (within the production boundary of the national accounts). Employed persons are either employees (working by agreement for another resident unit and receiving remuneration) or self-employed (owners of unincorporated enterprises).
	Household hours	*Population on 1 January*	The differences between total working hours in paid work and total available human time in hours per year (i.e. population multiplied by 8760).
Monetary Value-Added	Gross Value Added	*National accounts aggregated by industry (up to NACE A*64)*	Chain linked volumes (2005), million euro
Energy throughput	Energy products by final use	*Eurostat Energy Balances*	Data from final energy consumption by sector, excluding non-energy use and allocating distribution losses to the Energy Sector. Household and Transport are recalculated, see explanation below

In the case of China, human activity and monetary value-added data have been obtained from China Statistical Yearbook (NBSC, 2017), the 2010 population census of the People's Republic of China (NBSC, 2018a) and China Labour Statistical yearbook (NBSC, 2018b). In relation to the energy throughputs data, it have been obtained from China Energy Statistical Yearbook (NBSC, 2018c). For more details see Table 0-6.

Table 0-6 Main data sources used for China energy metabolic pattern analysis.

Data	Data inventories	Data sources	Brief descriptions
Human Activity	Workers number	*China Statistical Yearbook (2001-2016)*	With the number of employed persons at Year-end in urban and rural areas, and the details of the sectors of level n-2 are depicted from the proportion of *the 2010 population census*.
	Working hours	*China Labour Statistical yearbook (2001-2017), the 2010 population census of the People's Republic of China*	Weekly working hours in urban area by sector are from the series yearbook from 2001 to 2016. Since the survey only from the urban area; we adjusted the number from the 2010 Population Census of China.
	Household hours	*China Statistical yearbook (2001-2017)*	The differences between Working hours and total hours (Population multiplied by 8760).
Monetary Value-Added	GDP	*China Statistical Yearbook (2001-2017)*	Indices of gross domestic product from the yearbook, with year 2000 as constant.
Energy throughput	Energy carrier	*China Energy Statistical Yearbook (2001-2017)*	The data from the total final consumption of the China energy balance table, with the exclusion of the non-energy use.

One of the key issues when handling the accounting has been the reallocation of the energy carriers' consumption of the private transport (private cars and motorcycles). While in China it is already allocated in the household sector, in Europe it is allocated in the transport services sector. Therefore, energy consumption in the household sector for EU has been calculated by summing residential consumption (from the Eurostat Energy Balances (Eurostat, 2018a)) and fuel consumption by private cars (hypothesis: 80% of the total fleet) and motorcycles (hypothesis: 90% of the total fleet). The main data sources for this calculation are in Table 0-7.

Table 0-7 Data sources used for the transport calculation

Data	Data sources	Brief descriptions
$ET_{fuelTSEurostatij}$ $ET_{fuelHHEurostatij}$	*Eurostat*	Energy throughput of the transport and the households sectors
$nveh_{ijk}$	*Eurostat*	Stock of vehicles by category and NUTS 2 regions [tran_r_vehst]
x_{ijk}	*Eurostat*	Millions of kilometers [Mveh·km] (1990-2012) Motor vehicle movements on national territory, by vehicles registration [road_tf_vehmov] (2012-2016) Road traffic on national territory by type of vehicle and type of road (million Vkm) [road_tf_road]
$Fecon_{ijk}$	*Odyssee-mure project*	Fuel economy of the fleet for each country and year (for k=moto constant value of 4l/100km) [l/100km]
GCV_{diesel} $GCV_{gasoline}$	*IEA-EUROSTAT-OECD Energy Manual (pag. 181)*	Gross calorific value diesel and gasoline [MJ/l]
$Per_{dieselijk}$	*Eurostat*	percentage of diesel cars in the fleet per each year, country (for k=moto, $per_{dieselijk}$=0) [%] Passenger cars, by type of motor energy and size of engine [road_eqs_carmot]

Indexes:

- Countries: 28 EU countries (**i**)
- Years: 1990-2016 (**j**)
- Modes of transport: cars and motorbikes (**k**)

There is a large quantity of missing data, and so for each year we calculated a European average of km per vehicle (average of the countries):

$$\mathrm{avx_{ijk}} = \frac{\mathrm{x_{ijk}}}{\mathrm{nveh_{ijk}}}$$

$$\mathrm{avx_{EUjk}} = \frac{\sum_{\mathrm{i}} \mathrm{avx_{ijk}}}{\text{number of countries with } \mathrm{x_{ijk}}}$$

With this average ($\mathrm{avx_{jk}}$) we can calculate x_{ijk} for those which we don't have the data:

$$\mathrm{x_{ijk}} = \mathrm{avx_{EUjk}} \cdot \mathrm{nveh_{ijk}}$$

The $nveh_{ijk}$ database has also a lot of missing data. There are countries for which extrapolations or interpolations (linear or exponential) have been made. For others, we have used values for similar countries or countries with similar trends.

Finally, ET_{fuel_ijk} (fuels consumed by cars and motorbikes) can be calculated:

$$\mathrm{ET_{fuel\_ijk}} = \left[\left(\mathrm{GCV_{diesel}} \cdot \mathrm{per_{diesel_{ijk}}}\right) + \mathrm{GCV_{gasoline}} \cdot \left(100\% - \mathrm{per_{diesel_{ijk}}}\right)\right] \cdot \mathrm{x_{ijk}}$$

And to conclude, the ET from TS and HH has been rearranged. 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). To do so, we have made an assumption of the % of cars and motorbikes that run in the category HH.

$$\mathrm{ET_{fuelTS\_ij}} = \mathrm{ET_{fuelTSEurostat_{ij}}} - \mathrm{ET_{fuel_{ijmoto}}} \cdot 90\% - \mathrm{ET_{fuel_{ijcar}}} \cdot 80\%$$

$$\mathrm{ET_{fuelHH\_ij}} = \mathrm{ET_{fuelHHEurostat_{ij}}} + \mathrm{ET_{fuel_{ijmoto}}} \cdot 90\% + \mathrm{ET_{fuel_{ijcar}}} \cdot 80\%$$

Historical analysis of the metabolic pattern of the EU28 and China 2000-2016

In this chapter we use the energy end-use matrix to study changes in the economic performance of the economy of the EU28 and China over time in relation to their changing context. For reason of space we do not present again the logic and examples of the end-use matrix, because they have been presented (in theory and with examples) already twice in the previous deliverables: deliverable 4.2 – in relation to the whole economy of EU28 and the various EU countries; and deliverable 4.3 – in relation to the city of Barcelona. For this reason, we present here only the results of the analysis. The sources of the data used in this study are presented in Appendix 1.

Due to the presence of a Chinese PhD student visiting our Institute, not known at the moment of the writing of the proposal, we were able to generate a larger data set in relation to the metabolic analysis of China. Therefore, rather than using just two points in time, as suggested by the original title of the deliverable, we studied the time period 2000-2016 characterizing changes over the year. We describe the changes that took place in the two economic systems – EU28 and China by comparing the metabolic characteristics of the whole (at the level n), the characteristics of constituent components (Paid Work and Household sector, defined at the level n-1), the characteristics of the economic sectors (at the level n-2) and the metabolic characteristics of the sub-sectors (at the level n-3).

1.3 Contextualizing the analysis of the energy performance of the Paid Work sector inside the metabolic pattern of the economy

1.3.1 Analyzing the interface Level n (the whole) – Level n-1 (constituent components)

Adopting the conceptualization of the metabolic pattern of social-ecological systems (Giampietro et al., 2013; Giampietro and Sorman, 2012) we can visualize the metabolic pattern of a society (in this comparison EU and P.R. China) as determined by the metabolic pattern of a set of individual organs operating inside it. In particular, following the MuSIASEM approach presented in detail in deliverables 4.1 and 4.2 (Ripa and Giampietro, 2017; Ripoll-Bosch and Giampietro, 2018) we can define the following relations between the size of the various constituent components of the society (measured in hours of human activity per year at the level n) and the quantities of energy metabolized by them (measured in Joules per year at the level n). Considering a first split of the total size of human activity (Total Human Activity = population x 8,760) and of the total energy metabolized (Total Energy Throughput = quantity of energy per year measured in Primary Gross Energy Requirement) over two constituent compartments: HH (household) and PW (Paid Work) at the level n-1, we can write:

$$THA\ (\textit{level n}) = HA_{HH} + HA_{PW}\ \ (\textit{level n-1})$$

$$TET\ (\textit{level n}) = ET_{HH} + ET_{PW}\ \ (\textit{level n-1})$$

The forced metabolic relation over the size of the constituent components defines an expected pace of metabolism determined by the following equation of congruence across levels:

$$TET/THA\ (\textit{level n}) = EMR_{AS}\ \text{(average society)};$$

$$ET_{HH}\ /HA_{HH}\ (\textit{level n-1}) = EMR_{HH}\ \text{(household)};$$

$$ET_{PW}\ /HA_{PW}\ (\textit{level n-1}) = EMR_{PW}\ \text{(paid work)};$$

$$TET\ (\textit{level n}) = THA \times EMR_{AS}\ (\textit{level n}) = [HA_{HH} \times EMR_{HH}] + [HA_{PW} \times EMR_{PW}]\ (\textit{level n-1})$$

This relation shows that the overall metabolic pace of the society (EMR_{AS}) observed at the *level n* depends on four distinct factors that can only be observed at the *level n-1*:

(i) the two assessments of Human Activity of the Household sector and the Paid Work (HA_{HH} and HA_{PW}) sector; and

(ii) the two assessments of the pace of energy metabolism in the HH sector and the PW sector (ET_{HH} and ET_{PW}).

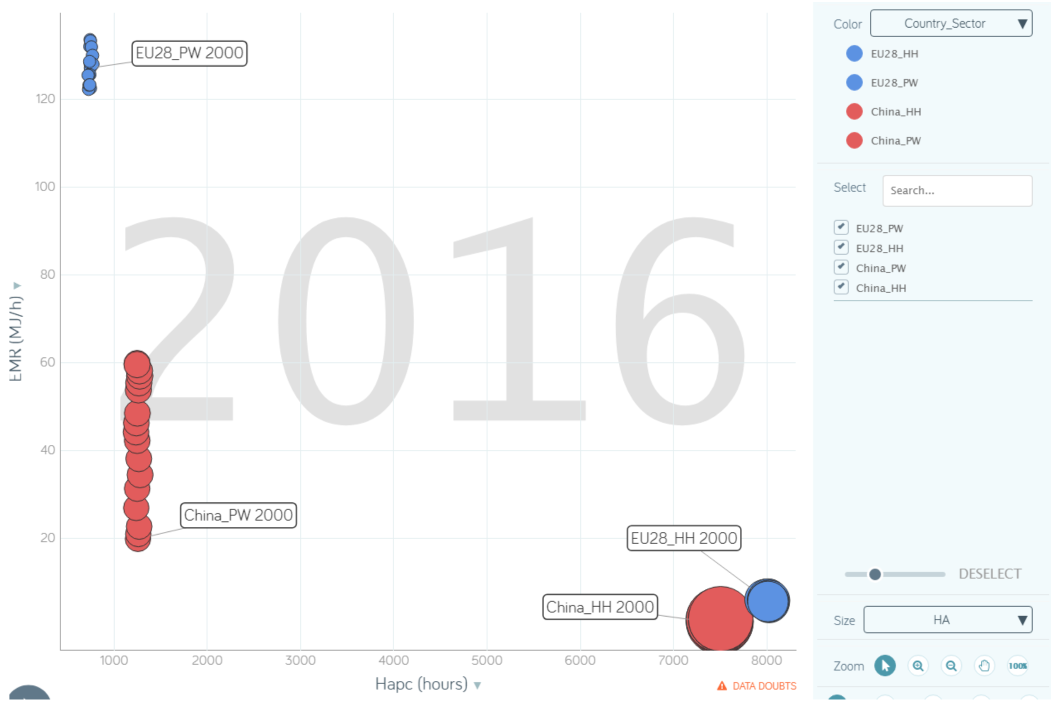

Figure 0-1 Graph of EMR_i (metabolic rate)-HA_i (size) the two metabolic characteristics of the HH and PW sectors (constituent components) of EU and China

It is important to carry out this analysis across levels of organization because using "overall values" to compare the performance of different countries observed only at the *level n* does imply the missing of the factors determining the differences observed at the higher hierarchical level, observable only at a lower hierarchical level. To illustrate this fact, we compare in Figure 0-1 the difference between the metabolic characteristics of the constituent components HH and PW of China and EU. It shows the clear difference in the value of metabolic rate between the HH and the PW of EU and China.

1. The difference between the values of EMR_i is evident for both EU and China: (i) for EU, EMR_{HH} is around 6 MJ/h whereas EMR_{PW} is in the range 120-130 MJ/h (a difference of 20-22 times!); (ii) for China, EMR_{HH} is around 1 MJ/h whereas EMR_{PW} is in the range 20-60 MJ/h (a difference of 20-60 times!);
2. The values of EMR_i of China and EU are quite different: (i) regarding EMR_{HH}, the HH of EU is metabolizing 6 times more energy than China; (ii) regarding EMR_{PW}, the PW of EU started metabolizing 6 times more than China in 2000, whereas the difference was only 2/1 in 2016.
3. The patterns of change in time of the metabolic characteristics of the two sectors HH and PW are quite different in EU and China. This is illustrated in Figure 0-2 and Figure 0-3 (due to the large differences in values, we had to use two graphs with different scales).

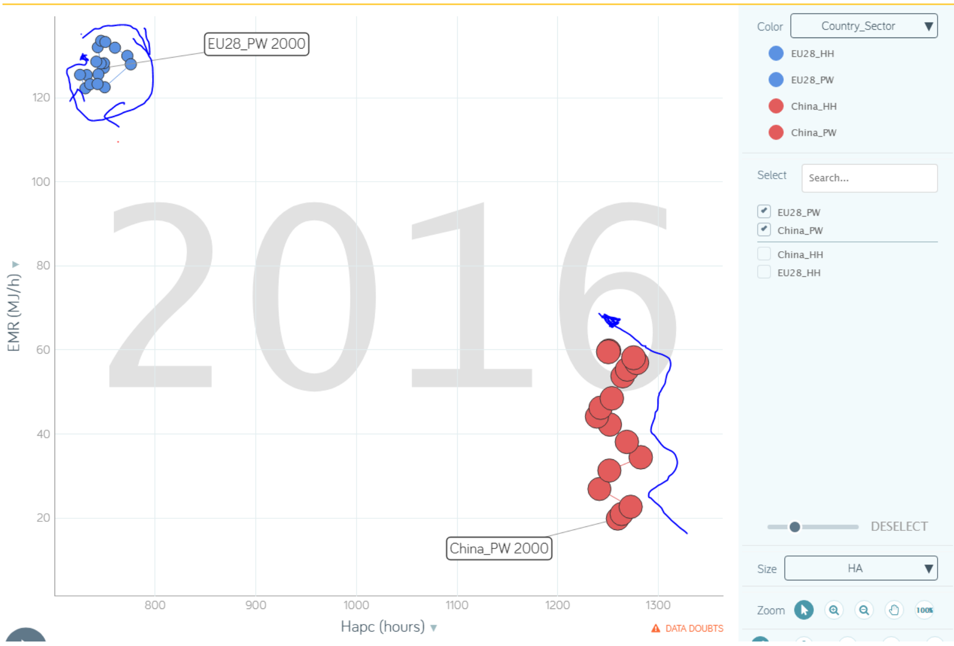

Figure 0-2 The changes of the metabolic characteristics of PW (EU and China) in time on the plane EMRi (metabolic rate)-HAi (size) over the period 2000-2017

Analyzing the changes in time of the metabolic characteristics of HH and PW in EU28 and in China, we can detect two important differences: (i) the metabolic rates of the constituent components are different; (ii) the trends of changes in the metabolic rates of HH and PW are different: in Europe the values of EMR_i are moving around attractor points (changes determined by short term adjustment to local economic situations), whereas in China the values of EMR_i are clearly moving up according to a well-established trend.

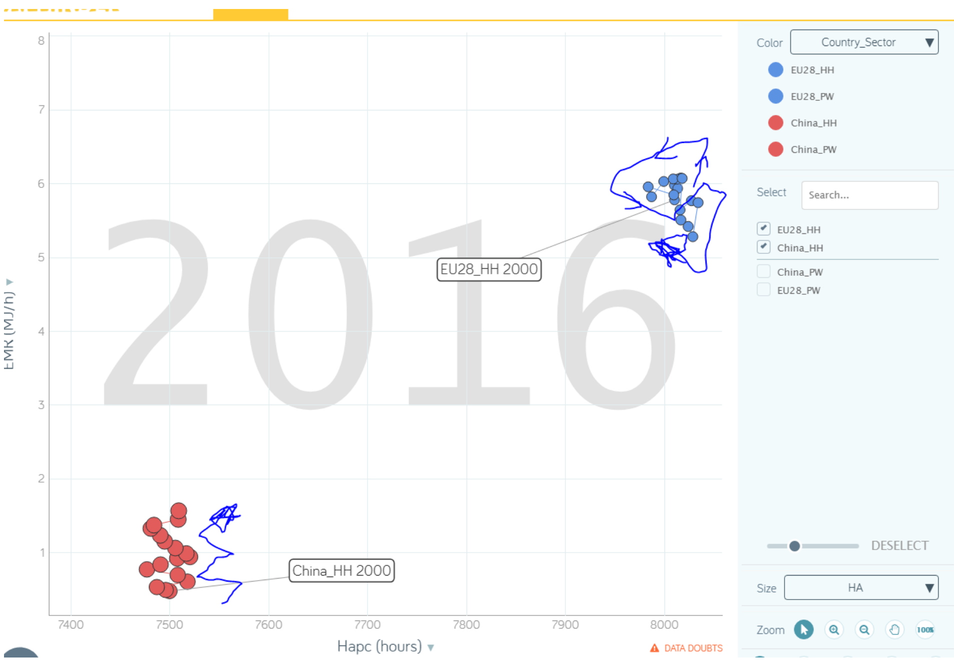

Figure 0-3 The changes of the metabolic characteristics of HH (EU and China) in time on the plane EMR_i (metabolic rate)-HA_i (size) over the period 2000-2017

In conclusion, we can say that if we look at the differences between the metabolic rates of EU and China at the level of the whole economy (level n) we cannot identify specific factors explaining existing differences or existing drivers. In order to explain differences and study the drivers, we have to open the level n and observe the elements at the level n-1. In the same way, we should be aware that at level n-1 we are still observing metabolic elements made-up of many heterogeneous metabolic elements expressing quite different metabolic characteristics. For example, the PW constituent component includes sectors such as industry, energy and mining that use much more energy per hour of work than other sectors such as service and government. Therefore, in order to be able to explain the changes illustrated in Figure 0-2 and Figure 0-3 we have to move to a lower level of analysis in order to be able to observe changes in the metabolic characteristics of economic sectors. In this way, we can finally understand how changes in the metabolic characteristics of the economic sectors observed at level n-2 can be used to explain changes in the metabolic characteristics observed at level n-1.

1.3.2 Analyzing the interface Level n-1 (constituent components) – Level n-2 (economic sectors) in relation to Gross Energy Requirement (J of thermal energy)

At the level n-2, we divide the n-1 constituent component Paid Work into five sectors: AF = Agriculture and Forestry; IN = Industry; Co = Construction; Tr = transport; SGnT = Service and Government no Transport.

$$PW \text{ (level n-1)} = AF + IN + Co + Tr + SGnT \text{ (level n-2)}$$

In this way it becomes possible to establish a bridge across quantitative assessments that have to result congruent across different levels of analysis:

$$THA = HA_{HH} + HA_{PW} \ldots = HA_{HH} + HA_{AF} + HA_{IN} + HA_{Co} + HA_{Tr} + HA_{SGnT}$$

(level n) *(level n-1)* *(level n-2)*

$$TET = ET_{HH} + ET_{PW} \ldots = ET_{HH} + ET_{AF} + ET_{IN} + ET_{Co} + ET_{Tr} + ET_{SGnT}$$

We provide below (Table 0-1) a comparison of the values of EMRi = ET_i /HA_i (*level n-2*) in the period 2000-2017 for the five sub-sectors found in EU28 and China.

Table 0-1 Comparison of the value of EMR (MJ/h Gross Energy Requirement thermal) on six sectors of EU28 and China over the period 2000-2016

Level n-2																		
EMR_GER (MJ/h)		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	201
Households	CHINA	1,4	1,3	1,3	1,4	1,4	1,5	1,5	1,6	1,5	1,5	1,6	1,6	1,7	1,7	1,7	1,8	1,9
	EU28	5,8	6,0	5,9	6,1	6,1	6,1	6,0	5,8	6,0	5,8	6,1	5,6	5,8	5,7	5,3	5,4	5,5
Agriculture&Forestry	CHINA	2,0	1,6	1,7	2,0	2,4	2,7	3,0	3,1	3,1	3,3	3,6	4,0	4,3	4,7	5,0	5,3	5,7
	EU28	50	50	50	51	55	56	56	56	57	57	58	58	61	63	62	64	68
Industry	CHINA	110	86	97	118	129	135	140	152	158	163	165	184	186	201	207	208	211
	EU28	399	403	411	428	435	441	436	439	428	418	452	442	444	441	433	435	-
Construction	CHINA	8,5	7,1	6,9	7,0	8,0	7,4	7,6	7,5	7,8	7,9	8,1	7,9	7,2	6,9	7,2	7,8	8,0
	EU28	12	13	14	12	12	12	12	11	12	12	12	14	15	16	15	15	15
Transport	CHINA	85	68	69	79	90	91	98	107	117	119	133	139	155	137	137	148	152
	EU28	601	607	614	628	656	666	678	687	662	662	668	661	648	654	669	674	691
Service&Government (without Transport)	CHINA	9,1	6,8	7,1	8,9	9,7	10	11	11	12	12	13	14	16	16	15	16	16
	EU28	39	41	40	43	43	44	44	42	44	44	46	44	44	44	42	43	43

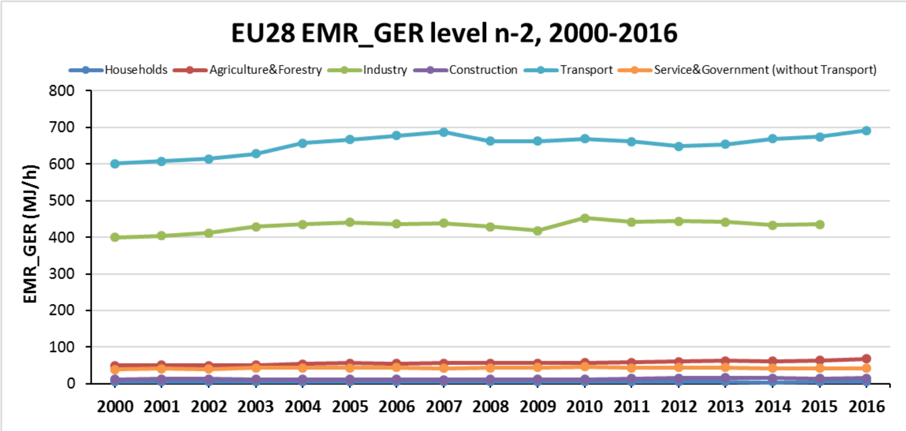

Figure 0-4 The values of EMR_i of the six sectors for EU28 at the level n-2 in the period 2000-2016

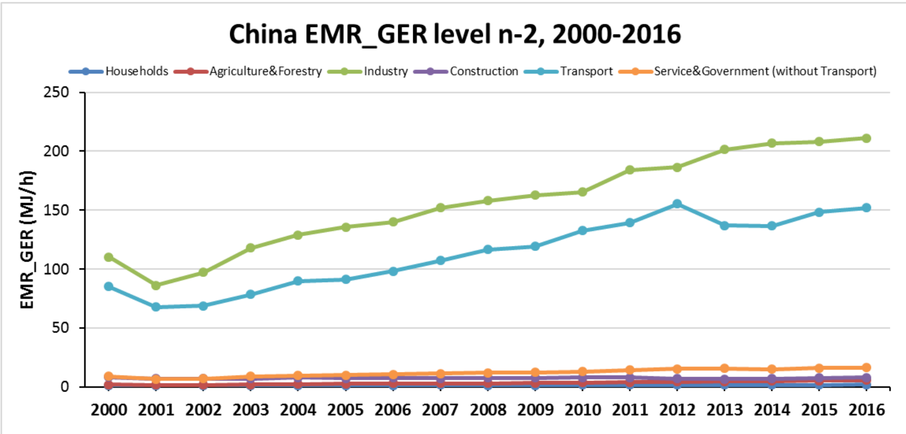

Figure 0-5 The values of EMRi of the six sectors for China at the level n-2 in the period 2000-2016

The changes in EMR_i both for EU28 and China are visualized in Figure 0-4 and Figure 0-5, they show the existence of the same phenomenon flagged in Figure 0-1: the sectors of industry (200 MJ/h) and transport (150 MJ/h) use much more energy per hour of work than sectors like Household (1.5 MJ/h) and Agriculture (5.5 MJ/h). That is, at the level n-2, we can see the existence of big differences in the values of EMR_i. This implies that, again, in order to understand the metabolic characteristics and the factors determining the level of consumption of energy at the level n-1, we have to study at level n-2 the metabolic characteristics, i.e. the relative size and metabolic rates, of the lower level elements making up the given constituent component at n-1. This analysis is needed not only to explain the values of the metabolic characteristics at a given level and at a given point in time, but also to study the trends of changes across different levels.

For example, Figure 0-6 and Figure 0-7 show the metabolic characteristics of the subsectors of EU28 and China considering a specific energy carrier, in this case electricity. We can appreciate that not only the value of the metabolic rates are different across sub-sectors but also the pattern of changes in time are quite different between EU28 and China. The EMR of electricity in the Household sector in China has been steadily growing, whereas in EU28 oscillates.

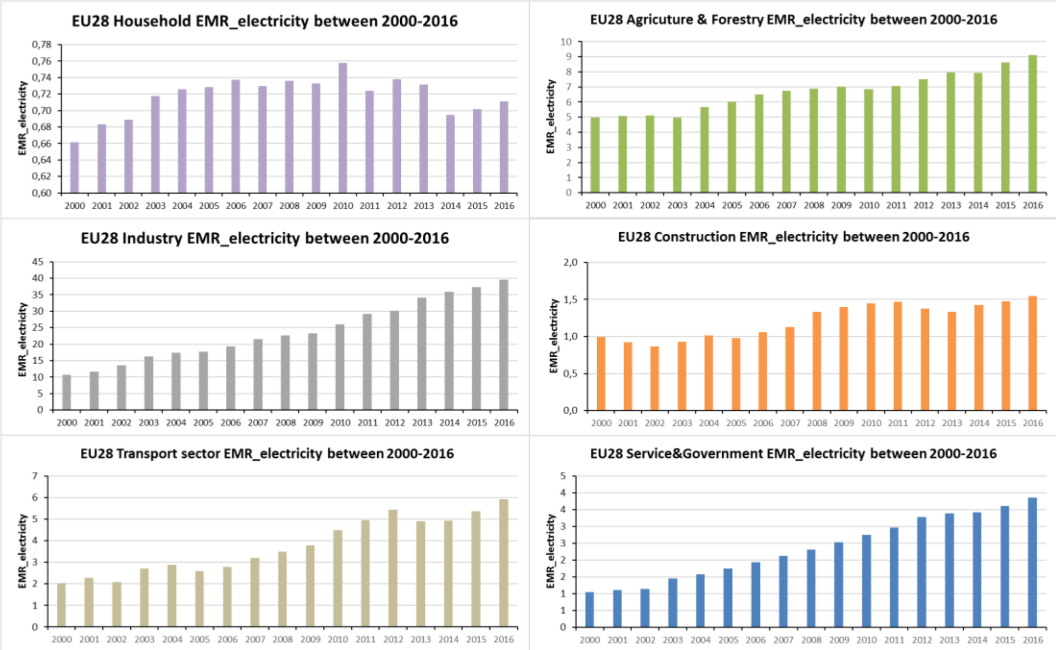

Figure 0-6 Observing the pattern of changes in time of EMR_i of electricity over the six sectors for EU28 in the period 2000-2016

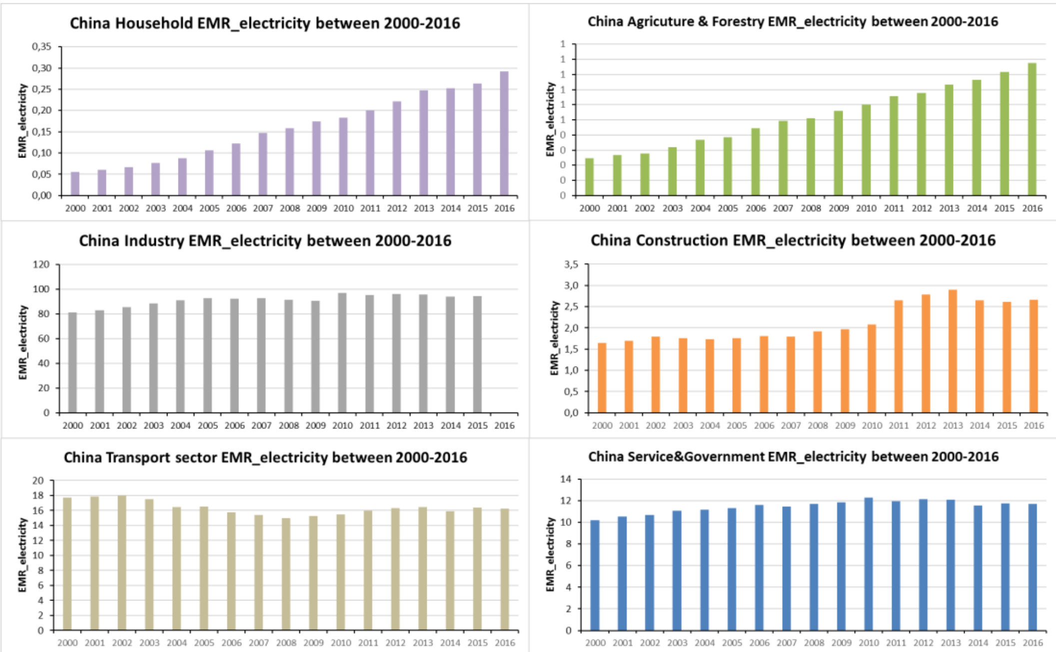

Figure 0-7 Observing the pattern of changes in time of EMRi of electricity over the six sectors for China in the period 2000-2016

By analyzing changes in time at level n-2, it becomes possible to study different trends and behavior in times of the different sub-sectors considered establishing a relation between different quantitative assessments. An example is given in Figure 0-8, where we compare the differences in time of the metabolic characteristics of the 6 subsectors of EU28 and China in the period 2000-2016. It clearly shows the power of analysis of the MuSIASEM method. The type of analysis presented in Figure 0-6 and Figure 0-7 still presents decontextualized quantities of energy use. Figure 0-8 shows: (i) the assessments of energy use given by the value of EMR_i are related to the requirement of "hours of work per capita per year" for the various sectors, the values of EMR_i on the Y axis and the values of HA_i on the X axis; (ii) in this graph the assessments associated with the position of the various points can be contextualized in relation to the positions of the other points; (iii) the graphs represent the pattern of changes over the period considered: the movement of the points; (iv) the size of the disks can be used to track the changes in one extensive variable, in this case the hours of work. When using this representation we can see key differences between EU28 and China:

1. In relation to AF (Agriculture and Forestry): (i) EU28 increases the energy metabolized per worker (level of technical capitalization) while further reducing the work force, already quite low; (ii) in China the reduction of the workforce is dramatic: it starts from a very large size, but is not accompanied by an increase in the technical capitalization of the sector;

2. In relation to Co (Construction): (i) EU28 reduced the number of workers while slightly increasing the level of technical capitalization; (ii) China increases dramatically the work force in this sector, increasing only slightly the technical capitalization;

3. In relation to IN (Industry): (i) EU28 reduced the number of workers by compensating this change with an increase in technical capitalization. A clear re-adjustment during the crisis of 2009 can be identified; (ii) China has increased initially both work force and technical capitalization, then it has followed the EU pattern (increase of technical capital and reduction of work force), probably due to the externalization of some low productive activities to other Asiatic countries. But this is a hypothesis that can only be analyzed by moving the observation to Level n-3 (in the next section);

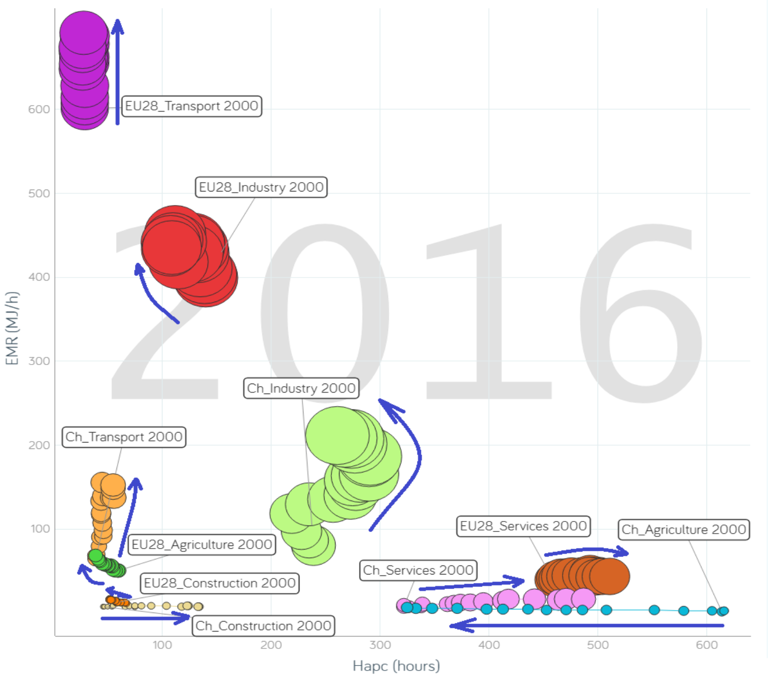

Figure 0-8 Pattern of changes in time (2000-2016) of EMR_i for the six sectors in EU28 and China

4. In relation to Ts (Transport): (i) EU28 first increased and then decreased the level of energy use per worker (in response to the 2009 crisis); (ii) China has been increasing steadily both the number of workers and the level of technical capital per worker;

5. In relation to SGnT (Service and Government no Transport): (i) this is the only sector in EU28 that dramatically increased the work force with a slight increase of technical capital per worker; (ii) China also increased dramatically the work force in the sector. This increase can also be explained by the need of absorbing the mass of workers coming out from the agricultural sector.

This may be interpreted as a force choice, a job in the service sector requires a lower level of technical capital per worker than in the industrial sector.

1.3.3 Analyzing the interface Level n-1 (constituent components) – level n-2 (sectors) in relation to the use of electricity

In the previous analysis we have been looking at the overall consumption of energy carriers measured in terms of Primary Gross Energy Requirement equivalent [NOTE – to obtain this result the given mix of electricity, fuels and thermal energy carriers has been converted in a notional quantity of thermal joules using a set of quality factors – this is a standard operation done by statistical offices, for a technical explanation see Giampietro et al (Giampietro et al., 2013)]. To illustrate the flexibility of the MuSIASEM approach, we provide in this section an example of the same analysis carried out in section 3.1.2, focusing only on the level of consumption of a specific energy carrier: electricity. Energy in the form of electricity has some special characteristics: (i) it cannot be easily stored and therefore it requires the ability to match in time and space the demand and the supply; (ii) it requires a quite complex system of distribution to cover the end uses of the country. Therefore, its large scale use is associated with a large requirement of fixed investments; (iii) on the positive side, electricity is a form of mechanical energy and therefore it is more useful to operate the technical capital and tools boosting the efficacy of human workers. For all these reasons, an increase in the consumption of electricity both in the HH and the PW sector is associated with economic development and it is determining positive effects both in the phase of economic production and final consumption. Below we provide the same type of comparison referring to the consumption of electricity in EU28 and China already presented in Section 3.1.2.

We provide below the values of $EMR_{i electric} = ET_{i electric} / HA_i$ (*level n-2*) in the period 2000-2016 for the six sectors described above in Table 2.2.

Table 0-2 Comparison of the value of $EMR_{electricity}$ (MJ/h) on six sectors of EU28 and China over 2000-2016

Level n-2																		
EMR_electricity (MJ/h)		2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	201
Households	CHINA	0,055	0,061	0,066	0,076	0,088	0,11	0,12	0,15	0,16	0,17	0,18	0,20	0,22	0,25	0,25	0,26	0,29
	EU28	0,66	0,68	0,69	0,72	0,73	0,73	0,74	0,73	0,74	0,73	0,76	0,72	0,74	0,73	0,69	0,70	0,71
Agriculture&Forestry	CHINA	0,25	0,27	0,28	0,32	0,37	0,39	0,45	0,49	0,51	0,56	0,60	0,66	0,68	0,73	0,77	0,82	0,87
	EU28	5,0	5,1	5,1	5,0	5,7	6,0	6,5	6,7	6,9	7,0	6,8	7,0	7,5	8,0	7,9	8,6	9,1
Industry	CHINA	11	12	14	16	17	18	19	22	23	23	26	29	30	34	36	37	39
	EU28	81	83	85	88	91	93	92	93	91	90	97	95	96	95	94	94	-
Construction	CHINA	0,99	0,92	0,87	0,93	1,01	0,98	1,1	1,1	1,3	1,4	1,4	1,5	1,4	1,3	1,4	1,5	1,5
	EU28	1,6	1,7	1,8	1,8	1,7	1,8	1,8	1,8	1,9	2,0	2,1	2,7	2,8	2,9	2,6	2,6	2,7
Transport	CHINA	2,0	2,3	2,1	2,7	2,9	2,6	2,8	3,2	3,5	3,8	4,5	5,0	5,4	4,9	4,9	5,4	5,9
	EU28	18	18	18	18	16	17	16	15	15	15	16	16	16	16	16	16	16
Service&Government (without Transport)	CHINA	1,1	1,1	1,1	1,5	1,6	1,7	1,9	2,1	2,3	2,5	2,8	3,0	3,3	3,4	3,4	3,6	3,9
	EU28	10	11	11	11	11	11	12	11	12	12	12	12	12	12	12	12	12

It should be noted that when comparing the $EMR_{INElectric}$ of the Industry in 2015, the EU28 had a value 2.5 times higher (94 MJ/h) than the one of China in the same year (37 MJ/h). As discussed before, this difference can be explained in terms of a different strategy of the use of labor. The input of electricity is used to increase the productivity of labor. Electricity can be considered as a factor substituting labor in the production function of the industry. Due to the large availability of working hours in the Paid Work sector, China so far adopted a solution based on a larger input of labor and smaller input of electricity. Still, because of the other positive characteristics of electricity we can notice that especially in the industrial sector the level of electricity consumption per worker is steadily growing in China (Figure 0-10).

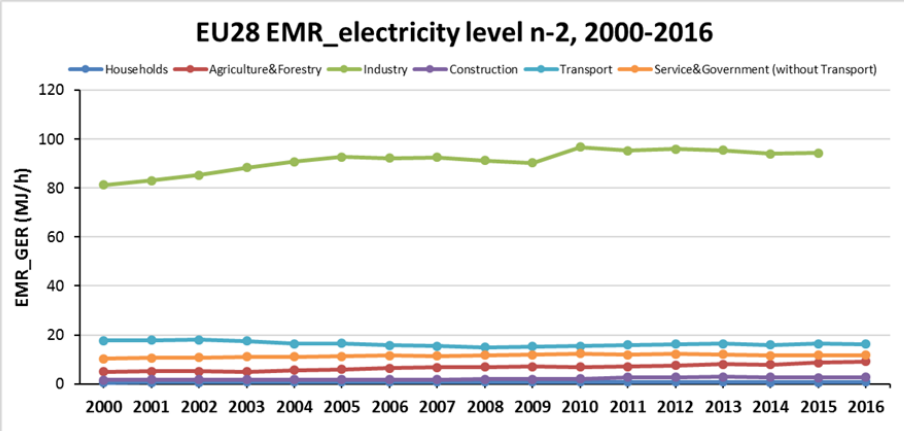

Figure 0-9 The values of $EMR_{ielectric}$ in China for the six sectors in 2000-2016

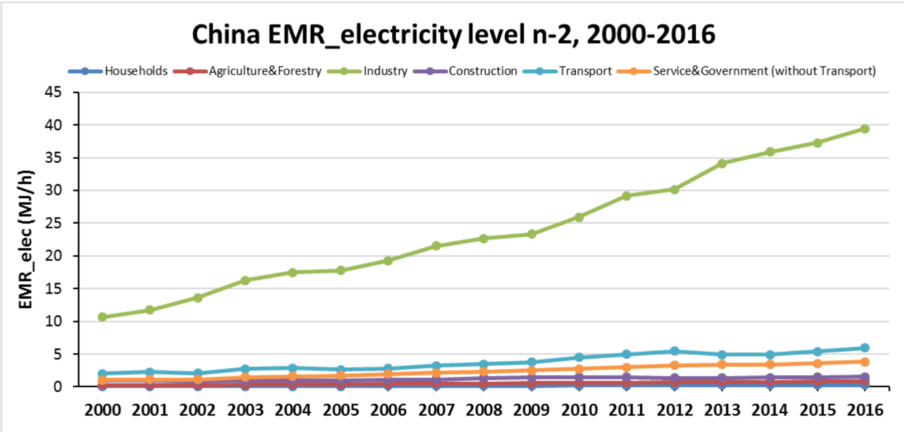

Figure 0-10 The values of $EMR_{ielectric}$ in China for the six sectors in 2000-2016

1.4 Comparing the use of energy carriers in sub-sectors (level n-3)

The adoption of the system of accounting of the end use matrix makes it possible to move down to another level of analysis and look at the use of the different energy carriers in different sub-sectors in order to have a better picture of the changes taking place during the considered period. In this section, we provide data of 5 sub-sectors of the industrial sector: 1. Textile and Leather; 2. Chemical and Petrochemical; 3. Basic Metals, 4. Machinery, 5. Transport Equipment. We provide below for each sub-sector a table comparing the different values of EMR_i over the period and a series of graphs illustrating the changes in EU28 and China.

1.4.1 Textile and Leather

Table 0-3 Values of EMR_i–in GER, electricity, heat and fuel- in EU28 and China for Textile and Leather in 2000-2016

Level n-3	Textil & Leather	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU28	EMR_GER (MJ/h)	91	92	93	94	92	83	81	80	77	77	79	75	75	76	73	74	-
	EMR_electricity (MJ/h)	19	19	20	19	19	19	18	19	19	18	19	19	19	19	18	19	-
	EMR_heat (MJ/h)	39	39	39	41	39	31	31	29	27	28	27	26	26	26	25	25	-
	EMR_fuel (MJ/h)	2,5	3,0	2,8	2,9	2,7	3,2	2,5	2,7	2,0	2,1	2,1	1,9	1,7	1,4	1,3	1,5	-
China	EMR_GER (MJ/h)	24	26	30	35	42	41	43	47	48	49	52	57	59	63	62	65	69
	EMR_electricity (MJ/h)	4,2	4,6	5,5	6,6	7,5	7,5	8,6	9,6	10	10	12	13	15	17	17	18	19
	EMR_heat (MJ/h)	12	13	15	17	21	21	20	21	21	20	20	22	20	19	17	18	19
	EMR_fuel (MJ/h)	1,4	1,5	1,5	1,4	1,5	1,1	1,0	1,1	1,2	1,3	1,4	1,1	0,90	0,82	0,73	0,72	0,65

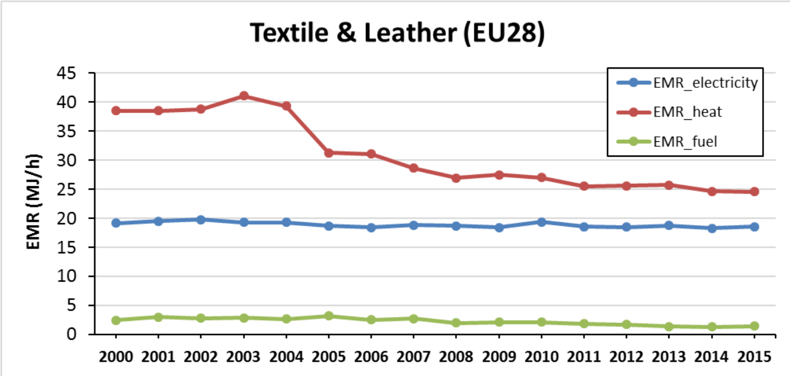

Figure 0-11 Comparing the values of EMR –electricity, heat and fuel - in EU28 for Textile and Leather in 2000-2016

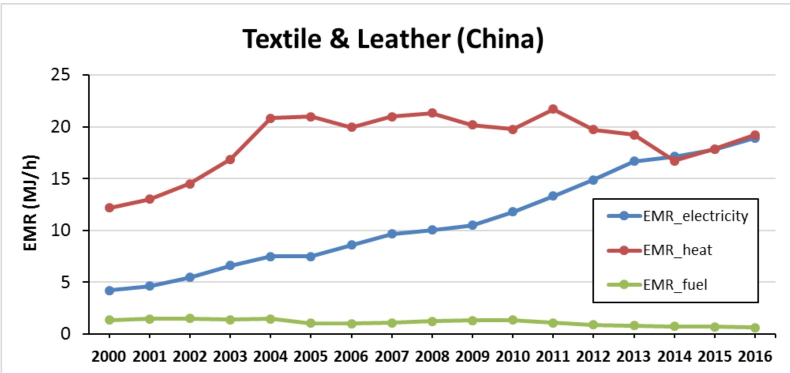

Figure 0-12 Comparing the values of EMR –electricity, heat and fuel - in China for Textile and Leather in 2000-2016

1.4.2 Chemical & Petrochemical

Table 0-4 Values of EMR_i –in GER, electricity, heat and fuel - in EU28 and China for Chemical & Petrochemical in 2000-2016

Level n-3	Chemical & Petrochemical	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU28	EMR_GER (MJ/h)	1077	1082	1086	1131	1112	1130	1107	1131	1129	1055	1129	1122	1114	1133	1109	1072	-
	EMR_electricity (MJ/h)	213	212	216	218	223	230	229	228	231	210	233	221	218	221	222	220	-
	EMR_heat (MJ/h)	519	526	517	554	523	521	503	527	520	500	513	538	534	549	524	497	-
	EMR_fuel (MJ/h)	5,6	7,3	9,6	12	13	13	11	13	11	11	11	12	16	11	11	6,3	-
China	EMR_GER (MJ/h)	148	171	204	246	295	308	332	360	355	349	372	413	354	406	436	450	444
	EMR_electricity (MJ/h)	19	20	24	29	31	32	36	40	40	41	43	48	52	62	66	68	70
	EMR_heat (MJ/h)	96	114	137	166	209	218	232	248	245	237	252	285	218	242	260	269	258
	EMR_fuel (MJ/h)	4,1	4,8	5,1	5,1	6,0	6,1	6,5	6,6	6,7	6,2	6,6	3,4	2,3	3,1	4,5	5,1	5,1

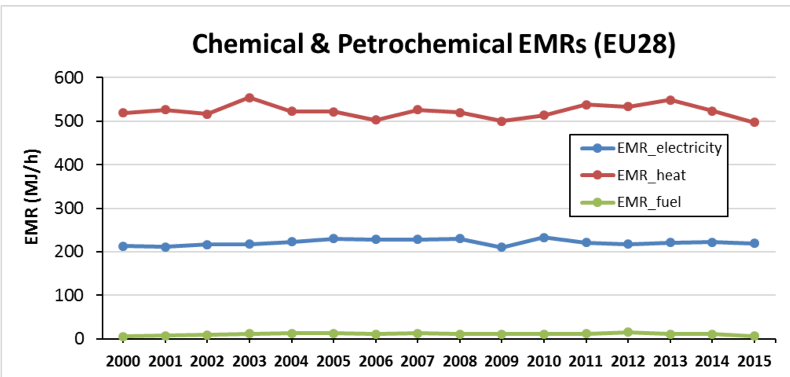

Figure 0-13 Values of EMR_i –electricity, heat and fuel - in EU28 for Chemical and Petrochemical in 2000-2016

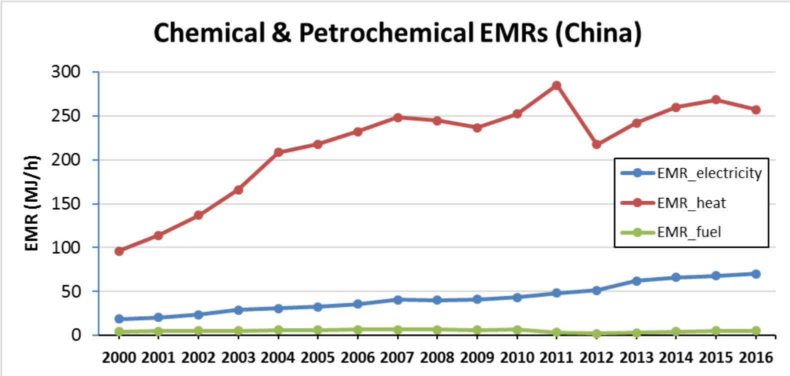

Figure 0-14 Values of EMR –electricity, heat and fuel - in China for Chemical and Petrochemical in 2000-2016

1.4.3 Basic Metals

Table 0-5 Values of EMR –in GER, electricity, heat and fuel - in EU28 and China for Basic Metal in 2000-2016

Level n-3	Basic Metals	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU28	EMR_GER (MJ/h)	1959	1909	1940	2033	2117	2074	2073	1984	1871	1555	1867	1906	1899	1915	1921	1968	-
	EMR_electricity (MJ/h)	323	327	336	348	373	371	370	360	343	294	341	355	350	345	347	356	-
	EMR_heat (MJ/h)	1111	1051	1061	1123	1145	1106	1109	1046	978	790	977	979	986	1017	1018	1040	-
	EMR_fuel (MJ/h)	13	12	8,5	7,8	7,2	7,3	6,0	6,5	5,9	5,3	6,3	5,9	5,5	5,2	4,0	5,7	-
China	EMR_GER (MJ/h)	297	329	381	484	542	649	720	803	819	865	890	992	943	1111	1173	1233	1318
	EMR_electricity (MJ/h)	29	32	38	49	57	64	75	89	91	93	107	121	118	144	155	176	193
	EMR_heat (MJ/h)	218	243	277	353	392	480	523	569	578	622	609	675	634	735	770	774	815
	EMR_fuel (MJ/h)	3,3	3,7	4,2	4,5	3,7	3,3	3,3	3,3	3,9	3,2	3,1	2,7	2,6	2,7	2,5	2,5	2,3

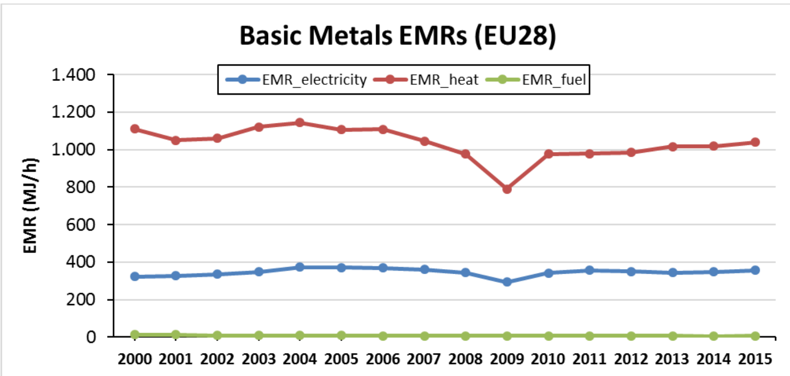

Figure 0-15 Values of EMR - electricity, heat and fuel - in EU28 for Basic Metals in 2000-2016

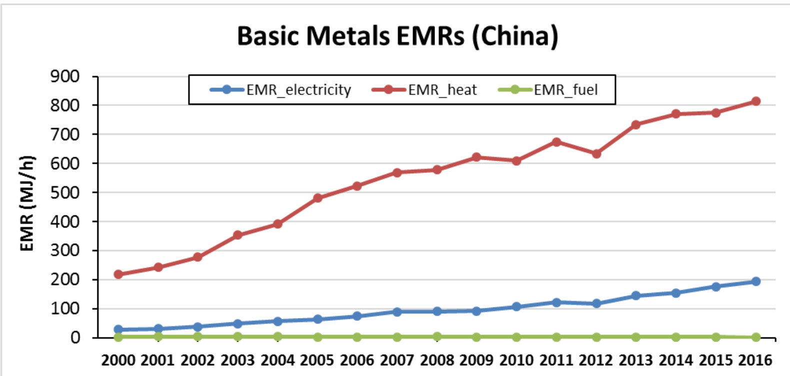

Figure 0-16 Values of EMR –electricity, heat and fuel - in China for Basic Metals in 2000-2016

1.4.4 Machinery

Table 0-6 Values of EMR –in GER, electricity, heat and fuel - in EU28 and China for Basic Metal in 2000-2016

Level n-3	Machinery	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU28	EMR_GER (MJ/h)	74	76	77	88	90	90	90	89	93	91	100	97	96	98	95	92	-
	EMR_electricity (MJ/h)	19	19	20	23	24	24	24	24	27	25	28	28	28	28	28	27	-
	EMR_heat (MJ/h)	23	24	24	25	26	25	24	23	22	22	24	22	22	23	21	21	-
	EMR_fuel (MJ/h)	3,0	3,0	3,1	3,2	3,0	3,0	2,6	2,7	2,3	3,0	2,8	2,2	2,1	2,0	1,7	1,5	-
China	EMR_GER (MJ/h)	21	22	26	30	31	32	35	36	40	38	41	44	41	40	33	41	44
	EMR_electricity (MJ/h)	4,0	4,5	5,5	6,8	7,4	7,6	8,2	8,8	9,7	9,6	11	12	12	12	10	13	14
	EMR_heat (MJ/h)	8,3	8,6	9,3	9,7	10	11	12	12	12	11	11	12	8,4	7,3	6,1	6,3	6,4
	EMR_fuel (MJ/h)	1,9	2,0	2,3	2,3	2,4	1,9	1,8	1,8	2,3	2,2	2,2	1,5	1,2	1,2	0,96	1,0	0,91

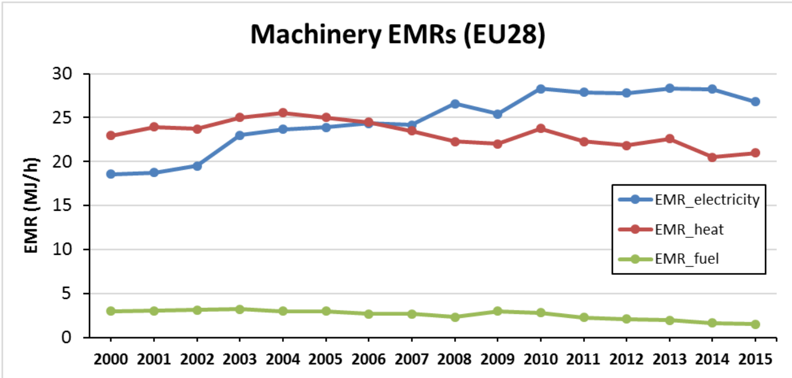

Figure 0-17 Values of EMR –electricity, heat and fuel - in EU28 for Machinery in 2000-2016

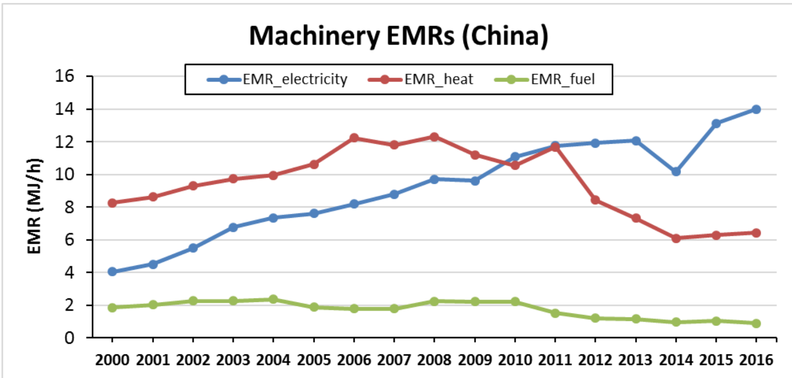

Figure 0-18 Values of EMR –electricity, heat and fuel - in China for Machinery in 2000-2016

1.4.5 Transport Equipment

Table 0-7 Values of EMR – in GER, electricity, heat, and fuel - in EU28 and China for Basic Metal in 2000-2016

Level n-3	Transport Equipment	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
EU28	EMR_GER (MJ/h)	118	120	121	127	129	129	127	127	124	119	133	127	129	131	126	123	-
	EMR_electricity (MJ/h)	32	32	33	33	34	35	35	36	36	34	38	36	37	37	37	36	-
	EMR_heat (MJ/h)	32	34	32	38	37	34	33	32	29	28	32	31	31	32	28	27	-
	EMR_fuel (MJ/h)	3,4	3,8	3,6	3,2	3,3	3,5	3,2	2,8	2,5	2,6	3,0	2,6	2,6	2,5	2,4	2,6	-
China	EMR_GER (MJ/h)	21	24	27	28	31	27	28	31	33	33	38	38	36	43	42	42	42
	EMR_electricity (MJ/h)	4,0	4,6	5,3	5,9	7,0	5,2	5,5	6,6	7,1	7,8	9,9	10	9,6	12	12	12	13
	EMR_heat (MJ/h)	9,4	9,7	11	11	10	11	12	11	11	10	9,6	9,5	9,6	11	10	9,1	8,2
	EMR_fuel (MJ/h)	1,8	1,9	1,8	1,9	2,6	2,4	2,2	2,3	3,1	2,4	2,5	2,2	1,9	1,8	1,6	1,5	1,4

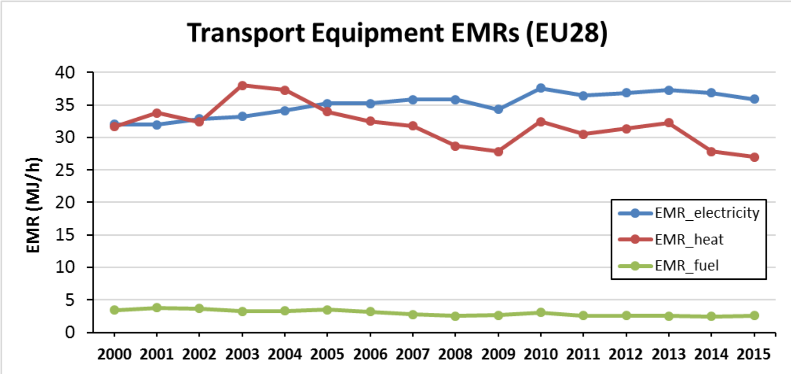

Figure 0-19 Values of EMR –electricity, heat, and fuel - in EU28 for Transport Equipment in 2000-2016

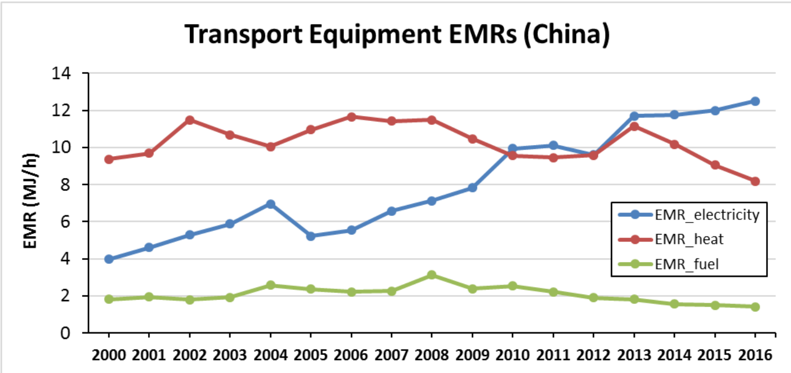

Figure 0-20 Values of EMR –electricity, heat and fuel - in China for Transport Equipment in 2000-2016

1.4.6 An overview of the 5 sub-sub-sectors together in Gross Energy Requirement

In Figure 0-21 and Figure 0-22, we can see two obvious differences in the metabolic characteristics of the various subsectors in the industrial sectors of EU28 and China: (1) the levels of EMR_i in EU28 are much higher than in China. They can reach values of "thousands of MJ/h" (basic metal and Chemical and Petrochemical). In China, the heterogeneity between the EMR_i across subsectors of the industrial sector is even sharper: the difference between the EMRs of basic metal and of textile is more than 20/1. This entails that changes in the weight in the mix of the various sub-sectors may have more important effects than changes in the technical coefficients of the processes. For example, in order to reduce the energy use of the industrial sector a reduction of 10% the activities in the basic metals subsector may result much more effective than increasing of 50% the efficiency in the activities of the textile subsector!; (2) the values of the EMRs in EU28 are quite stable in the period considered (excluding a punctual effect associated with the 2008/2009 crisis), whereas the values of the EMR_i of China are growing during the period considered, with a clear acceleration of the energy sector. This pattern of change will be studied using the metabolic decomposition analysis in Section 4.

D.4.4 Multi-scale integrated comparison of the metabolic pattern of EU28 and China in time

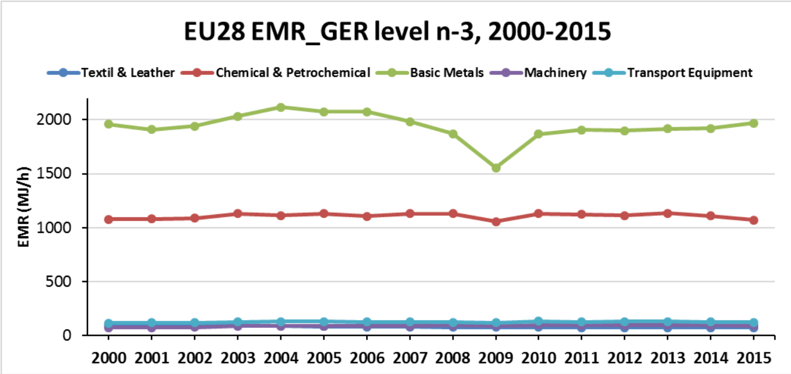

Figure 0-21 Values of EMR_i of the five sub-sectors – in Joules of GER thermal - in EU28 in 2000-2016

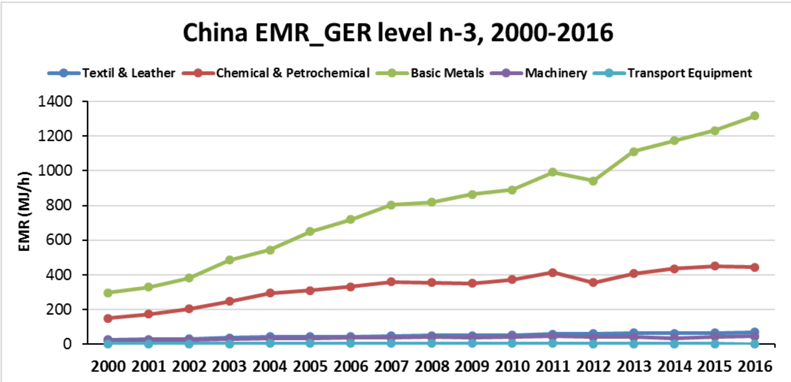

Figure 0-22 Values of EMR_i of the five sub-sectors – in Joules of GER thermal - in China in 2000-2016

Factors to be considered to explain changes in energy end-uses

In this chapter we present a metabolic decomposition analysis of the factors that can explain changes in the pattern of energy end-uses for both the EU28 and China. The decomposition proposed here is based on the distinction between fund and flow elements proposed by Georgescu-Roegen (1971). This point has been discussed in details in previous deliverables, so we do not provide a theoretical explanation here. Very briefly, fund elements – (i) human activity associated with the presence of people; (ii) power capacity associated with the presence of technology; (iii) land uses associated with the presence of land - are elements that maintain their identity during the duration of the assessment. That is, in statistics, the quantities per year of work force, available technology and land use are supposed to remain the same in the quantitative representation based on assessment per year. On the contrary, flow elements are either produced or consumed during the duration of the analysis. Therefore, fund elements refer to what the system is made of, whereas flow elements are useful to describe what the system is doing. The rationale of metabolic analysis assumes that the ratio of flow and fund element – the food eaten per day, the energy used to carry out a given task, the water evapotraspirated by crops to produce their biomass – can be used as benchmarks to characterize qualitative aspects of a process. For this reason, our decomposition analysis assumes that changes in an extensive variable can be decomposed in: (i) a change in a fund element (in this case human activity – hours of work, HA_i); and (ii) a change in a flow-fund ratio (in this case a metabolic rate – the Exosomatic Metabolic Rate, EMR_i).

In this chapter we present a decomposition analysis referring to changes in the pattern of energy end uses in EU28 and China across two periods: 2000 -2007 and 2007-2015. Using the end-use matrix, we present the analysis of changes in the two metabolic systems observed at the same point in time across 4 hierarchical levels of analysis: (i) level n (whole society); (ii) level n-1 (constituent components); (iii) level n-2 (economic sectors); (iv) level n-3 (economic subsectors inside the industrial sector).

The first section (Section 4.1) provides the overall view provided by end use matrices describing the set of forced relations over these 4 types of quantitative assessments. Then, in the remaining sections, we will illustrate the decomposition analysis of the changes level by level. Therefore, section 4.1 provides the general quantitative framework represented by the multilevel end use matrices calculated for both EU28 and China at three points in time: 2000-2007-2015. This set of end use matrices provides an overview of the set of forced relations making it possible to keep coherence in the results of the decomposition analysis carried out at different levels. As explained in the previous deliverable, the redundancy in the information space associated with the end use matrix generates a "sudoku effect" on the values written in the matrix. If a quantity of hours of labor or a quantity of Joules of energy is moved away from or into a specific cell of the grid (when altering the value of the corresponding EMR – e.g. a reduction of labor in the energy and mining sector with the same energy use) this quantity of hours of labor and/or Joules of energy has to result in a change in the profile of flow and fund elements in other cells of the grid – e.g. an increase in labor in the service sector in the SG sector or an increase in unemployment, that is the HH sector. So the end use matrices presented below represents the tool used to contextualize the decomposition analysis in order to gain insights about the large scale effect of local changes (bottom-up drivers/upward causation) and the local effect of large scale changes (top-down drivers/downward causation). This feature is especially important if we assume that social-ecological systems undergo evolutionary phases of expansions (when they are capable of affecting the characteristics of their environment) and phases of stagnation (when their environment is affecting their characteristics).

1.5 The end use matrix keeping coherence across four levels of analysis: Level n (Average Society), Level n-1 (PW vs HH – constituent components); Level n-2 (six sectors); Level n-3 inside industry (five subsectors) – 2000→2007 and 2007→2015.

The end use matrix provides a conceptual framework for the accounting of flow and fund elements across different levels of analysis guaranteeing coherence among the data included in the set. In fact, in order to generate a quantitative analysis we have to focus on a given representation referring to the measurement of just at a single fund element (e.g. HA – hours of human activity) observed at a given level of analysis (e.g. level n-2 economic sectors), and a measurement of just a single flow (e.g. electricity) in a single year (e.g. 2007). However, if we want to establish relations over different types of quantitative assessments obtained in this way - extensive variables (e.g. the number of working hours in manufacturing in 2007) or intensive variables (e.g. the level of electricity consumption per hours of labor in paper and pulp industry) it is essential that all these different numbers result coherent within a common accounting framework, as done in the examples given in Chapter 2.

We described at the beginning of Section 3 the mechanism of accounting generating redundancy in the information space of the end use matrix. A piece of information like the Exosomatic Metabolic Rate (EMR_i) can be expressed as the ratio of two extensive variables: (i) the Energy Throughput – the flow – measured in MJ per year; and (ii) the fund element providing the hours of work – HA_i measured in hours per year. We saw that starting from the whole society, we can stablish forced relations over these extensive and intensive variables:

THA (*level n*) = $HA_{HH} + HA_{PW}$ (*level n-1*) – relation over extensive variables – fund elements

TET (*level n*) = $ET_{HH} + ET_{PW}$ (*level n-1*) – relation over intensive variables – flow elements

The forced metabolic relation over the size of the constituent components defines an expected pace of metabolism determined by the following equation of congruence across levels:

TET/THA (*level n*)= EMR_{AS} (average society);

ET_{HH} /HA_{HH} (*level n-1*)= EMR_{HH} (household);

ET_{PW} /HA_{PW} (*level n-1*)= EMR_{PW} (paid work);

But then by using the redundancy of the two set of relation we can write:

TET (*level n*) = THA x EMR_{AS} (*level n*) = [HA_{HH} x EMR_{HH}] + [HA_{PW} x EMR_{PW}] (*level n-1*)

This relation of congruence can be used to establish a set of expected relations over the size of extensive variables defined at different hierarchical levels. The size of a flow or fund element calculated at a given level of analysis must be equal to the sum of the size of the elements on the lower level inside that element.

The two sets of relations: $ET_{ilevelx} = \Sigma\ (ET_{ilevelx-1})_j$ ←→ $HA_{ilevelx} = \Sigma\ (HA_{ilevelx-1})_j$ do establish a vertical constraint across data written, across different hierarchical levels in the grid of the matrix.

The two sets of relations: $ET_{ilevelx-1}$ /$HA_{ilevelx-1}$ = $EMR_{ilevelx-1}$ ←→ $ET_{ilevelx-1}$ = $HA_{ilevelx-1}$ x $EMR_{ilevelx-1}$ make it possible to link a horizontal constraints that can be moved across levels.

When combined together, the integrated set of relations generates a "sudoku effect" on the possible relations that can be taken by data included in the grid (Giampietro and Bukkens, 206).

There is an important feature that makes this system of accounting complex and very effective for sustainability analysis. The set of relations over the data in the matrix is obtained determined by building redundancy in the information space – i.e. the same value of a cell can be calculated in two non-equivalent ways! Therefore, this set of relations is no deterministic. The values in the grid are contingent on chosen source of data and the pre-analytical choice of how to carry out the representation – i.e. whether using a top-down approach based on the use of statistical data (diagnostic mode), or a bottom-up approach using estimated technical coefficients (anticipation mode). That is, we can either enter expected final state and see what are the possible combinations of values that would be required to have an admissible combination of extensive and intensive variables, or we can start with the existence of limiting factors and explore the option space determined by the existing set of relations and by the given constraints. This ability to handle impredicative relations of causality, generaally absent in conventional modelling tools, is determined by the level of redundancy established in the information space. Data may be defined in non-equivalent ways. The resulting mutual information inside the dataset makes it possible to use this quantitative framework both in a diagnostic mode (what we are doing in this deliverable) but also in anticipatory mode (when considering changes in relevant characteristics of the metabolic pattern – e.g. change in demographic characteristics, changes in the pattern of final consumption, a forced reduction of the use of a specific type of energy carrier - liquid fuels).

In the following pages we present the end use matrices of EU28 and China for the years 2000, 2007 and 2015 – with the quantitative assessments of the metabolic characteristics of the various components carried out at level n, level n-1, level n-2, and level n-3 (Table 0-1, Table 0-2, Table 0-3, Table 0-4, Table 0-5 and Table 0-6). The metabolic decomposition analysis of the changes will follow in the next sections.

Again, a full description of the rationale and the set of relations over the data given in the end use matrix is available in the deliverable D 4.2.

Table 0-1 EU28 End-use Matrix for the year 2000

Levels	2000 EU28	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 €)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand €)	ET_GER (PJ/year)	EMR_GER (MJ/h)	EEI (MJ/€)
n	Average Society	4.268	2,5	5,3	4,3	2,2	10.868	22.624	18.152	9.480	8760	22	46	37	141	19	68924	16	7,3
n-1	Household	3.905	0,66	2,0	2,1	-	2.583	7.618	8.236	-	8014	5,3	16	17	46	-	22545	5,8	-
n-1	Paid Work	363	23	41	27	26	8.285	15.006	9.915	9.480	746	17	31	20	95	19	46379	128	4,9
n-2	Agriculture & Forestry	29	5,0	13	25	6,1	145	371	720	178	60	0,30	0,76	1,5	3,0	0,36	1466	50	8,3
n-2	Industrial sector	68	81	181	7,8	27	5.556	12.345	532	1.827	140	11	25	1,1	56	3,7	27268	399	15
n-2	Construction	28	1,6	2,2	6,0	21	46	61	170	598	58	0,094	0,12	0,35	0,72	1,2	350	12	0,58
n-2	Services & Government (without Transport)	224	10	8,9	3,7	30	2.286	1.985	823	6.602	459	4,7	4,1	1,7	18	14	8728	39	1,3
n-2	Transport Services	14	18	17	538	20	252	244	7.670	284	29	0,52	0,50	16	18	0,58	8567	601	30
n-3	Energy & Mining	4,6	402	652	17	66	1.841	2.986	77	301	9,4	3,8	6,1	0,16	16	0,62	7831	1710	26
n-3	Food and Tabacco	9,0	40	96	8,4	24	357	860	76	213	18	0,73	1,8	0,16	3,8	0,44	1860	207	8,7
n-3	Textile and Leather	7,5	19	39	2,5	11	145	291	19	83	15	0,30	0,60	0,039	1,40	0,17	684	91	8,2
n-3	Wood and Wood Products	2,6	30	69	3,2	13	81	183	8,6	35	5,4	0,17	0,37	0,018	0,82	0,072	400	151	11
n-3	Paper, Pulp and Print	3,5	136	283	3,4	26	474	987	12	91	7,2	0,97	2,0	0,025	4,6	0,19	2228	638	24
n-3	Chemical and Petrochemical	3,4	213	519	5,6	50	720	1.751	19	168	6,9	1,5	3,6	0,039	7,5	0,35	3634	1077	22
n-3	Non-Metallic Minerals	3,2	89	477	12	22	287	1.544	38	71	6,6	0,59	3,2	0,079	4,8	0,15	2326	719	33
n-3	Basic Metals	2,3	323	1.111	13	32	735	2.531	29	72	4,7	1,5	5,2	0,059	9,2	0,15	4464	1959	62
n-3	Machinery	18	19	23	3,0	25	342	424	55	467	38	0,70	0,87	0,11	2,8	0,96	1364	74	2,9
n-3	Transport Equipment	5,9	32	32	3,4	29	189	187	20	174	12	0,39	0,38	0,041	1,4	0,36	697	118	4,0
n-3	Non-Specified Industry (Rubber, Plastic products, Forniture & others)	7,8	49	77	23	19	386	601	178	150	16	0,79	1,2	0,37	3,7	0,31	1780	228	12

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Table 0-2 EU28 End-use Matrix for the year 2007

Levels	2007 EU28	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 €)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand €)	ET_GER (PJ/year)	EMR_GER (MJ/h)	EEI (MJ/€)
n	Average Society	4.365	2,8	5,3	4,3	2,5	12.091	23.110	18.733	11.091	8760	24	46	38	147	22	73159	17	6,6
n-1	Household	3.982	0,73	1,9	2,0	-	2.904	7.735	7.903	-	7991	5,8	16	16	46	-	23159	5,8	-
	Paid Work	383	24	40	28	29	9.187	15.376	10.830	11.091	769	18	31	22	100	22	50001	130	4,5
n-2	Agriculture & Forestry	25	6,7	14	25	7,2	167	336	615	180	50	0,34	0,67	1,2	2,8	0,36	1384	56	7,7
	Industrial sector	64	93	191	7,9	33	5.900	12.159	502	2.090	128	12	24	1,0	56	4,2	27943	439	13
	Construction	33	1,8	1,7	4,6	20	60	56	152	671	67	0,12	0,11	0,30	0,73	1,3	363	11	0,54
	Services & Government (without transport)	247	11	9,8	2,7	32	2.838	2.416	657	7.826	496	5,7	4,8	1,3	21	16	10424	42	1,3
	Transport Services	14	15	28	618	23	222	408	8.905	326	29	0,44	0,82	18	20	0,65	9886	687	30
n-3	Energy & Mining	4,1	467	776	14	72	1.912	3.180	59	296	8,2	3,8	6,4	0,12	16	0,59	8192	2000	28
	Food and Tabacco	8,9	45	88	7,1	26	403	781	63	232	18	0,81	1,6	0,13	3,8	0,47	1888	213	8,1
	Textile and Leather	5,9	19	29	2,7	12	111	168	16	71	12	0,22	0,34	0,032	0,94	0,14	470	80	6,7
	Wood and Wood Products	2,5	41	77	3,0	15	101	193	7,6	39	5,0	0,20	0,39	0,015	0,93	0,078	463	185	12
	Paper, Pulp and Print	3,2	167	340	3,6	31	528	1.073	11	96	6,3	1,1	2,2	0,023	4,9	0,19	2451	777	25
	Chemical and Petrochemical	3,2	228	527	13	66	724	1.669	41	211	6,4	1,5	3,3	0,081	7,2	0,42	3586	1131	17
	Non-Metallic Minerals	3,0	104	529	13	27	314	1.592	40	80	6,0	0,63	3,2	0,081	4,9	0,16	2444	813	31
	Basic Metals	2,2	360	1.046	6,5	34	782	2.275	14	73	4,4	1,6	4,6	0,029	8,7	0,15	4315	1984	59
	Machinery	18	24	23	2,7	34	429	416	47	595	36	0,86	0,84	0,095	3,2	1,2	1574	89	2,6
	Transport Equipment	5,6	36	32	2,8	40	200	177	16	225	11	0,40	0,36	0,031	1,4	0,45	711	127	3,2
	Non-Specified Industry (Rubber, Plastic products, Furniture & others)	7,5	53	84	25	23	396	634	187	172	15	0,80	1,3	0,38	3,7	0,34	1848	245	11

Table 0-3 EU28 End-use Matrix for the year 2015

Levels	2015 EU28	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 €)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand €)	ET_GER (PJ/year)	EMR GER (MJ/h)	EEI (MJ/€)
n	Average Society	4.455	2,6	4,7	3,8	2,6	11.557	21.103	17.126	11.581	8760	23	41	34	134	23	68163	15	5,9
n-1	Household	4.082	0,70	1,8	1,8	-	2.864	7.485	7.200	-	8028	5,6	15	14	43	-	22103	5,4	-
n-1	Paid Work	372	23	37	27	31	8.693	13.618	9.926	11.581	732	17	27	20	91	23	46060	124	4,0
n-2	Agriculture & Forestry	21	8,6	15	27	9,3	178	307	552	192	41	0,35	0,60	1,1	2,6	0,38	1320	64	6,9
n-2	Industrial sector	55	94	185	6,1	38	5.209	10.199	338	2.106	109	10	20	0,66	47	4,1	24027	435	11
n-2	Construction	27	2,6	3,1	4,9	21	69	83	129	561	52	0,14	0,16	0,25	0,77	1,1	392	15	0,70
n-2	Services & Government (without transport)	256	12	10	2,1	33	3.010	2.601	550	8.425	504	5,9	5,1	1,1	22	17	10945	43	1,3
n-2	Transport Services	14	16	31	601	22	228	428	8.357	306	27	0,45	0,84	16	18	0,60	9375	674	31
n-3	Energy & Mining	3,7	470	765	19	76	1.727	2.812	69	281	7,2	3,4	5,5	0,14	14	0,55	7353	1999	26
n-3	Food and Tabacco	8,4	49	91	3,8	30	416	769	32	249	17	0,82	1,5	0,064	3,7	0,49	1880	223	7,6
n-3	Textile and Leather	4,1	19	25	1,5	14	76	101	6,0	58	8,1	0,15	0,20	0,012	0,60	0,11	304	74	5,3
n-3	Wood and Wood Products	1,9	46	134	4,5	17	87	249	8,4	33	3,7	0,17	0,49	0,017	0,95	0,064	482	258	15
n-3	Paper, Pulp and Print	2,4	172	402	3,1	36	421	982	7,7	88	4,8	0,83	1,9	0,015	4,1	0,17	2079	850	24
n-3	Chemical and Petrochemical	3,0	220	497	6,3	79	650	1.472	19	233	5,8	1,3	2,9	0,037	6,2	0,46	3174	1072	14
n-3	Non-Metallic Minerals	2,2	111	528	13	30	241	1.152	29	65	4,3	0,47	2,3	0,057	3,6	0,13	1807	828	28
n-3	Basic Metals	1,8	356	1.040	5,7	44	636	1.857	10	79	3,5	1,3	3,7	0,020	6,9	0,16	3514	1968	45
n-3	Machinery	16	27	21	1,5	37	422	330	23	588	31	0,83	0,65	0,046	2,8	1,2	1447	92	2,5
n-3	Transport Equipment	5,4	36	27	2,6	50	192	145	14	266	11	0,38	0,28	0,027	1,3	0,52	657	123	2,5
n-3	Non-Specified Industry (Rubber, Plastic products, Furniture & others)	6,6	51	50	18	25	340	329	119	168	13	0,67	0,65	0,23	2,6	0,33	1330	201	7,9

Table 0-4 China End-use Matrix for the year 2000

Levels	2000 China	HA (10^6 h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	EJP (¥/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 ¥)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand ¥)	ET_GER (PJ/year)	EMR^{GER} (MJ/h)	EEI (MJ/¥)
n	Average Society	11.103	0,41	2,5	0,54	0,90	4.515	27.732	6.076	10.028	8760	3,6	22	4,8	36	7,9	45503	4,1	4,5
n-1	Household	9.506	0,055	1,2	0,029	-	523	11.213	280	-	7500	0,41	8,8	0,22	10	-	12848	1,4	-
n-1	Paid Work	1.597	2,5	10	3,6	6,3	3.992	16.519	5.796	10.028	1260	3,1	13	4,6	26	7,9	32655	20	3,3
n-2	Agriculture & Forestry	779	0,25	0,40	0,58	1,9	192	312	452	1.494	614	0,15	0,25	0,36	1,0	1,2	1261	1,6	0,84
n-2	Industrial sector	302	11	48	4,5	13	3.212	14.614	1.277	4.026	239	2,5	12	1,0	19	3,2	24210	80	6,0
n-2	Construction	58	1,0	2,4	2,4	8,9	58	141	169	518	46	0,045	0,11	0,13	0,36	0,41	459	7,9	0,89
n-2	Services & Government (without Transport)	408	1,1	2,0	2,0	8,5	101	819	833	3.472	322	0,080	0,65	0,66	1,5	2,7	1914	4,7	0,55
n-2	Transport Services	50	2,0	13	57	10	430	633	3.066	518	39	0,34	0,50	2,4	3,8	0,41	4811	97	9,3
n-3	Energy & Mining	65	14	47	7,6	16	876	3.055	451	1.022	51	0,69	2,4	0,36	4,6	0,81	5774	89	5,7
n-3	Food and Tabacco	22	5,7	30	3,4	21	127	663	67	453	17	0,10	0,52	0,053	0,83	0,36	1058	48	2,3
n-3	Textile and Leather	38	4,2	12	1,4	9,3	161	465	52	353	30	0,13	0,37	0,041	0,74	0,28	934	24	2,6
n-3	Wood and Wood Products	2,3	5,0	28	2,0	11	12	66	4,5	25	1,8	0,009	0,052	0,0036	0,079	0,020	100	43	3,9
n-3	Paper, Pulp and Print	9,5	10	40	3,2	10	97	380	26	99	7,5	0,076	0,30	0,020	0,52	0,078	657	69	6,6
n-3	Chemical and Petrochemical	28	19	96	4,6	14	518	2.680	116	379	22	0,41	2,1	0,091	3,3	0,30	4136	148	11
n-3	Non-Metallic Minerals	18	15	128	9,7	10	275	2.333	156	182	14	0,22	1,8	0,12	2,5	0,14	3201	176	18
n-3	Basic Metals	23	29	218	3,7	13	655	4.919	75	293	18	0,52	3,9	0,059	5,3	0,23	6691	297	23
n-3	Machinery	62	4,0	8,3	1,8	14	250	510	115	856	49	0,20	0,40	0,090	1,0	0,68	1272	21	1,5
n-3	Transport Equipment	18	4,0	9,4	1,9	12	73	173	34	214	15	0,058	0,14	0,026	0,31	0,17	396	21	1,9
n-3	Non-Specified Industry (Rubber, Plastic products, Furniture & others)	17	10	16	3,9	8,9	169	272	61	151	13	0,13	0,21	0,048	0,61	0,12	771	45	5,1

Table 0-5 China End-use Matrix for the year 2007

Levels	2007 China	HA (10^9 h/year)	EMR_elec (MJ/h)	EMR_heat (MJ/h)	EMR_fuel (MJ/h)	ELP (¥/h)	ET_elec (PJ/year)	ET_heat (PJ/year)	ET_fuel (PJ/year)	GVA (10^9 ¥)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand ¥)	ET_GER (PJ/year)	EMR_GER (MJ/h)	EEI (MJ/¥)
n	Average Society	11.575	0,95	4,2	0,7	1,5	11.040	48.886	8.541	17.568	8760	8,4	37	6,5	65	13	86021	7,4	4,9
n-1	Household	9.920	0,15	1,1	0,058	-	1.463	11.016	577	-	7508	1,1	8,3	0,44	12	-	15383	1,6	-
n-1	Paid Work	1.655	5,8	23	4,8	11	9.577	37.870	7.965	17.568	1252	7,2	29	6,0	53	13	70638	43	4,0
n-2	Agriculture & Forestry	643	0,49	0,91	0,93	2,8	317	587	595	1.811	486	0,24	0,44	0,45	1,5	1,4	2003	3,1	1,1
n-2	Industrial sector	368	22	93	3,6	20	7.923	34.103	1.307	7.227	278	6,0	26	0,99	42	5,5	55932	152	7,7
n-2	Construction	98	1,1	1,9	2,7	8,3	111	187	262	821	75	0,084	0,14	0,20	0,56	0,62	738	7,5	0,90
n-2	Services & Government (without transport)	486	2,1	3,8	2,2	14	192	1.833	1.051	6.775	368	0,15	1,4	0,80	2,6	5,1	3380	7,0	0,50
n-2	Transport Services	60	3,2	19	79	16	1.034	1.160	4.748	935	45	0,78	0,88	3,6	6,5	0,71	8585	144	9,2
n-3	Energy & Mining	72	23	76	8,0	16	1.652	5.482	577	1.146	55	1,3	4,1	0,44	7,8	0,87	10336	143	9,0
n-3	Food and Tabacco	25	9,0	60	2,3	25	225	1.511	58	637	19	0,17	1,1	0,044	1,6	0,48	2152	86	3,4
n-3	Textile and Leather	49	9,6	21	1,1	11	476	1.037	54	560	37	0,36	0,78	0,041	1,8	0,42	2325	47	4,2
n-3	Wood and Wood Products	3,1	17	61	2,7	30	54	185	8,4	92	2,3	0,041	0,14	0,006	0,25	0,069	333	109	3,6
n-3	Paper, Pulp and Print	8,9	21	87	2,5	21	184	771	22	184	6,7	0,14	0,58	0,017	0,96	0,14	1269	143	6,9
n-3	Chemical and Petrochemical	29	40	248	6,6	21	1.162	7.138	190	592	22	0,88	5,4	0,14	7,8	0,45	10338	360	17
n-3	Non-Metallic Minerals	18	38	362	7,7	22	668	6.445	137	392	13	0,51	4,9	0,10	6,3	0,30	8314	467	21
n-3	Basic Metals	24	89	569	3,3	30	2.183	13.939	82	746	19	1,7	11	0,062	15	0,56	19675	803	26
n-3	Machinery	92	8,8	12	1,8	22	806	1.080	165	2.047	69	0,6	0,82	0,12	2,5	1,5	3332	36	1,6
n-3	Transport Equipment	23	6,6	11	2,3	18	150	261	52	402	17	0,11	0,20	0,039	0,53	0,30	703	31	1,7
n-3	Non-Specified Industry (Rubber, Plastic products, Furniture & others)	24	15	16	2,2	18	363	384	53	431	18	0,28	0,29	0,040	1,0	0,33	1379	58	3,2

Table 0-6 China End-use Matrix for the year 2015

Levels	2015 China	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 ¥)	per capita HA (h/year)	per capita ET_elec (GJ/year)	per capita ET_heat (GJ/year)	per capita ET_fuel (GJ/year)	per capita ET_GER (GJ/year)	per capita GVA (thousand €)	ET_GER (PJ/year)	EMR GER (MJ/h)	EEI (MJ/€)
n	Average Society	12.042	1,6	4,6	1,1	2,8	19.822	55.819	13.685	33.346	8760	14	41	10	88	24	120843	10,0	3,6
n-1	Household	10.322	0,26	0,99	0,15	-	2.725	10.221	1.554	-	7509	2,0	7,4	1,1	14	-	18832	1,8	-
n-1	Paid Work	1.720	9,9	27	7,1	19	17.097	45.598	12.131	33.346	1251	12	33	8,8	74	24	102011	59	3,1
n-2	Agriculture & Forestry	458	0,82	1,6	1,6	4,9	375	743	738	2.255	333	0,27	0,54	0,54	1,8	1,6	2451	5,3	1,1
n-2	Industrial sector	368	37	109	2,9	38	13.727	39.977	1.075	14.106	268	10	29	0,78	56	10	76606	208	5,4
n-2	Construction	170	1,5	1,6	2,5	8,2	252	265	419	1.389	124	0,18	0,19	0,30	0,97	1,0	1336	7,8	0,96
n-2	Services & Government (without Transport)	648	3,6	4,1	2,7	21	405	2.627	1.763	13.759	471	0,29	1,9	1,3	4,0	10	5440	8,4	0,40
n-2	Transport Services	75	5,4	26	108	24	2.338	1.986	8.136	1.837	55	1,7	1,4	5,9	12	1,3	16178	215	8,8
n-3	Energy & Mining	56	50	90	7,9	45	2.792	4.991	438	2.524	41	2,0	3,6	0,32	9,2	1,8	12661	227	5,0
n-3	Food and Tabacco	28	14	41	1,9	58	395	1.118	52	1.608	20	0,29	0,81	0,038	1,6	1,2	2191	80	1,4
n-3	Textile and Leather	39	18	18	0,72	28	698	699	28	1.105	28	0,51	0,51	0,020	1,84	0,80	2534	65	2,3
n-3	Wood and Wood Products	2,6	35	60	3,1	84	92	155	8,2	219	1,9	0,067	0,11	0,006	0,29	0,16	400	154	1,8
n-3	Paper, Pulp and Print	8,1	33	71	1,9	40	269	570	16	320	5,9	0,20	0,41	0,011	0,93	0,23	1282	159	4,0
n-3	Chemical and Petrochemical	29	68	269	5,1	46	1.956	7.737	146	1.313	21	1,4	5,6	0,11	9,4	0,96	12950	450	9,9
n-3	Non-Metallic Minerals	16	72	402	8,7	52	1.119	6.278	136	808	11	0,81	4,6	0,10	6,8	0,59	9312	596	12
n-3	Basic Metals	22	176	774	2,5	43	3.904	17.168	55	954	16	2,8	12	0,040	20	0,69	27333	1233	29
n-3	Machinery	115	13	6,3	1,0	30	1.513	725	121	3.424	84	1,1	0,53	0,088	3,5	2,5	4765	41	1,4
n-3	Transport Equipment	29	12	9,1	1,5	37	343	259	43	1.068	21	0,25	0,19	0,031	0,87	0,78	1190	42	1,1
n-3	Non-Specified Industry (Rubber, Plastic products, Furniture & others)	25	26	11	1,3	31	647	279	33	763	18	0,47	0,20	0,024	1,4	0,56	1988	81	2,6

1.6 Effects of changes in Human Activity (HA_i) and level of technical capital per worker (EMR_i) in the use of energy of EU28 and China: 2000→2007 and 2007→2015.

1.6.1 Biophysical fund-flow decomposition - level n (the whole economy)

In this section we explain the changes in overall energy consumption (calculated in Gross Energy Requirement Thermal – 1 Ton of Oil Equivalent = 42 GJ of GER). The overall change over the considered period in the Total Energy Throughput – ΔTET – is explained as determined by a change in HA_i (quantities of human activity – hours/year) and in a change in EMR_i (Exosomatic Metabolic Rate – MJ/hour) according to the equation:

$$ET_i = HA_i \times EMR_i$$

This relation is applied at different hierarchical levels of analysis. When applied to the level n – the whole system: (i) the throughput of the element ET_i becomes the total throughput of the economy – Total Energy Throughput (TET); (ii) the amount of human activity becomes the total amount of human activity available in a year (the population times 8,760 hours in a year) – Total Human Activity (THA); and (iii) the Exosomatic Metabolic Rate is referred to the Average of Society (EMR_{AS}).

1.6.1.1 The period 2000-2007

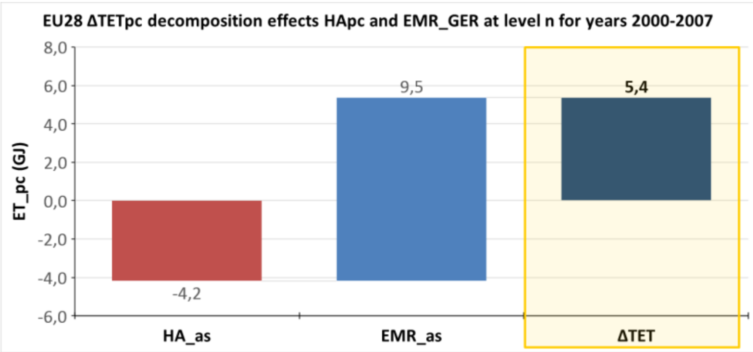


Figure 0-1 EU28 - decomposition analysis of the increase in TET at the level n in the period 2000-2007

We can see in Figure 0-1 that in the period 2000-2007 the increase in energy end uses of EU28 (+ 5.4 GJ GER per capita per year) was due to the combination of two contrasting trends: a reduction of HA in Europe and an increase in the EMR_{AS}.

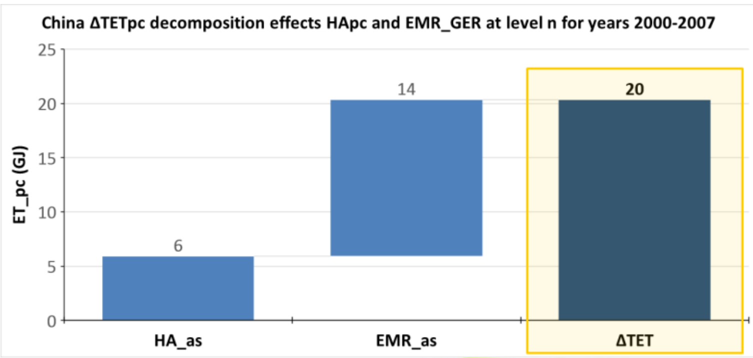


Figure 0-2 China - decomposition analysis of the increase in TET at the level n in the period 2000-2007

Over the same period, we can see that the increase in energy end uses in China was much larger (+ 20.0 GJ GER per capita per year, almost four times more!) and this fact was determined by a combination of two positive factors: a growth in human activity and a growth in EMR.

1.6.1.2 The period 2007-2015

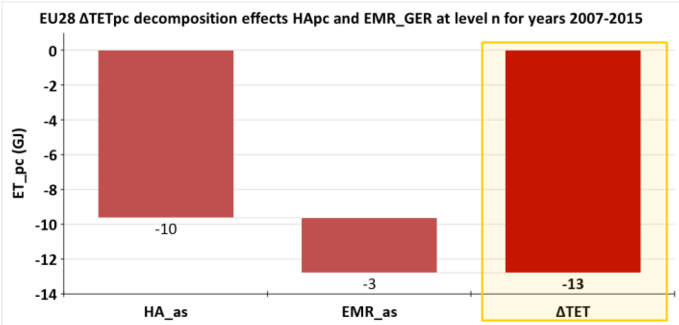


Figure 0-3 EU28 - decomposition analysis of the increase in TET at the level n in the period 2007-2015

We can see in Figure 0-3 the effect of the global economic crisis on the metabolic characteristics of EU28. The economy experienced a sharp reduction of energy end uses that was interpreted by some analysts as the effect of increases in energy efficiency. Other explanations are possible, but they would require studying the changes that took place inside the metabolic pattern of the economy at lower hierarchical levels. As a matter of fact, in our decomposition exercise, the reduction is due to a shrinking of human activity in the metabolic pattern. However, this is not associated with a reduction of the population of EU28. Rather to a reduction of hour of human activity in the categories having a very high EMR_i (reduction of employment in productive sectors). Put in another way, this figure simply tells us that this is not the right level of analysis to study the factors that determined the reduction of energy use in EU28. At the level of the whole we cannot see and understand the effects of changes that took place inside the system in the form of restructuring of activities among economic sectors and sub-sectors. If we want to answer questions like: what has changed? who is using less energy? Was EU28 using energy in 2015 "better" than in 2007? We have to look at the pattern at a lower hierarchical level.

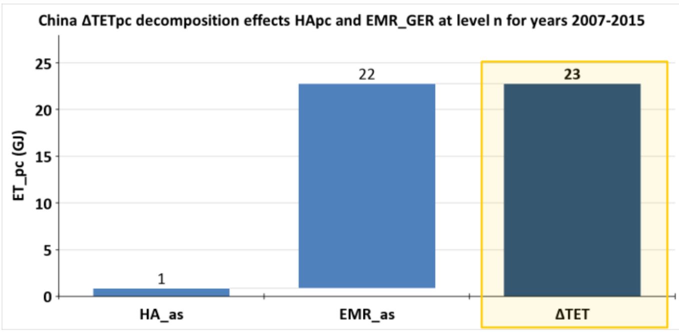


Figure 0-4 China - decomposition analysis of the increase in TET at the level n in the period 2007-2015

We can see in Figure 0-4 a major difference of China with EU28. The global economic crisis in the period 2007-2015 did not affect China in the same way it affected EU28. Also in this second period, for China the increase in the overall energy end uses seems to be driven more by an increase in EMR than by an increase in population, but at this level of aggregation it is not possible to identify the factors. However, following the same reasoning done for EU28 we should expect that the overall change in HA in the PW of China did not alter much the overall energy intensity of the PW sector. In fact, we already saw (in Figure 0-5) that the big changes in the allocation of labor that took place in China moved hours of work away from Agriculture into Service and Government sector (with similar value of EMR_i) and that the industrial sector changed much more in terms of EMR_i than in terms of HA_i. However, these differences can be studied only at a lower hierarchical level of analysis.

1.7 Effects of changes in Human Activity (HA_i) and level of technical capital per worker (EMR_i) in the use of energy in EU28 and China: 2000→2007 and 2007→2015

1.7.1 Biophysical fund-flow decomposition - level n-1 (constituent components)

In this section we move down of a level of analysis and look at the metabolic characteristics of the society using a different criterion of analysis. We separate the functional compartment of the society in two constituent components, required to have the economic process: (i) the household sector – expressing the activity of final consumption; and (ii) the paid work sector – expressing the activity of production of goods and services. The concept of metabolism entails the existence of a direct relation between the characteristics of the sectors producing and the sectors consuming goods and services. Both compete for the same endowment of inputs: fund and flow elements are required both to produce and consume. In relation to this point the end use matrix addresses the existence of a dynamic equilibrium over the requirement of inputs of these two compartments. As suggested by Zipf (1941), in order to be able to produce more a society has to invest more fund and flow elements in consuming more. However, things changed with globalization. As illustrated in this deliverable, right now developed countries such as EU28 can specialize investing the vast majority of their fund and flow elements in consuming, leaving the role of producing to other countries.

1.7.1.1 The period 2000-2007

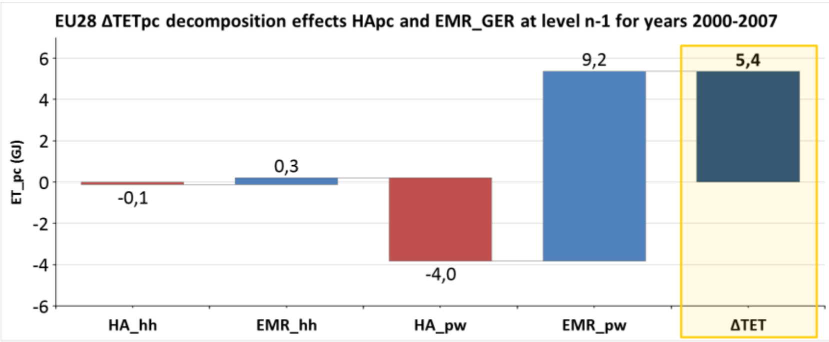


Figure 0-5 EU28 - decomposition analysis of the increase in TET at the level n-1 in the period 2000-2007

By looking at a lower hierarchical level in Figure 0-5, we get more insights about what happened in Europe in the period 2000-2007 (in comparison of the information given in Figure 0-3). Basically, no big changes happen in the final consumption sector (HH), whereas more important adjustments took place in the Paid Work. A reduction of working hours in PW was more than compensated by an increase of the level of energy end use per worker (biophysical capitalization of the paid work).

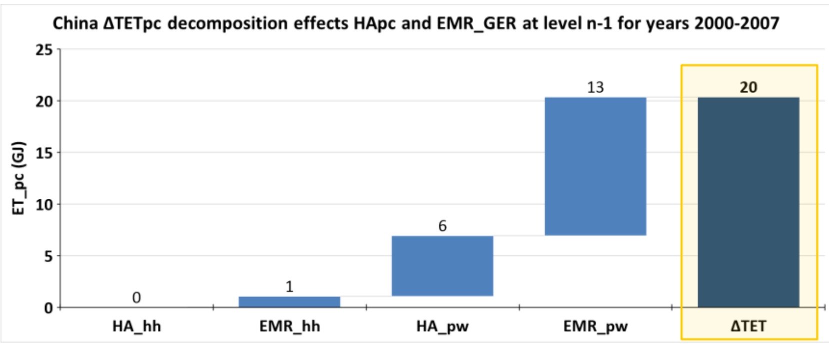


Figure 0-6 China - decomposition analysis of the increase in TET at the level n-1 in the period 2000-2007

When coming to the analysis of China at the level n-2 (Figure 0-6), we can see a similar behavior in terms of the negligible effect of the final consumption sector on the overall increase of energy use. On the contrary, in relation to the changes of end uses in the PW, we can appreciate that both an increase of working hours associated with an increase in the level of energy use per working hour have contributed in a more important way to the overall increase in ET_{PW}.

1.7.1.2 The period 2007-2015

As anticipated by the analysis done at the level n, in the period 2007-2015 we have a major difference in the pattern of changes that took place in the metabolic pattern of EU28 and China. In one case (EU28) the crisis affected the original pattern of end use, in the other (China) the crisis did not affect much the ongoing trends.

Looking at the changes that took place in EU28 (Figure 0-7) we can appreciate an overall reduction of TET, that has been generated by a reduction of the energy uses in final consumption (HH), but more significantly by a reduction of the energy uses in PW. The reduction in PW is due to two causes, the reduction of working hours (in minor part) and the reduction of the energy use per working hour.

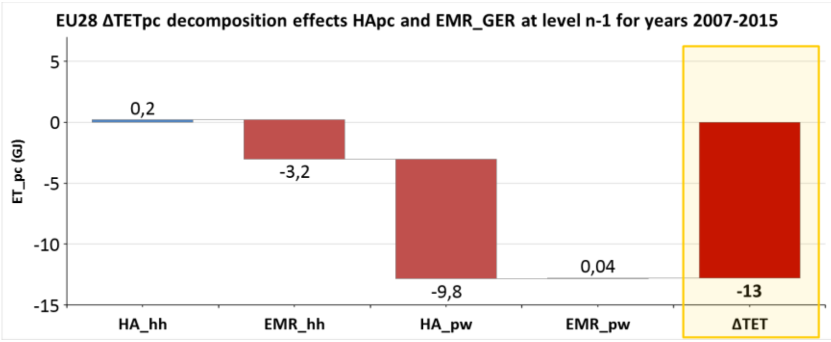


Figure 0-7 EU28 - decomposition analysis of the increase in TET at the level n-1 in the period 2007-2015

This reduction in energy use in the PW can be interpreted in different ways: (i) by an increase in efficiency of the various economic sector: the PW sector produces as before, but consuming less energy carriers; (ii) by an increase of externalization: increasing the imports; and (iii) by a boost in credit leverage: increasing the level of debts and quantitative easing from the EU central bank. This makes it possible to keep a high economic activity of the financial sector and final consumption of imported food, energy and other products without producing them. Also in this case, an analysis carried out at the level PW is too aggregated to provide reliable information to be used for explanations.

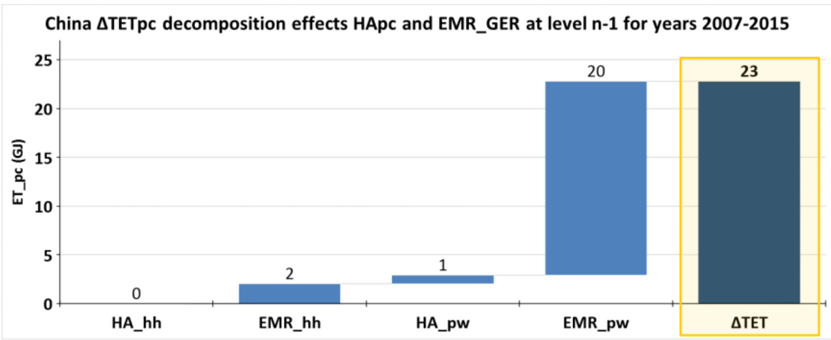


Figure 0-8 China - decomposition analysis of the increase in TET at the level n-1 in the period 2007-2015

Completely different is the situation of China (Figure 0-8), which continued the trend of changes in its metabolic pattern as in the previous period. The contribution of changes due to an increase in energy end use in the final consumption sector (HH) is limited, the increase in energy end uses in the PW sector is due to a combination of a limited increase in terms of hours of work in PW and a robust increased in the value of EMR.

It should be noted that, at this level of analysis, we cannot make any inference in relation to how technical changes (efficiency of conversion of energy in specific production/consumption processes) affects changes in the overall energy end uses in the economy. In relation to both EU28 and China, the same increase in ET_{PW} can be due to: (i) the use of more technology per hour of work than before; (ii) the use of the same amount of technology per hour of work as before but with a lower level of efficiency; (iii) a structural change in the economy that boosted the production of Added Value in economic sectors characterized by a high EMR_i (e.g. industry) associated with a reduction of activities in economic sectors with a low EMR_i (e.g. services). That is, for understanding what happened in these two systems in the two periods considered we have to analyze the changes that took place in the metabolic pattern at a lower hierarchical level of analysis.

1.8 Effects of changes in Human Activity (HA_i) and level of technical capital per worker (EMR_i) in the use of energy of China and EU28: 2000→2007 and 2007→2015

1.8.1 Biophysical fund-flow decomposition – Level n-2 (economic sectors)

At a lower hierarchical level of analysis it becomes possible to identify which economic sectors contributed more or less to the changes of energy end uses of the whole economy. In this way, it becomes possible to see which sectors were the winners or the losers in the evolutionary changes of the economy continuously adjusting its mix of economic activities on the threats and opportunities provided by its context. The sector considered are: AF = Agriculture and Forestry; IN = Industry; Co = Construction; Tr = transport; SGnT = Service and Government no Transport.

1.8.1.1 The period 2000-2007

Starting with the changes in EU28 at this level we can identify the sector that have been contracting and those that have been expanding their energy end uses.

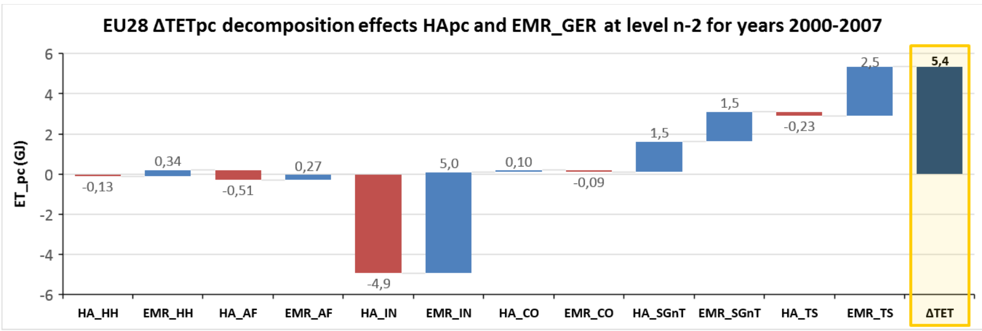


Figure 0-9 EU28 - decomposition analysis of the increase in TET at the level n-2 in the period 2000-2007

In Figure 0-9 we can see that Agriculture and Industry have been the big losers in the changes over this period in terms of jobs. The reduction in the agricultural sectors looks moderate in the graph, but the level of employment was already quite low at the beginning of the period. The reduction of labor in the industrial sector is more relevant in the graph. The effect of the reduction of working hours in the sector on the total energy end use has been compensated by a concomitant increase of technical capital per worker (EMR). The energy services including transport have increased both in hours of labor and EMR.

The situation is totally different in China (Figure 0-10) where industry has been the big winner in the redistribution of human activity and energy end uses. In this period, they have been the drivers of the increase in TET.

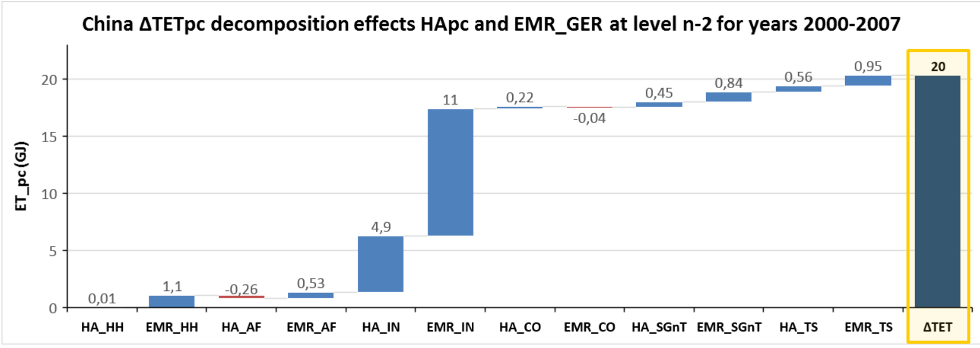


Figure 0-10 China - decomposition analysis of the increase in TET at the level n-2 in the period 2000-2007

1.8.1.2 The period 2007-2015

At this level we can have a better picture of the effects of the crisis on the metabolic pattern of EU28 (Figure 0-11): (i) the household sector has reduced its level of energy end uses; (ii) the agriculture experienced an additional reduction of employment (compensated by an increase in EMR); (iii) the big loser has been, again, the industrial sector that not only experienced a reduction in working hours but also a reduction in energy end uses per working hour (associated with the closing of factories?).

Looking at changes in the Service sector we can see an opposite trend, with an increase in the employment and a reduction of EMR. Especially interesting is what happened in the transport sector, which increased slightly the level of employment while reducing the energy end use per working hour. This may indicate some structural changes inside the sector, that is, a change in the mix of sub-sectors and/or an improvement in the management or in the technologies used that led to a reduction of energy end use per hour of work (assuming that the performance of the sector remained unchanged).

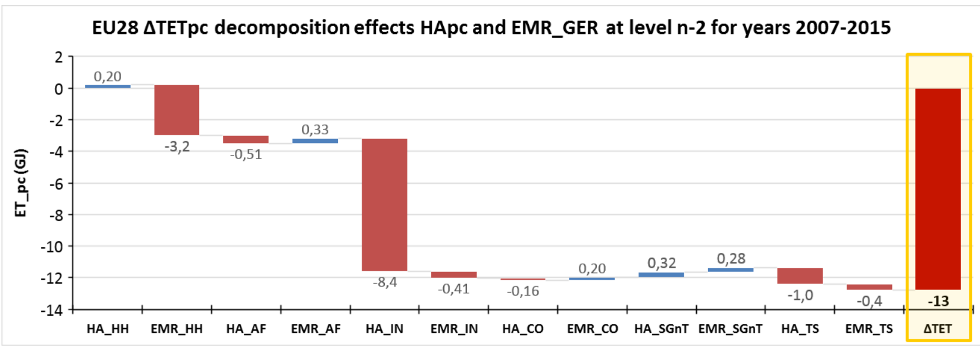


Figure 0-11 EU28 - decomposition analysis of the increase in TET at the level n-2 in the period 2007-2015

Remaining at this level of analysis we can see that the differences between the changes in the metabolic pattern of EU28 and China observed at the level n-1 remain also at this level. In fact, we can notice that in China the trend of changes in the metabolic pattern in the period 2007-2015 remained very similar to the pattern of changes in the period 2000-2007 also when observed at level n-2. The industrial sector was again the major winner pushing up the total level of energy end uses of the whole economy. In this second period this result was determined more by an increase in the technical capital (the energy end uses per working hour) than to an increase of working hours, which on the contrary remained quite stable in total size. Other relevant increases in EMR had taken place in the HH (a timid improvement in the material standard of living in the residential sector) and in the transport sector.

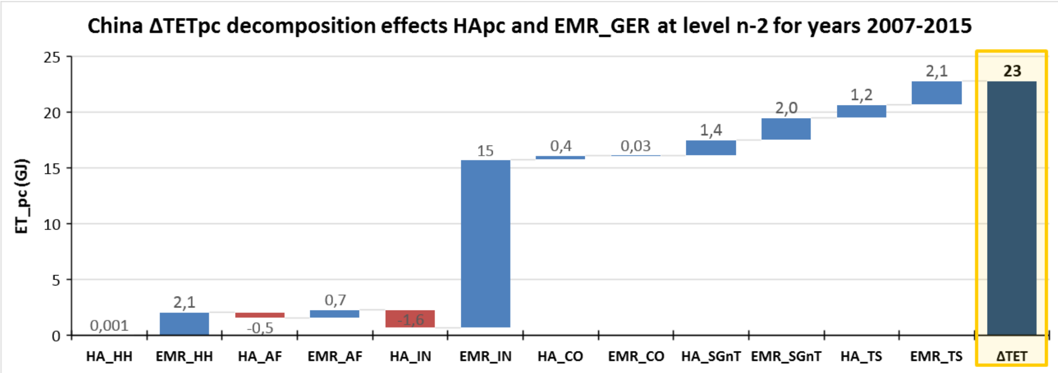


Figure 0-12 China - decomposition analysis of the increase in TET at the level n-2 in the period 2007-2015

1.9 Effects of changes in Human Activity (HA_i) and level of technical capital per worker (EMR_i) in the use of energy of China and EU28 : 2000→2007 and 2007→2015

1.9.1 Biophysical factors decomposition - level n-3 (sub-sectors)

1.9.1.1 The period 2000-2007

When considering all the sub-sectors included in the end use matrix at the level n-3 we can obtain the overview of the type given in Figure 0-13.

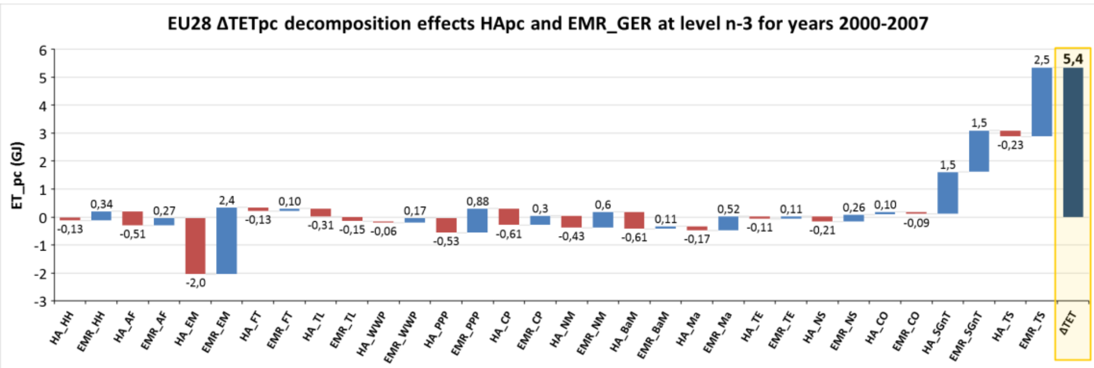


Figure 0-13 EU28 - decomposition analysis of the increase in TET at the level n-3 for all subsectors in the period 2000-2007

Again, it should be noted that we are illustrating the potentiality of a methodology of analysis and we do not have a specific set of research questions in relation to a set of specific purposes. Therefore the discussion of the results is necessarily limited. We want only to illustrate that in this way, it becomes possible to identify the sub-sectors that are more relevant in relation to overall changes and identify also the factors that should be considered when studying the behaviour of these relevant subsectors. By considering the sub-sectors inside the industrial sector we can have a more specific analysis of the factors determining changes in the metabolic characteristics of the sectors. An example is represented by the graph in Figure 0-14.

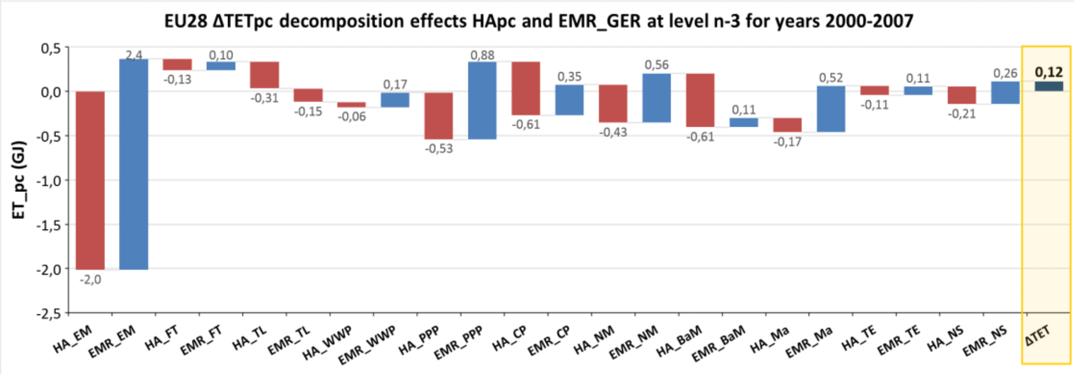


Figure 0-14 EU28 - decomposition analysis of the increase in TET at the level n-3 only for the subsectors operating in the industrial sector in the period 2000-2007

In Figure 0-14 we can identify the elements that had major compensations in relation to decrease of HA and increase of EMR (e.g. EM) and elements that reduced both (e.g. textile).

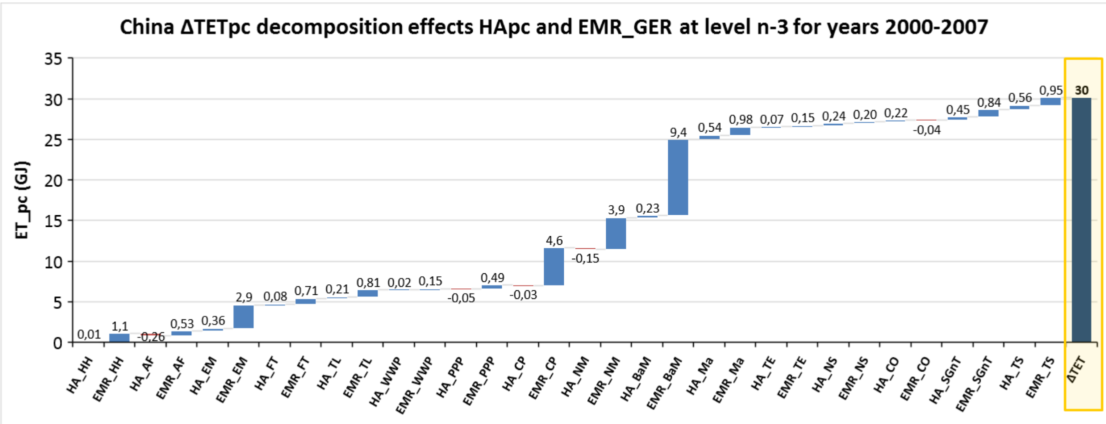


Figure 0-15 China - decomposition analysis of the increase in TET at the level n-3 for all subsectors in the period 2000-2007

Looking at the graph of China we find only minor cases of compensation between reduction of extensive (HA_i) and intensive (EMR_i) variables.

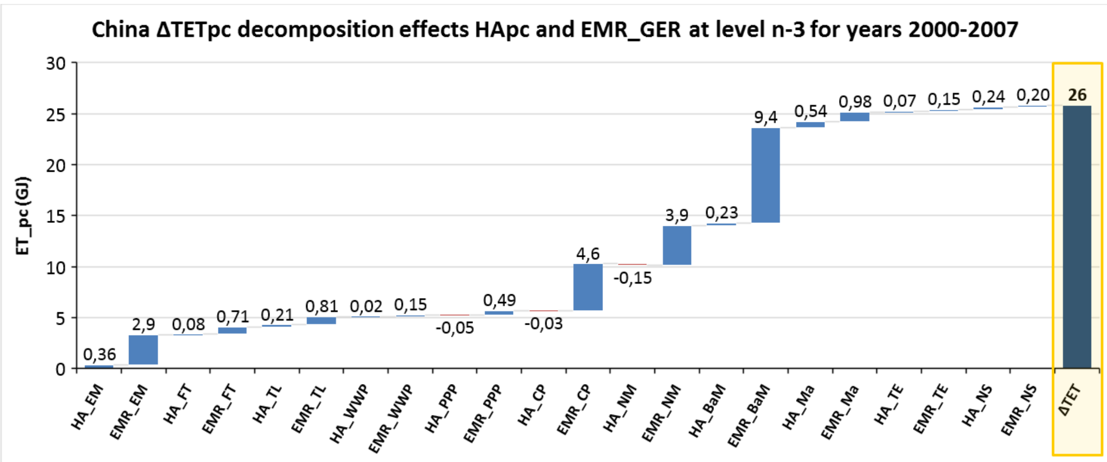


Figure 0-16 China - decomposition analysis of the increase in TET at the level n-3 for the subsectors operating in the industrial sector in the period 2000-2007

Considering the industrial sector of China we hardly find any significant compensation over changes in extensive (HA_i) and intensive variables (EMR_i): they both grow.

1.9.1.2 The period 2007-2015

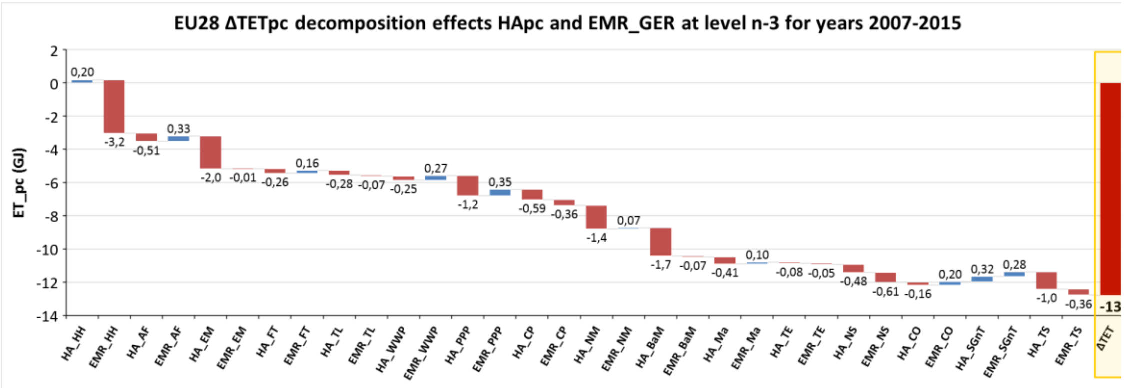


Figure 0-17 EU28 - decomposition analysis of the increase in TET at the level n-3 for all subsectors in the period 2007-2015

The analysis carried out at level n-3 confirms the findings obtained by the decomposition at level n-2 illustrated in Figure 0-11. However, it makes it possible a better definition of the contribution of the various subsectors. This analysis is important because at this level one can study the role of externalization (imports) of the goods produced in the various sub-sectors. Note that we did not do an analysis of this type in this chapter (we address the issue of externalization in Chapter 5 using a different approach).

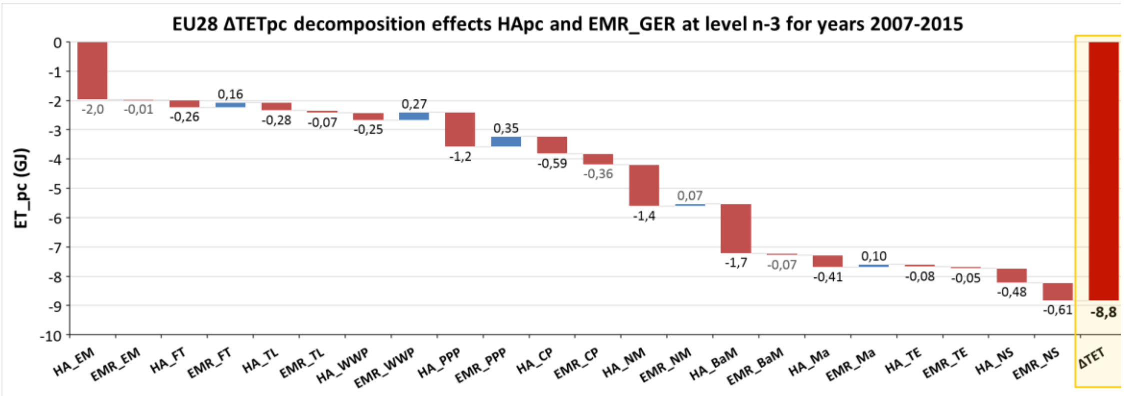


Figure 0-18 EU28 - decomposition analysis of the increase in TET at the level n-3 for the subsectors operating in the industrial sector in the period 2007-2015

The same analysis carried out at level n-3 is illustrated for China in Figure 0-19. In this second period we can see example of compensation over changes in extensive (HAi) and intensive variables (EMRi) in some of the sectors. An important example in the Energ and Mining sector, in which capitalization has reduced labor. When focusing only on the changes that took place inside the industrial sector (Figure 0-20) we can see the same phenomenon of technical capitalization of the Non-metallic minerals (NM) and Basic Metals (BaM) due to their key role of sustaining the rapid generation of technical capital and infrastructure in the economy.

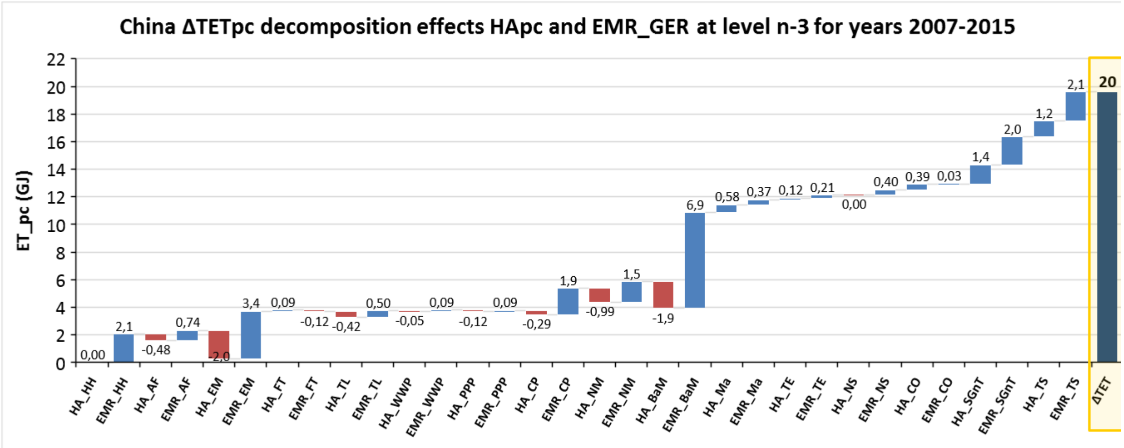


Figure 0-19 China - decomposition analysis of the increase in TET at the level n-3 for all subsectors in the period 2007-2015

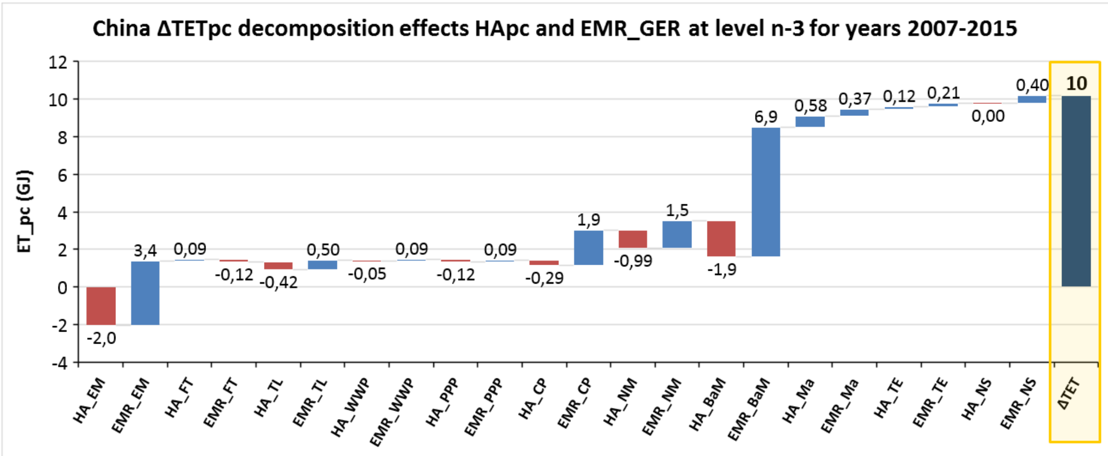


Figure 0-20 China - decomposition analysis of the increase in TET at the level n-3 for the subsectors operating in the industrial sector in the period 2007-2015

1.10 The big picture of the changes of EU28 and China over the considered period: 2000→2015

To wrap-up this analysis let's have a look at the different decomposition exercises across the whole period 2000-2015 at the different levels to get the big picture. In this section we just provide an overall visualization of the various graphs already shown so far. The goal of this comparison is to contextualize the importance of the differences described in the decomposition at different levels of analysis in relation to the overall size of the metabolic pattern.

1.10.1 An overview of the overall change described at different levels for EU28

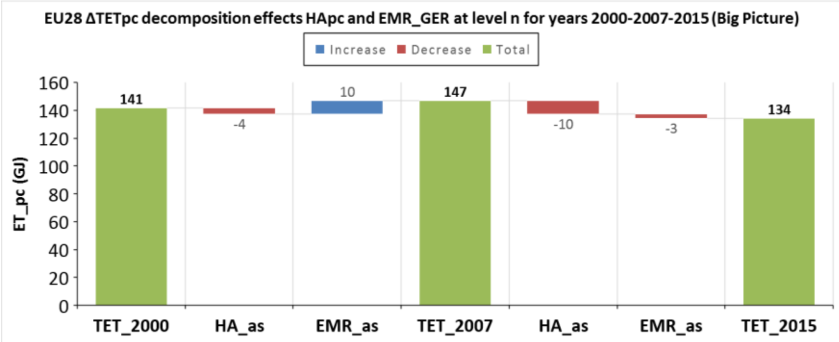


Figure 0-21 The big picture EU28 at the level n, ET per capita per year

Figure 0-21 shows the decomposition illustrated at the level of the whole economy

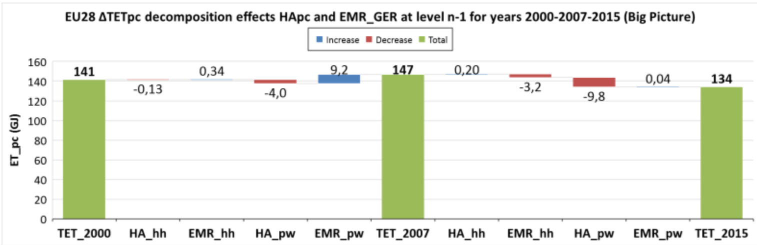


Figure 0-22 The big picture EU28 at the level n-1, ET per capita per year

Figure 0-22 shows the decomposition illustrated at the level of the constituent components

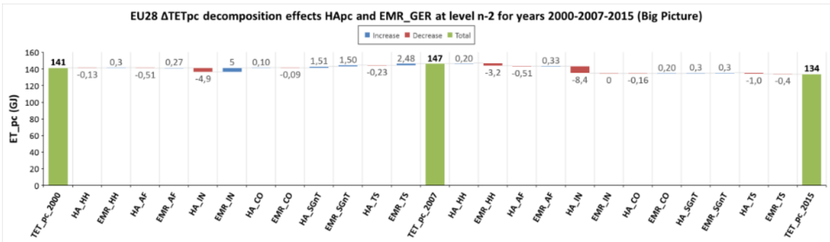


Figure 0-23 The big picture EU28 at the level n-2, ET per capita per year

Figure 0-23 shows the decomposition illustrated at the level of the economic sectors.

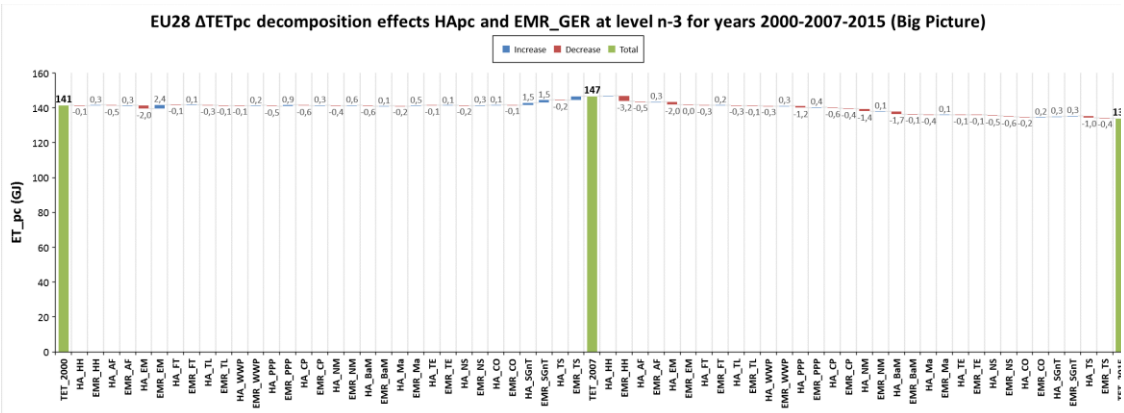


Figure 0-24 The big picture EU28 at the level n-3, ET per capita per year

Figure 0-24 shows the decomposition illustrated at the level of the economic sub-sectors.

In this comparison we can see that the overall pattern of EU28 remained quite stable – as already observed in the preliminary analysis given in Figure 0-1. That is, when focusing on the changes across levels of analysis we can see differences, metabolic elements that are winners and losers, and various explanations for changes. However, when getting back to the big picture, we can appreciate that the EU28 is a quite mature and resilient metabolic system, capable of guaranteeing a high level of overall homeostasis associated with high living standards.

1.10.2 An overview of the overall change described at different levels for China

The same visualization is now provided for China.

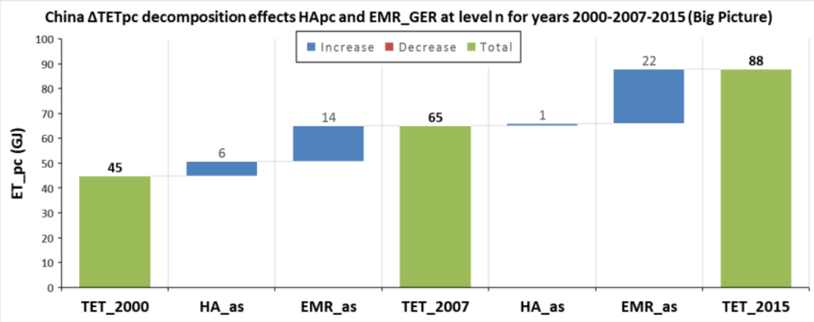


Figure 0-25 The big picture EU28 at the level n, ET per capita per year

Figure 0-25 shows the decomposition illustrated at the level of the whole economy

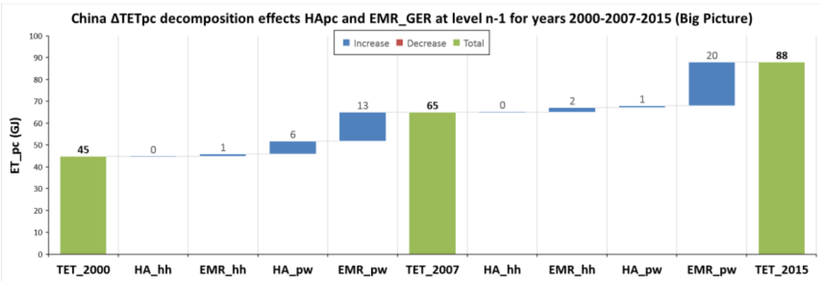


Figure 0-26 The big picture EU28 at the level n-1, ET per capita per year

Figure 0-26 shows the decomposition illustrated at the level of the constituent components

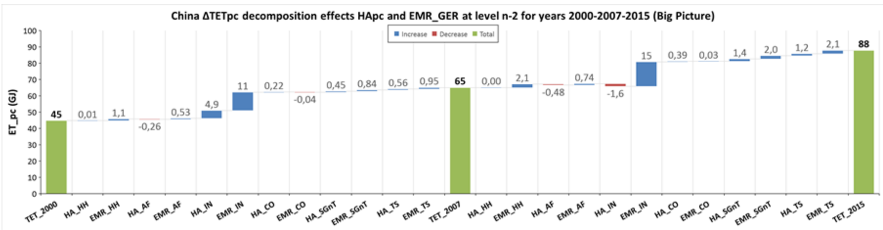


Figure 0-27 The big picture EU28 at the level n-2, ET per capita per year

Figure 0-27 shows the decomposition illustrated at the level of the economic sectors.

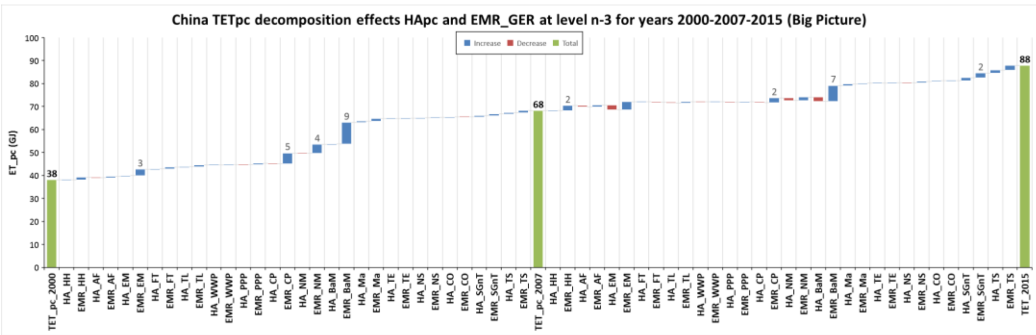


Figure 0-28 The big picture China at the level n-3, ET per capita per year

Figure 0-28 shows the decomposition illustrated at the level of the economic sub-sectors.

In this comparison, we can see that, regarding the overall amount of energy end uses in this period, China has kept growing – as already observed in the preliminary analysis given in Figure 0-1. When looking at the big picture, we can appreciate that the China is a metabolic system which is in transition, buidling technical capital and infrastructure (in fact it is the industrial sector that drives up the end uses). We can also see that in the second period considered, China is also starting to fulfill the mission of improving the level of final consumption of the household.

1.11 The economic narrative of changes: Effects of changes in Human Activity (HA_i) and Economic Job Productivity (EJP_i) in relation to GDP of EU28 and China – 2000-2007-2015 (link to economic narratives)

1.11.1 Fund-flow decomposition done on monetary flows

This section has the scope of illustrating that the same type of decomposition analysis based on fund-flow variables can also be done by using assessment of flows referring to monetary values: quantities of GVA produced in the various sectors measured in € per year. According to the shocen method, this decomposition can only be applied to the economic elements operating inside the PW constituent component. For the economic sectors and sub-sectors, it is possible to calculate quantities of GVA produced in the various subsectors per year (extensive variables) that can be related to the quantities of human activity - work hours per year (extensive variables) in the form of an intensive variable – Economic Job Productivity (EJP).

The four sets of relations used for the decomposition are analogous to those used for the energy accounting in the end use matrix:

- $GVA_{ilevelx} = \sum (GVA_{ilevelx-1})_j \leftrightarrow HA_{ilevelx} = \sum (HA_{ilevelx-1})_j$ - establishing a vertical constraint across data written, across different hierarchical levels in the grid of the matrix.
- $GVA_{ilevelx-1} / HA_{ilevelx-1} = EJP_{ilevelx-1} \leftrightarrow GVA_{ilevelx-1} = HA_{ilevelx-1} \times EJP_{ilevelx-1}$ – defining a horizontal constraint that can be moved across levels.

1.11.1.1 EU28 Decomposition at level n-2

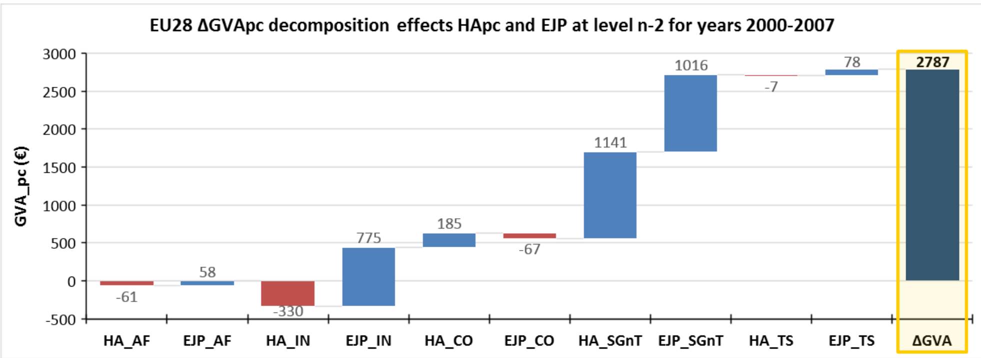


Figure 0-29 EU28 - decomposition analysis of the increase in GVA at the level n-2 in the period 2000-2007

The decomposition in Figure 4-29 (in contrast to the pattern illustrated in Figure 0-9 referring to changes in EMR_i over the same period of time) shows the decrease of labor in the industrial sector, compensated by an increase in EJP – probably due to a reduction of labor in non competitive activities - and a movement of the working hours to the generation of GVA in the service sector.

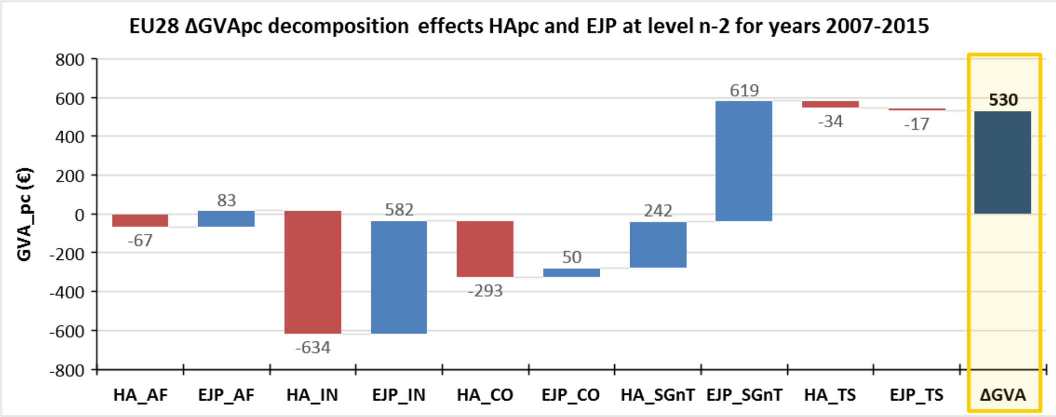


Figure 0-30 EU28 - decomposition analysis of the increase in GVA at the level n-2 in the period 2007-2015

A similar pattern is followed in the second period (Figure 0-30) when going through the crisis, where the contraction of the work in the industry is more pronounced. The increase in the generation of added value in the service sector is due more to increased in EJP_i than to increases in HA_i.

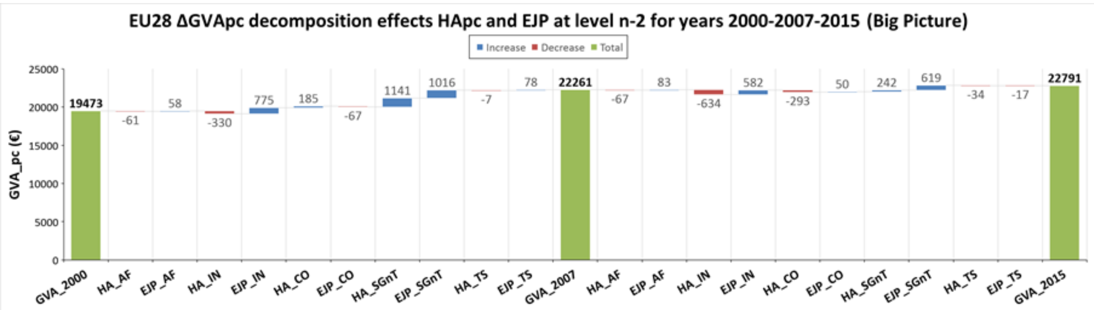


Figure 0-31 EU28 - decomposition analysis of the increase in GVA at the level n-2 - the big picture - period 2000-2015

Looking at the big picture (Figure 0-31) we can say that in the first period the GVA in EU28 was still growing (even if slowly), whereas in the second period the GVA remained constant in spite of an important reduction of energy use in the PW sector. As shown in Figure 0-30, this was due only to the contribution of the service sector.

1.11.2 China - decomposition at level n-2

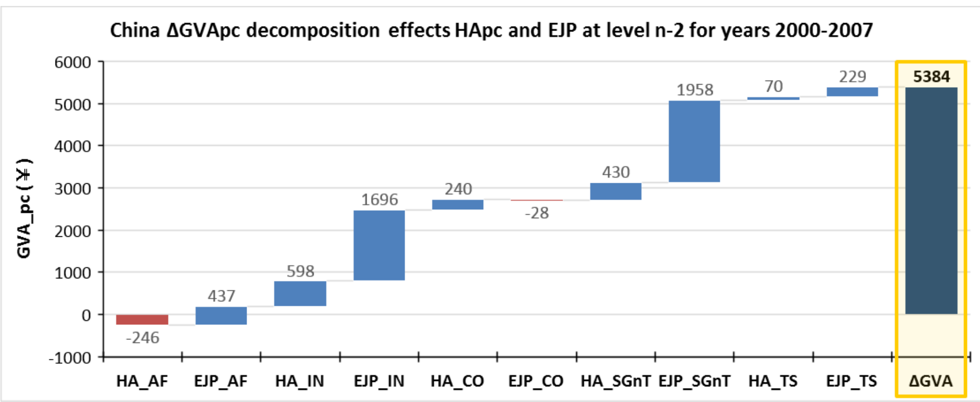


Figure 0-32 China - decomposition analysis of the increase in GVA at the level n-2 in the period 2000-2007

The decomposition shown in Figure 0-32 (to be contrasted with the pattern illustrated in Figure 0-10 referring to changes in EMR_i over the same period of time) shows a decrease of labor in the agricultural sector, compensated by an increase in EJP (due to a reduction of labor in subsistence activities) and a movement of the working hours to the generation of GVA in the industrial and the service sector.

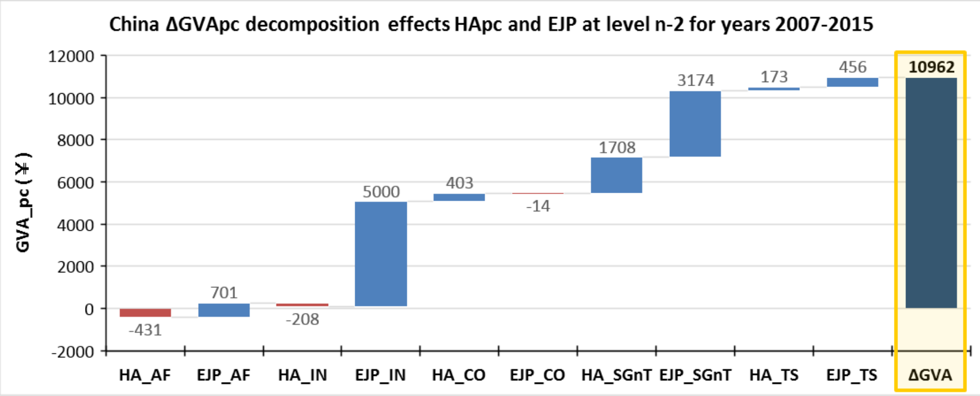


Figure 0-33 China - decomposition analysis of the increase in GVA at the level n-2 in the period 2007-2015

Changes in the second period (Figure 0-33) show that the growth of added value in the industrial sector is determined by an increase in EJP (with a minimal reduction of working hours) indicating a specialization on more competitive activities and probably an increasing demand on the globale market (accessible through the WTO). In the service sector there is an increase in both HA_i and EJP_i.

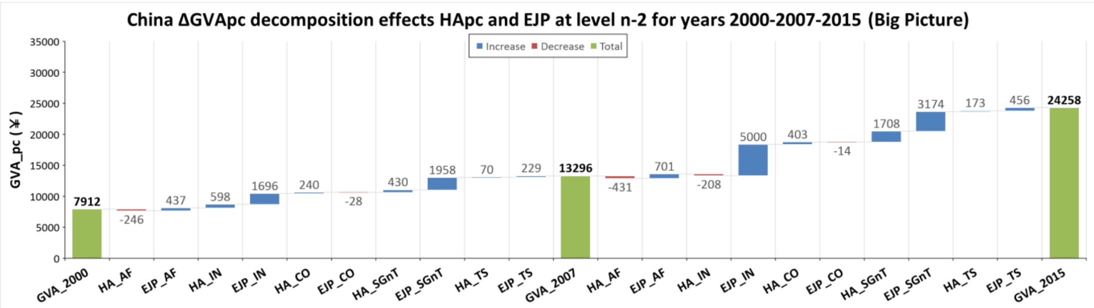


Figure 0-34 China - decomposition analysis of the increase in GVA at the level n-2 (the big picture) in 2000-2015

The big picture (Figure 0-34) confirms the continuous growth of China economy unaffected by the crisis. As a matter of fact, the industrial sector of China seems to have taken advantage by the shrinking of the industrial sectors in developed countries.

1.11.3 EU28 - decomposition at level n-3

As already seen with the decomposition analysis across levels when considering changes in energy end uses (HA_i ←→ EMR_i), also in the analysis of the relation between HA_i and EJP_i we find similar results. The finer grain of the analysis of this level makes it possible to identify specific sectors and sub-sectors making the difference.

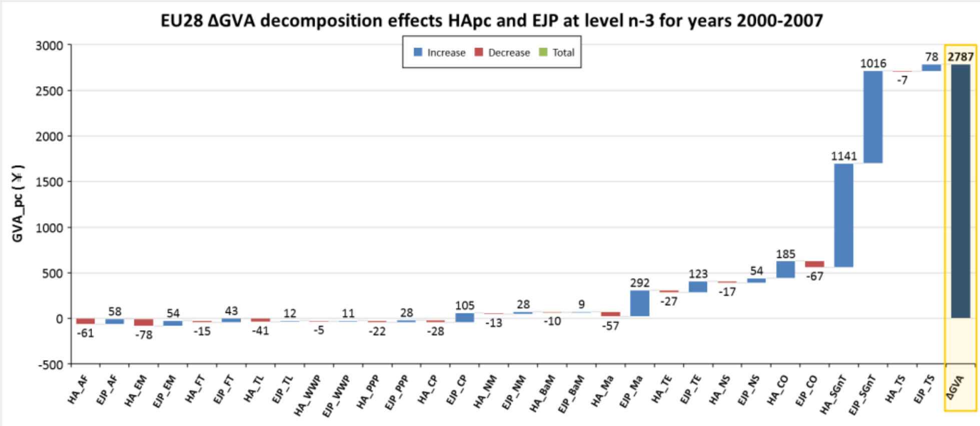


Figure 0-35 EU28 - decomposition analysis of the increase in GVA at the level n-3 - period 2000-2007

The analysis of changes in EJP_i in the first period (Figure 0-35) confirms what already found earlier: a common reduction of labor all over the sectors dealing with biophysical transformations and a massive increase of HA and EJP in the service sector.

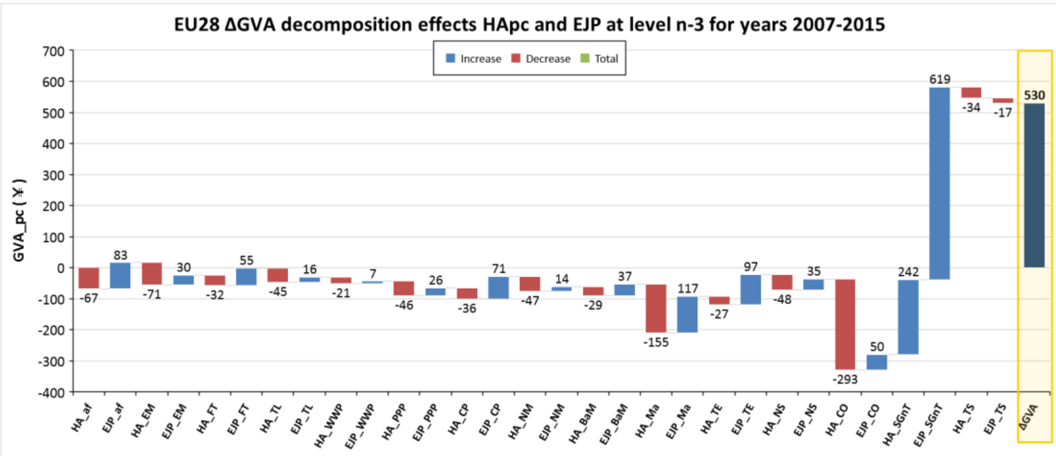


Figure 0-36 EU28 - decomposition analysis of the increase in GVA at the level n-2 - period 2007-2015

In the second period (Figure 0-36)- the trend was reinforced. All sectors dealing with biophysical processes reduced their number of working hours, with a dramatic reduction in construction. The service sector compensated all the negative trends.

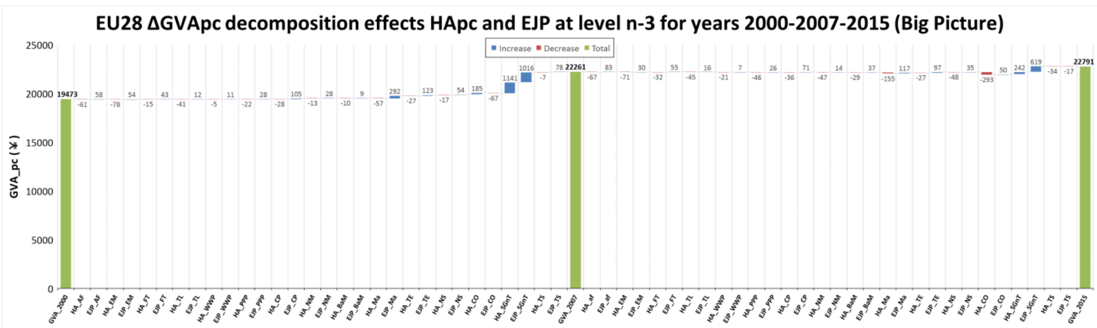


Figure 0-37 EU28 - decomposition analysis of the increase in GVA at the level n-2 – the big picture period 2000-2015

When considering the big picture over the two periods (Figure 0-37) we can confirm the stability of the metabolic pattern of EU28 during the period considered.

1.11.4 China - decomposition at level n-3

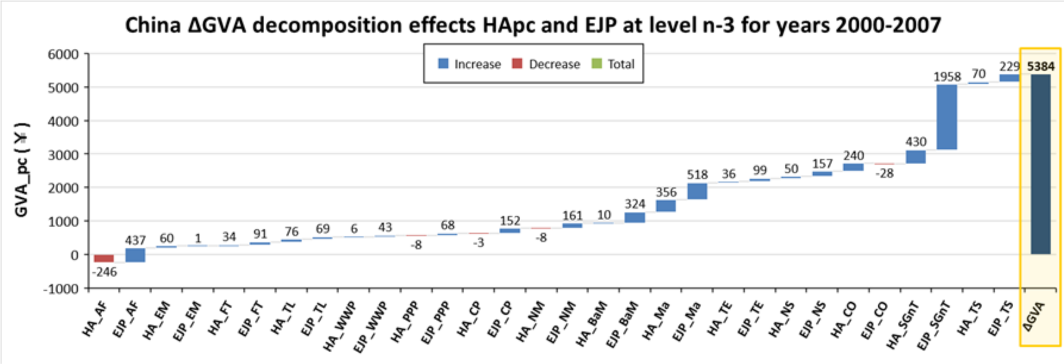


Figure 0-38 China - decomposition analysis of the increase in GVA at the level n-3 - period 2000-2007

The data given in Figure 0-38 make it possible to visualize the individual contributions of the various sectors to the total increase in GVA in the first period.

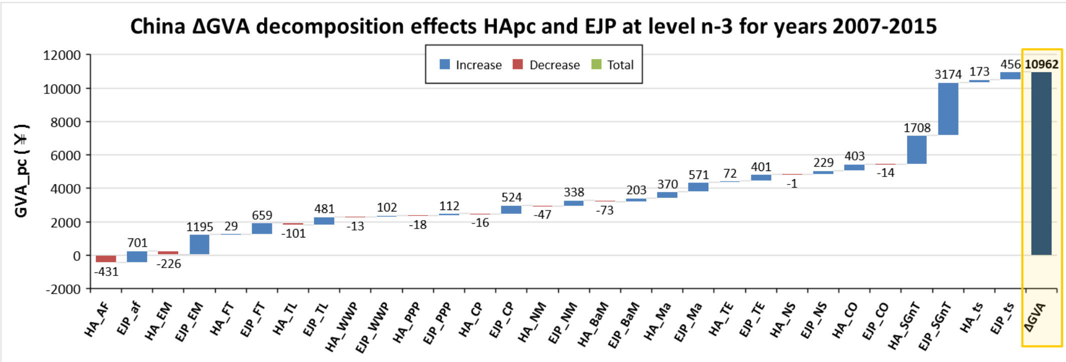


Figure 0-39 China - decomposition analysis of the increase in GVA at the level n-2 - period 2007-2015

The data given in Figure 0-39 make it possible to visualize the individual contributions of the various sectors to the total increase in GVA during the world economic crisis. At this level we can still visualize the important contribution of the service sector (because it is not disaggregated in this analysis) but we can no longer visualize the important contribution of the industrial sector. In fact, we can only see a series of smaller contributions determined by its lower level sub-sectors. We can notice that in both periods the primary sectors – agriculture and energy and mining have reduced their amount of working hours and increased their values of EMR_i.

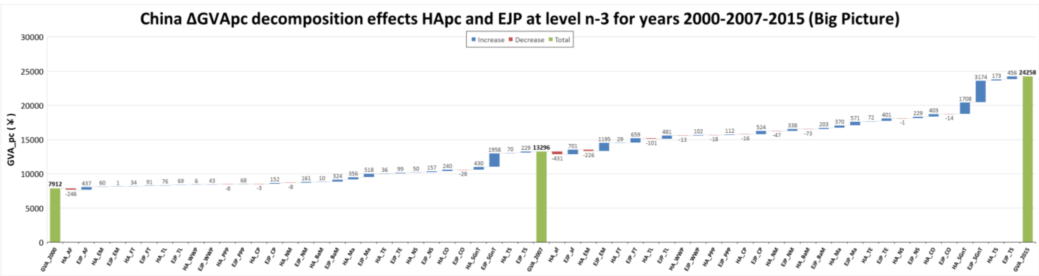


Figure 0-40 China - decomposition analysis of the increase in GVA at the level n-2, the big picture, period 2000-2015

When considering the big picture over the two periods (Figure 0-40) describing the changes in the elements of the Chinese economy at the level n-3 we can confirm the findings obtained with the biophysical analysis: during the considered period of time we can observe a generalized vitality of the various sectors and subsectors of the Chinese economy.

The implications of the level of openness of the economy: externalization and trade in relation to the end-use matrix of China and EU28

(Lead author: Laura Pérez-Sánchez)

1.12 Introduction

Since 2001 and the joining of China to the WTO, the role of China has changed from an autarchic economy to the largest exporter economy in the world. This transformation has not been without problems. The EU and the USA have repeatedly alleged that China does not respect WTO rules by subsidizing production, while China claims to have assumed additional obligations and fewer rights (Hilpert, 2014). At present, we find ourselves in the midst of a geopolitical fight oscillating back-and-forth between liberalization and protectionism, and an upsurge of multilateral trade agreements. One of the last moves regarding protectionism has the USA and China as main characters, increasing import tariffs for some products in what it could be called a "trade war" (Hsu, 2018), in which the EU has found itself involved (European Commission, 2018b).

As regards EU-China relations, the two countries have engaged in the High-level Economic and Trade Dialogue since 2011. In the EU-China 2020 Strategic Agenda for Cooperation they have declared to aim at: "*Enhance the EU-China Industrial Dialogue and Consultation Mechanism, strengthen policy exchanges to facilitate industrial products trade, particularly in the fields of automobile industry, industrial energy efficiency, raw materials, ship building and small and medium sized enterprises*" (EEAS, 2014). However, China's intentions to negotiate and put into force a Free Trade Agreement (FTA) have met with reservations from the EU: "*China has suggested further deepening the relationship through an FTA, but the EU will only be ready to engage in such a process once the right conditions are met, as expressed in the EU–China 2020 strategic agenda for cooperation*" (European Commission, 2015).

In order to establish FTAs, or any trade policy in general, not only monetary returns are relevant, but also the biophysical resource base of the products traded (energy, labor, materials, etc.). Such an analysis is also relevant in relation to the growing sustainability concerns (e.g., consumption-based indicators (Liu, 2015)). In the literature several studies are available of the impact of trade in relation to the biophysical performance of the EU economy. For example, assessments of the environmental and resource footprints of the EU (Tukker et al., 2016), or the labor embodied in trade (Simas et al., 2015). On the side of China, there are studies on domestic content of value added and technology intensity (Upward et al., 2013), CO_2 emissions embodied in foreign trade (Zhao et al., 2014) and domestic value added and employment (Chen et al., 2012).

In this chapter we explore the possibility of studying the implications of the openness of the economy of the EU28 and China looking at how the terms of trade affects their energy performance. As showed in the previous chapters international trade and externalization are key aspects of the globalization process. They have permitted the transformation from industrial to post-industrial society in most of the EU during the past decades. As we have seen in the preceding chapters, the rapid expansion of the tertiary sector in the EU (both in terms of work force and services provided) would not have been possible without these globalization processes. By replacing the requirement of labor in the primary and secondary sectors with imports, EU28 has been capable of moving the majority of its work force (more than 60%!) to the service sector. The rapid evolution of the Chinese economy raises questions as to whether China will undergo a similar transformation and what implications this could have for the EU. In the future, in a globalized knowledge economy, if nobody will produce the primary and secondary physical goods required by the economy (imported at the moment by EU28) who will?

A preliminary analysis of the externalization of the energy sector in the EU was made with MuSIASEM in the Horizon 2020 project MAGIC (GA 689669) (Ripa et al., n.d.). In this chapter we complement that exploratory study by assessing the embodied flows of human activity (labor) and flows of energy carriers associated with the trade between China and the EU28 in the year 2012. However, in this study we adopt a different approach to the assessment. Our calculation is based on a combination of MuSIASEM and multi-regional input-output tables (MRIO). In relation to embodied quantities of human activity, we not only consider the bilateral trade between China and Eu28, but also assess the impact of EU trade with the rest of the world. This information is important to assess the level of self-sufficiency of the economy in terms of labor demand in the case the option of cheap and abundant imports will be reduced in the future. After re-calculating the values of the EMRs for the domestic end-use matrix of the EU28 and China to include the human labor and energy resources embodied in trade we can have a better picture of how dependent China and EU28 are on trade for their “metabolic security”.

1.13 Results and discussion

1.13.1 Human Activity Embodied in trade

Looking at the total extensive values of HA (Figure 0-1), we can see that China uses many more hours of human activity in its economy because of its larger population size. However, in this graph we calculate also the quantity of HA that is embodied in the imported goods and services. This implies that the total HA used in the economy depends not only on the quantity of hours of paid work taking place inside the economy (direct HA), but also by the level of imports (embodied HA). When considering the hours of paid work embodied in the traded goods and services, China is a major exporter of embodied HA. The exports from China to EU alone (60.4Gh) are higher than all the exports from EU to anywhere in the world combined (40.0Gh). The imports of embodied HA to China from EU (5.2Gh) are quite small. Therefore, the trade balance between China and EU is equal to a net quantity of 55,3Gh/year imported to EU (around 110 hours of HA per capita/year). Compared with China, EU relies more on embodied HA both in relative (hours per capita) and absolute terms (total hours), in spite of its smaller population. This analysis can be done by visualizing the same data using per capita assessments (Figure 0-2).

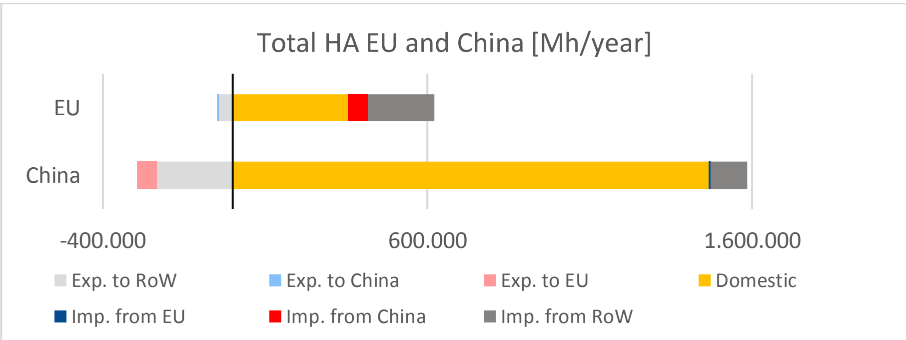


Figure 0-1 Total HA embodied in trade for EU and China in 2012 [Mh/year]

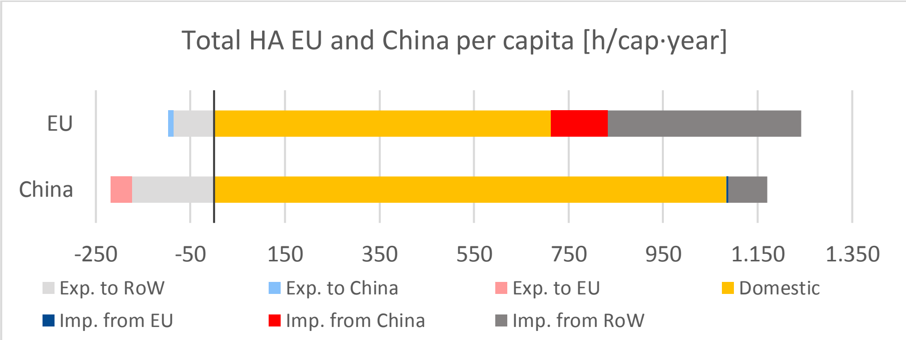


Figure 0-2 Total HA per capita embodied in trade for EU and China in 2012 [h/cap·year]

Considering the values of HA per capita we can analyze in another way the hours of labor required to produce what is consumed domestically (positive values on the right of the vertical axis) and exported (negative values on the left of the vertical axis). Not all hours of work required to produce what is consumed domestically are hours of work taking place in the local economy. For example, looking at the EU bar on the right, we can see that the domestic consumption in EU depends on a significant "virtual injection of hours of labor" both from China (in red) and from the Rest of the World (RoW) (grey). These embodied hours of HA associated with imports (around 500 hours of paid work p.c. year) from the rest of the world represent a significant fraction of the domestic supply of hours of paid work (around 730 hours of paid work p.c. year). It should be noted that, when coming to this type of assessments it is almost impossible to provide exact estimates of the embodied hours in traded products due to the extreme openness of modern economies. A problem with this method of assessment is represented by the fact that it does not make a distinction between the import of biophysical products and import of services. Coming back to the role of embodied work from China, according to this method of estimation almost 10% of the final consumption of Europeans is based on it. However, the contribution of the hours of work from China to the functioning of the EU economy could be much more significant when considering that the hours from China are more related to biophysical products or Chinese made components. That is, depending on the specific products, the injection of hours of work has a different role in reducing labor in the productive sectors (EM, AG, Industry) and the expansion of labor in the service sectors (knowledge economy) in the EU economy.

As already explained in the previous chapters, it is the different demographic structure and the different work-loads between EU and China that explains the existence of this supply of "virtual labor" moving from China into the EU economy. As discussed in the introductory section of this deliverable (Figure 0-1) China has a much lower dependency ratio, due to its favorable demographics (a large fraction of the population in working age, a legacy of the one-child policy) and longer working hours per worker. This difference can be seen with the sum of the bars of domestic work supply, which are much longer for China (around 1,000h/capita/year) than for EU (around 730h/capita/year).

As explained in Chapter 2 and 3, the different economic structures affect the differences illustrated in Figure 0-2. When we disaggregate the overall economy into sub-sectors, we can see that China tends to: (i) export more biophysical products; and (ii) be more self-sufficient than EU in relation to domestic supply. When coming to the bilateral relation, China imports significantly less from the EU than it exports. This is especially relevant for industry. As noted earlier, EU relies strongly on work performed outside its borders in all the productive sectors: (i) the energy sector; (ii) agriculture and fishing; (iii) industry; and (iv) Mining and quarrying. Not only EU relies more on embodied labor, but also on the embodied primary sources essential for guaranteeing an adequate supply from these sectors. The total externalization of Mining and quarrying in EU may be explained either as a consequence of resource scarcity, or also as a consequence of NIMBY opposition to mining projects. If we assess the quantity of labor required to produce the imported commodities referring to the productive sectors we discover that this quantity of embodied labor is almost 80% of the total embodied labor getting into EU. In China the fraction of HA (hours in the paid work) going to export is approximately 15%. It must be noted that even though China is considered by many as "the factory of the world" it is only a part of the Global Supply Chains. In some cases, it is only the final assembler of goods, whose parts have been manufactured elsewhere. Thus, "Made in China" products do have often many other origins. This implies that share of the grey bar of "Imports from RoW" Figure 0-1 and in Figure 0-2 might belong to products that are identified as Chinese imports to EU, but it is difficult to track the origin of all the parts and components. To make things more difficult, the data referring to the Service sector (without transport) is heavily muddling this type of analysis. The sub-sector Financial intermediation generates a great share of the $VA_{services}$ of exports from China to EU (47% of the $VA_{CHN\text{->}EUServices}$), but this added value is associated with little amounts of HA – about 2.8% of the total $HA_{CHNservices}$. Thus, we repeat again that what is presented here should be considered as a first exploratory study, whose results must be considered as a first attempt to apply a quantitative analysis of the biophysical implications of trade based on the metabolic narrative.

Table 0-1 Trade balance between China and EU28 per sub-sectors.

	Trade balance	
	Absolute [Gh]	Per capita [h/cap EU]
Agriculture and fishing	11.0	22
Mining and Quarrying	1.9	4
Industry	22.7	45
Electricity, Gas and Water	0.5	1
Construction	0.2	0
Services without transp.	16.8	34
Transport	2.1	4
TOTAL	**55.3**	**111**

Looking at the comparison of the values per capita and per sub-sector (Figure 0-3) we can confirm the differences already observed in the previous chapters: (i) the share of HA invested in Agriculture and Fishing in China is much larger than in EU. Moreover, when considering the hours of work in EU agriculture the hours of work inside Europe are smaller than the hours embodied in imports; (ii) the requirements of HA in Mining and Quarrying is much larger in EU than in China. However the vast majority of this work is taking place outside the EU borders; (iii) also in relation to industry, EU has a larger requirement of HA than China and also in this case, the majority of the required work is done outside EU; (iv) when coming to Services, EU has a larger requirement of HA per capita (both local and embodied) than China. This fact illustrates clearly the dependence of the EU knowledge economy on working hours performed elsewhere. Considering the big difference in the endowment of hours of work in the paid work sector per person per year (730 in Europe and 1,250 in China) one can only wonder how is it possible that Europe can invest in its economy more hours of work per capita in the service sector than China. The conclusion is that the European Union *is a service-centered society that relies on embodied quantities of hours of work performed elsewhere for the supply of its material consumption*. However, when we are adding to the original 730 hours of work per capita in the Paid Work sector the approximate estimated value of another 500 hours of work per capita embodied in the imports, we see that there is no "magic" in the European solution. When summing to the actual working hours in Europe the virtual working hours embodied in imports we find a requirement of working hours of 1,230 p.c./year. This value is quite similar to the one found in China.

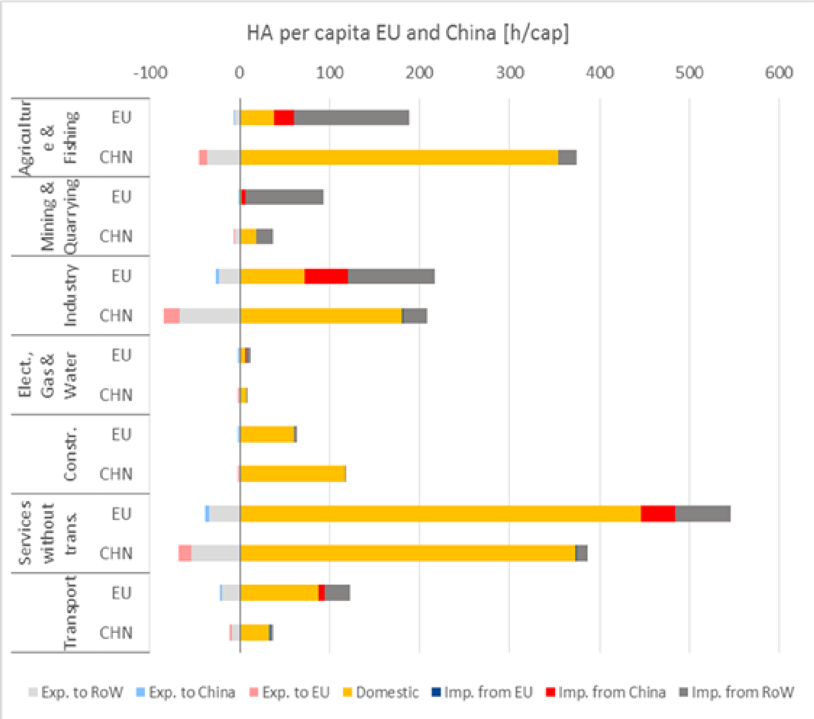


Figure 0-3 Human Activity per capita embodied in trade EU-China per sub-sectors in 2012 [h/cap]

If we would carry out this analysis at a lower level (as done in Chapter 3) we could study many more peculiar differences among the two economies. As shown in Chapter 3, China is currently building infrastructure and dwellings in cities and for this reason it doubles the amount of hours per capita in Construction to those of EU, and it has as well a similar consumption of HA in industry. Priorities in the Chinese economy are the generalization of the covering of basic needs, change in consumption patterns and lifestyle according to the expectations of the Chinese people.

1.13.2 Energy Throughput embodied in trade

In the case of ET, there are no data on the energy carriers' consumption of Rest of the World. Thus the results of this section are focused only on the bilateral relation between EU and China and don't include imports and exports of RoW. The analysis presented here is referring to consumption of energy carriers. That is, the quantities of electricity are referring to the secondary energy input consumed (and not to the energy required to produce the electricity). For this reason, as explained earlier, the characterization of energy use can be carried out in two different ways:

(1) by accounting categories of energy carriers reflecting their different qualities – electricity (mechanical energy), fuels (stored thermal energy) and process heat (thermal energy that cannot be stored);

(2) by aggregating the various quantities of energy carriers referring to different qualities into an overall quantity – Gross Energy Requirement, thermal equivalent – measured in Joules of Tons of Oil Equivalent.

By using the first approach one can study more in details the implications of a different mix of energy carriers used in the economy. Especially important is the electricity that is an energy carrier extremely useful both in the phase of production and in the phase of consumption. An analysis based on the analysis of different carriers is important if we want to study the implications of the different mixes of economic activities carried out (liquid fuels are essential for transport, process heat for industrial processes, electricity is a powerful saver of working hours everywhere it is applied). However, as explained earlier this analysis can be done, with the data set used in this deliverable, but due to the lack of robustness of the estimates, we should take with extreme care the results. To illustrate the possibility of generating this analysis we illustrate the results of the analysis carried out for the three flows of energy carriers in Appendix 1. The example given in Appendix 1 shows clearly that this analysis would be very important to study the relevance of the mix of imported and exported commodities on the net supply of embodied flows of energy carriers. The results illustrated in Table 0-2, for example, show that when considering the embodied quantities of energy carriers in the imported goods, the economy of Europe has a significant gain in the import of electricity. This is a very important consideration in relation to the fight against climate change. In fact, it should be noted that the electricity produced in China (because of the use of coal in the mix of Primary Energy Sources) is associated with a much larger level of emissions that the electricity produced in EU.

Table 0-2 Share of the ET embodied in Imports to China and EU in relation to their respective domestic production ET consumption for the 3 EC [%] and absolute trade balance [PJ to EU], negative values mean imports to China from EU.

	Electricity	Heat	Fuels
China	1.1%	8.5%	5.0%
EU	26.7%	4.4%	2.8%
Trade balance [PJ to EU]	+1,445	-38	39

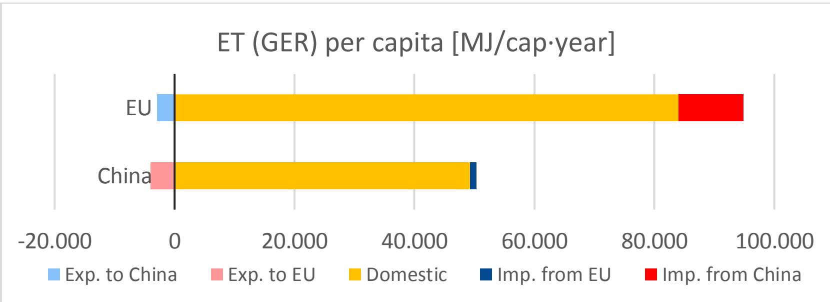


Figure 4-7 Total ET (GER) per capita embodied in trade for EU and China in 2012 [MJ/cap·year]

Regarding the embodied quantities of energy carriers in imports from China, our analysis in the year 2012 indicates approximately: (i) 700 PJ of electricity (1,750 PJ of GER thermal); (ii) 200 PJ of process heat (the same quantity in J of GER thermal); (iii) 60 PJ of fuels (the same quantity in J of GER thermal), for a total of approximately 2,000 PJ of GER thermal.

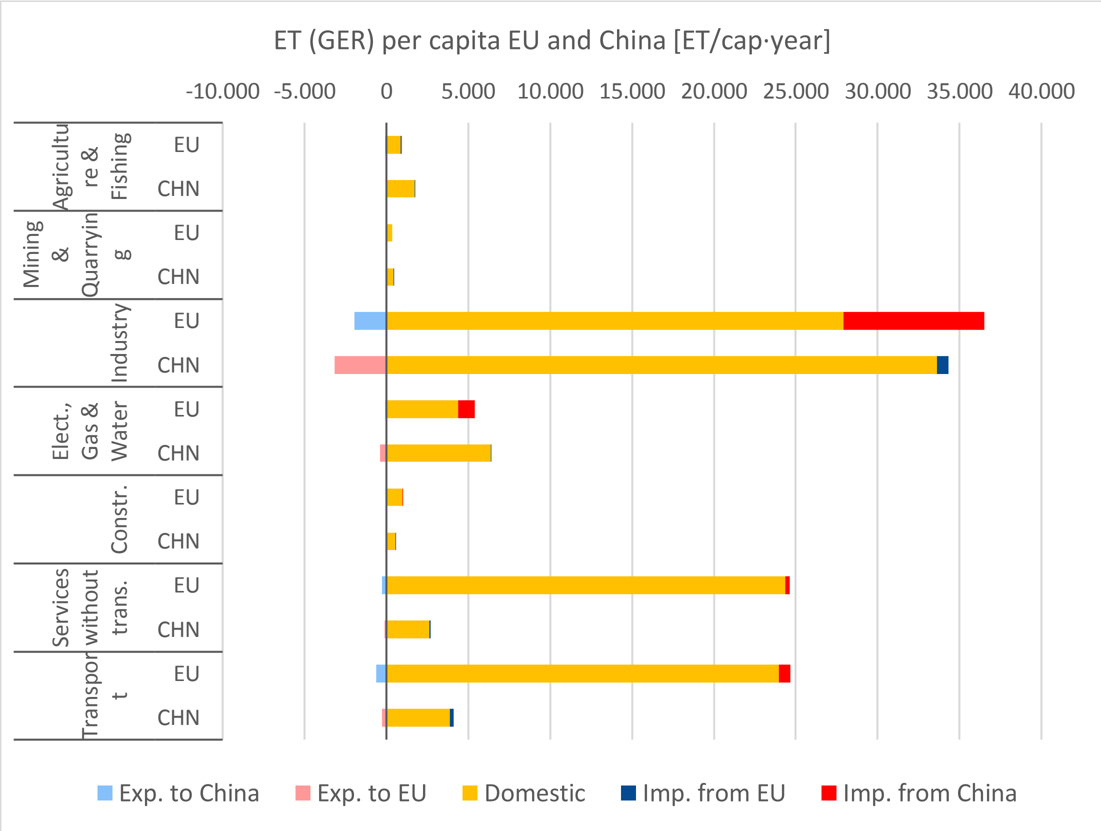


Figure 0-4 ET (GER) per capita embodied in trade per sub-sectors for EU and China in 2012 [MJ/cap·year]

1.13.3 How the values of EMR_i would change if we included embodied resources

The analysis of the comparison for China and EU has been extensively analyzed in the chapters 0 and 0 where we have compared the metabolic characteristics of the various functional elements of the economy using extensive variables – i.e. the size of the fund element Human Activity and the size of the flow elements Energy Throughputs (energy carriers). However, that analysis was based only on the direct use of quantities of working hours and energy carriers inside the borders of the economy. After having analyzed the embodied HA and ETs in trade, it becomes possible to calculate the virtual quantities of HA and ET embodied in the imports. These quantities are used indirectly by the economy to guarantee the final consumption.

In the analysis presented here we considered only the effect of the bilateral trade between China and EU. The analysis divided by typology of energy carriers reduced even more the effect of changes in EMR. For example, when considering the changes in EMR due to the bilateral exchanges with EU28 in the PW sector of China the effects are barely visible. Things are different for EU, for which the imports from China are significant in a few sectors such as Mining and quarrying, Wood and paper, Petroleum, chemical and non-metallic mineral products, and Metal products, electrical and machinery – see the analysis in the Appendix 1. However, we can try to carry out a thought experiment, starting from the data analyzed when looking at the bilateral trade between EU and China to estimate the effect that trade has in boosting the EMR of the PW sector in EU.

Looking at the embodied quantities associated with imports from China we did estimate that EU gets: 110 working hours per capita per year in the Paid Work sector; and (ii) 2,000 PJ of GER thermal per year in the PW sector (the reference year was 2012). This implies a ratio of 18 PJ of GER thermal per hour per capita/year. Let's extrapolate these two values found for the trade with China to the other imports coming to EU from the rest of the world. Then, using the same ratio and starting from the estimation of 500 working hours per capita per year embodied in the imports from the rest of the world we can consider that they imply also an equivalent virtual input of 9,100 PJ of GER thermal. With this data we can calculate a "corrected EMR_{PW}" considering the effect of trade. The calculation is simple:

$$\text{Direct } EMR_{PW} = ET_{PW}/HA_{PW} = 46{,}000 \text{ PJ p.c. year}/370 \text{ h p.c. year} = 124 \text{ MJ/h}$$

$$\text{Corrected } EMR^{*}_{PW} = ET^{*}_{PW}/HA^{*}_{PW} = 55{,}000 \text{ PJ p.c. year}/840 \text{ h p.c. year} = 65 \text{ MJ/h}$$

After having calculated these new values we can go back to the representation of the differences in the metabolic characteristics of the Paid Work illustrated at the beginning of this document in the left graph of Figure 0-1 and see a completely different picture (Figure 0-5). As illustrated in the figure when we consider the end uses of HA and energy carriers required for operating the local supply system (the various activities within PW taking place inside the border) and we sum to that the end uses of HA and energy carriers required for operating the "virtual supply system" (the various activities within a virtual PW sector taking place in the rest of the world) we can see that the number of working hours associated with the functionality of EU economy moves from 730 to 1,230 p.c. per year and the EMR_{PW} moves from 124 MJ/h to 65 MJ/h.

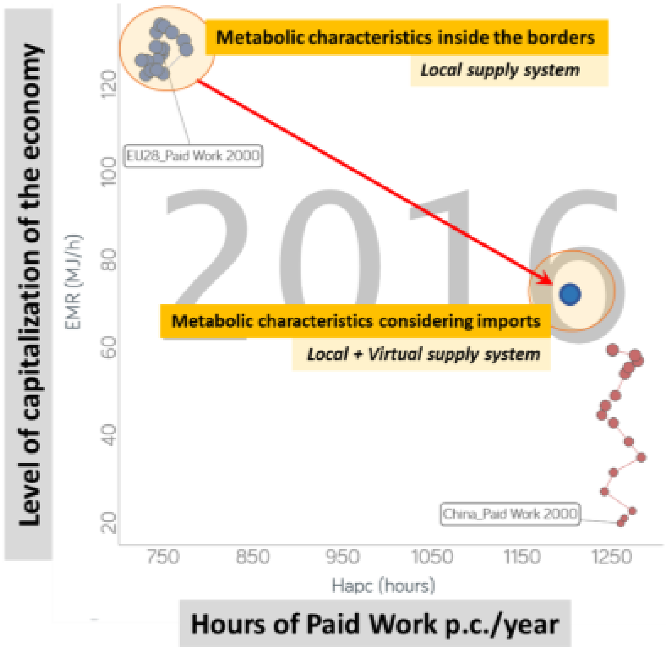


Figure 0-5 The difference in the metabolic characteristics of the PW sector of EU28 and China, when considering or not considering the effect of imports

We want to flag again that this assessment is not robust. The assessment based on economic statistics entails including a lot of confusion about the factors determining the estimated embodied quantities. In relation to this point there is another EU project – MAGIC – that using the MuSIASEM accounting scheme together with relational analysis is carrying out the same type of assessment using a different approach. The analysis of embodied quantities is based on a bottom-up characterization of the profiles of requirement of production factors (associated with typologies of imported commodities). This analysis based on the concept of the metabolic pattern of social-ecological systems can track the requirement of secondary inputs (flows and funds that are generated inside the technosphere) and the requirement of primary flows – i.e. primary sources of energy, food and minerals and primary sinks of emissions, wastes and pollutants (flows and funds whose stabilization is determined by processes outside human control in the biosphere). In this alternative method of assessment of embodied production factors it becomes possible to disaggregate the analysis at the level of sub-sectors. In this way on can obtain more robust results, but the data requirements is much more important. In fact, it requires the definition of approximate characteristics of the production functions to be calculated country by country. In the MAGIC project selected typologies of production functions (processors) are associated with the different countries of origins and this strategy reduces the requirement of data. This approach still under development in MAGIC was outside the reach of the EUFORIE project.

4.4 Conclusions of this preliminary study on the effects of externalization

Once again we want to remind the reader that what is presented in this chapter is an exploratory study having the goal to illustrate the importance of considering the effects that trade has on altering the metabolic characteristics of complex economies. In particular we have been estimating (starting from the information found in economic input output tables) the amount of working hours and the amount of energy carriers embodied in the imports. The quantities of energy carriers were measured in two different methods: (i) in a single assessment – measured in Joules of Gross Energy Requirement thermal - obtained by aggregating the quantities of carriers of different qualities in a single number using quality factors (presented in the main text); and (ii) in a set of three different assessments (for electricity, fuels and process heat) presented in Appendix 1. These data have to be considered very coarse approximations. Still we believe that they illustrate quite well the crucial importance of carrying out this type of analysis.

Coming to the results obtained in this analysis:

In relation to the virtual quantities of Human Activity embodied in the imports: Europe imports large amounts of hours of work (about 500 hours of work per capita per year). This injection of “virtual” working hours is essential because it reduced the work requirement in productive sectors (agriculture, mining and industry). This implies that less European workers have to get involved in those sectors. Something positive: (i) for the European citizens because service-related jobs have better conditions and status; and (ii) for the economy because financial activities and other service activities tend to provide a high GVA production compared with the biophysical investment required.

In relation to the virtual quantities of Energy Carriers embodied in the imports: The embodied quantities of energy carriers are not as important for the EU economy as the hours of human activity. They are not particularly significant when considering the overall quantity expressed in GER. We can find a significant value, when considering the energy carriers separately for the embodied electricity from Chinese industry to EU.

In relation to changes in the Energy Exosomatic Metabolic rate due to imports: we could calculate changes on the original profile of EMR_i (keeping separated the quantities of energy carriers of different quality) only in relation to the effects of the bilateral exchanges between China and EU. These changes are not very relevant except for some sub-sectors related to mining and industry in the EU. However if we carry out a thought experiment imagining to combine together the inputs from China and the Rest of the World, using for the overall assessment of the effect the characteristics of the Chinese economy [i.e. we assume that China would produce all what is imported in EU at the moment and we apply on the imports the technical coefficients calculated for China] we could estimate a significant reduction of the EMR_{PW} from 124 MJ/h (as measured looking at the date from statistics) to 65 MJ/h (as resulting in the correction considering the inflows of both energy carriers and hours of work in the Paid Work sector).

Finally, it should be noted that in this analysis we are not subtracting the amount of embodied production factors going into the production of exports, because in terms of end uses of the economy, the working hours and energy carriers used for producing goods and services that are exported are in any case necessary to the functioning of the economy. They are produced, like the other goods and services consumed domestically or exported, to generate GVA.

Wrapping-up: lessons learned from the analysis of the factors that determined changes in the metabolic pattern of EU28 and China – 2000-2016

(Lead author: Mario Giampietro)

In this section we try to connect the dots presented in the previous chapters in order to get the big picture of what the various pieces of information presented so far imply in terms of sustainability of both EU28 and China. Section 6.1 addresses the implications of the differences in the demographic and socio-economic contexts in which the economic process takes place; Section 6.2 compares two holistic visions of the pattern of metabolic changes that took place in the considered period both in EU28 and China; Section 6.3 look ahead into the future, trying to anticipate potential troubles that can be identified using this analysis and compare the strategies that have been driving the evolution of the metabolic pattern of EU28 and China and their implications; Section 6.4 provides a few reflections on the findings of this deliverable.

1.14 The implications of the difference in the demographic and socio-economic context

Even though economic models seem to assume that we can expect the same pattern of economic dynamics across different typologies of socio-economic systems, the analysis presented so far provides evidence for challenging this assumption. In our comparison it is evident that the two economies of EU28 and China are operating in socio-economic conditions quite different and demographic characteristics quite different. As a matter of fact the staggering difference in hours in Paid Work per capita per year – 730 in EU28 vs 1250 in China implies that when analyzing these two economies using indicators calculated per capita we are missing a huge elephant in the room. For example considering the values of nominal GDP p.c. for 2017 (IMF, 2018) we found 8,100 USD for China and 33,700 for EU. EU value is 4 times larger than the value of China. However, if we express these values per hour of work in the PW then we find a different picture 6.5 USD/hour of work in PW for China and 46.2 USD/hour of work in PW in EU. With this assessment EU value is 7 times larger. The difference between the message given by the two indicators (GDP p.c./year and GDP/hour of work in the PW sector average over the year) is quite significant and it is simply surprising that economic analysis tend to be based on quantitative indicators calculated per capita. In fact the choice of indicators per capita implies ignoring the implications of demographic differences and demographic changes.

There are at least two factors to be considered that are very relevant to understand the changes of an economy:

(i) the demographic structure, associated with life expectancy and fertility rates. The demographic structure is important because a high dependency ratio (e.g. in EU) – meaning a large fraction of the population outside the work force - reduces the potential supply of workers to be allocated to the activities of the PW. Moreover it implies also a large fraction of people requiring assistance in the form of both economic resources (for a large fraction of retired people) and hours of labor in the health care system and security. That is an ageing society faces an additional burden when coming to economic growth;

(ii) the level of welfare. A high level of welfare translates into a lower work load per year for the employed (which is associated with the reduced supply of workers in PW in an ageing society). Moreover a high level of welfare tends to increase also the number of unemployed. In fact, in a wealthy country nobody wants to accept long working hours and low pay. For example in the South of Spain and in the South of Italy where the level of unemployment is very high immigrants from Africa are needed to work in the agricultural sector, because the local unemployed would not accept this type of job.

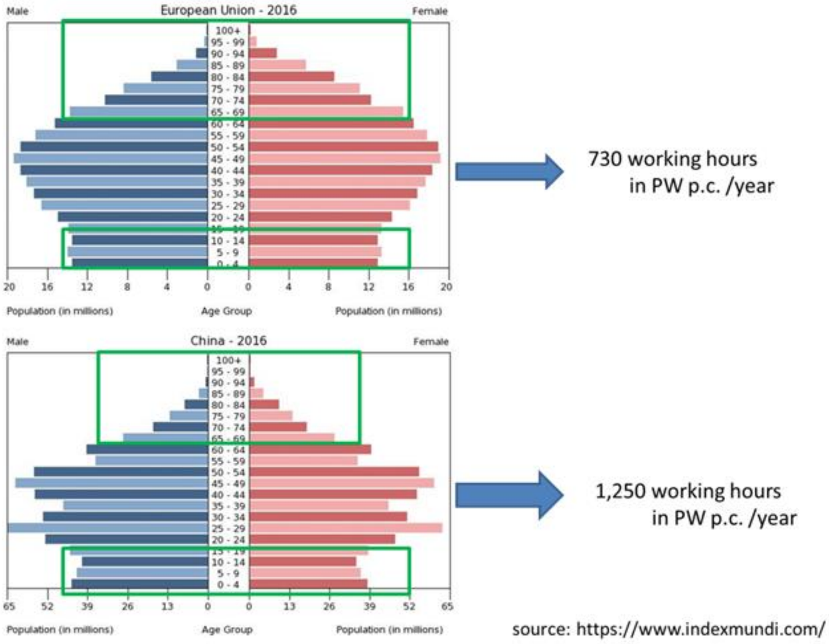


Figure 0-1 A comparison of the population pyramids of EU and China

The two population pyramids are shown in Figure 0-1 with the age classes in the dependent population highlighted in green boxes, we can see the larger mass of retired people on the top green box of dependent population. It should be noted that the difference in hours of work in the PW sector is not only dependent by the number of people in the work force but also by the different work load per year in EU (variable in different EU countries, but in general well below the 1,800 hours/year) and China (variable but often above the 2,400 hours/year).

Last but not least the demographic situation has a direct consequence also on the level of externalization. When the internal work supply is reduced and there is a growing non-negotiable requirement of hours of work in the service sector for the assistance of the dependent population, the externalization of working hours through import of goods becomes a fatal attractor (or in alternative immigration). The requirement of hours of work in the productive sectors can be easily externalized through importing goods produced elsewhere, whereas, when coming to services – taking care of people, health, education, public security, civil protection, media, running of institutions – it is almost impossible to externalize jobs.

1.15 How can we interpret changes in Europe and in China

1.15.1 Changes in Europe

The detailed analysis done in Chapter 2 and Chapter 3 are resumed quite well in the graph shown in Figure 0-2, Figure 0-3, Figure 0-4 and Figure 0-5. The plane in Figure 0-2 has "working hours in the subsectors of the industry" (horizontal axis) and "level of technical capitalization" indicated by the proxy variable Exosomatic Metabolic Rate per hour of work (vertical axis). The trajectories are indicated by the yearly movements of different disks in the period going from the year 2000 – 2016.

Figure 0-2 An overview of changes in EU28 at level n-3 – EMRi-HAipc in the PW sector without Services – 2000-2016 (bubble size reflects the size of ETi)

In Figure 0-2, we can appreciate that in the considered period EU has reduced employment and increased the level of capitalization per worker. However, even if this is difficult to see on the graph, the movement was not linear, because of the crisis several sector inverted the direction of change over the given trajectory.

The plane in Figure 0-3 is the same as Figure 0-2. The only difference is that the scale has been expanded in order to be able to include also the analysis of changes in the Service Sector.

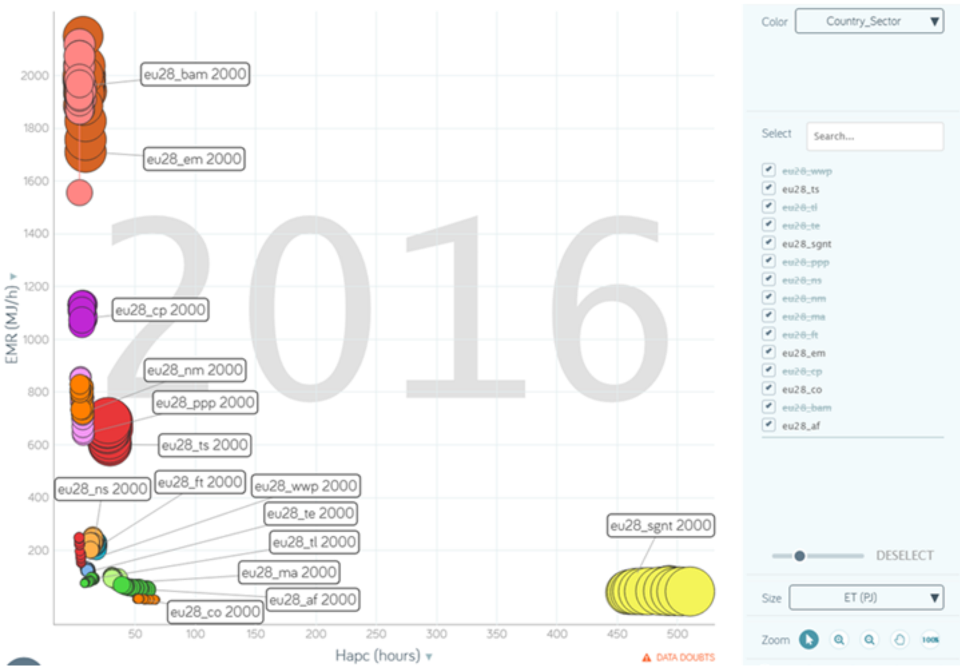


Figure 0-3 An overview of changes in EU28 at level n-3 – EMRi-HAipc – all the sectors together including the services – 2000-2016 (bubble size reflect the value of ET)

In Figure 0-3 we can appreciate two things. First, the difference in working hours between the service sector and the productive sector is so big that we had to enlarge the scale of visualization to observe the two patterns of change (inside industry and inside services). Second whereas the industrial sector shrinks in terms of employment (following the trends that reduced the agricultural and energy sector during the industrial revolution) the service sector keeps expanding steadily.

In Figure 0-4 we use a different plane with “working hours in the subsectors of the industry” (horizontal axis) and “economic job productivity” – i.e. GVA of the subsector divided the working hours in the subsector (vertical axis). Figure 0-4 is analogous to Figure 0-2 with EJP replacing EMR on the vertical axis.

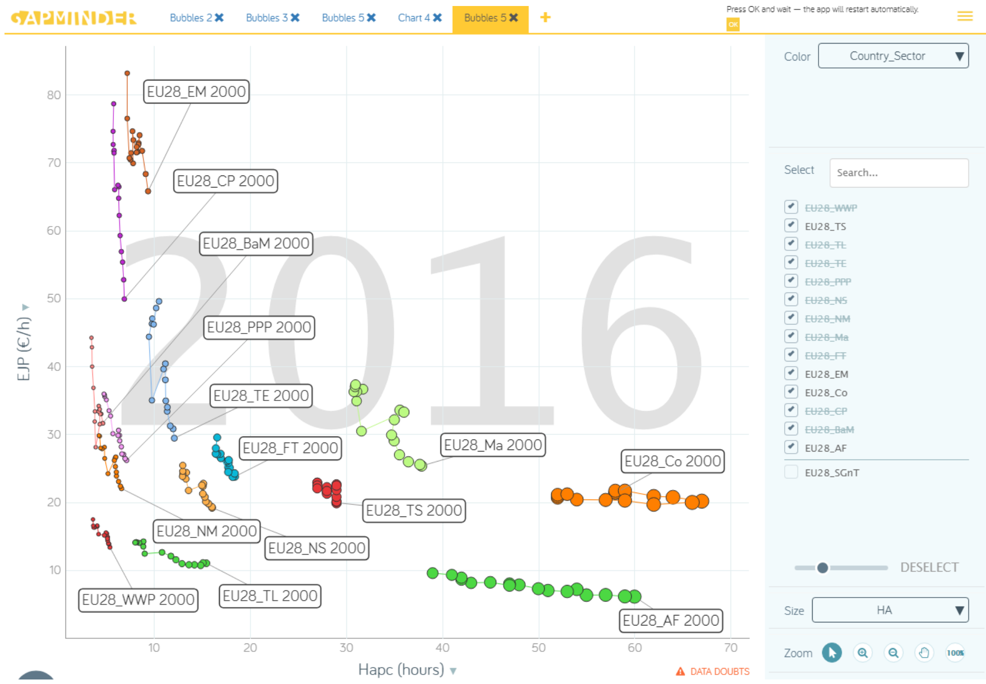


Figure 0-4 An overview of changes in EU28 at level n-3 – EJP-HAi (PW without Services) 2000-2016 (bubble size reflect the value of GVA)

In Figure 0-4 we can appreciate the economic view of the process of liquidation of the biophysical activities taking place in the EU economy. Those economic subsectors that cannot increase the EJP are simply liquidated: the energy sector, the agricultural sector, construction after the crisis, the textile sector.

The two axes of Figure 0-5 are the same as in Figure 0-4. The only difference is that the scale has been expanded in order to be able to include also the analysis of changes in the Service Sector. Therefore, Figure 0-5 is the analogous of Figure 0-3 with EJP replacing EMR on the vertical axis.

In Figure 0-5 we can appreciate that also in an economic view the subsectors inside the industrial sector become more and more insignificant in terms of working hours. This shrinking of the workforce is due to desperate attempt of increasing the level of EJP in order to survive the competition from the international market. On the contrary the Service sector keeps expanding both in working hours and in EJP.

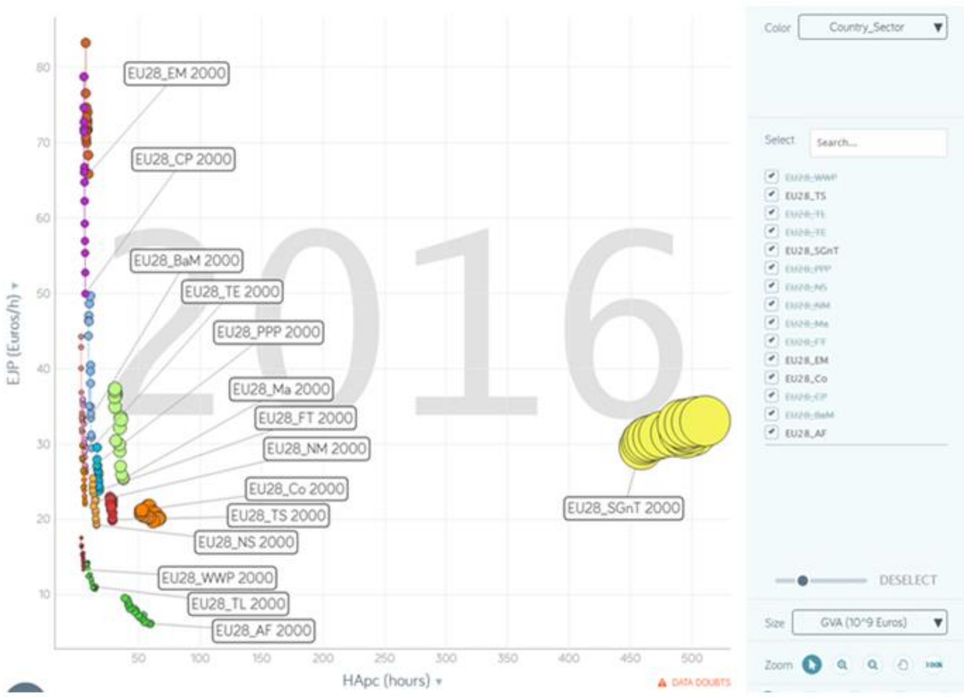


Figure 0-5 An overview of changes in EU28 at level n-3 – EJPi-HAipc – all the sector together – 2000-2016 (bubble size reflect the value of GVA)

1.15.2 Changes in China

As done in the previous section for EU we resume below the detailed analysis done in Chapter 2 and Chapter 3. Again we first provide an overview of the changes observed at the level n-3 of the sub-sector in the productive sectors (Figure 0-6) and the in the whole PW sector including both the productive sectors and the service sector in the same picture –Figure 0-7. Then we move to an analysis based on the adoption of an economic narratives and we repeat the analysis – by substituting the indicator EMR_i with the indicator EJP_i in the vertical axis: we first provide an overview of the changes observed at the level n-3 of the sub-sector in the whole PW sector including both the productive sectors and the service sector in the same picture –Figure 0-8.

In Figure 0-6 dealing with a biophysical view of the changes we can appreciate a clear difference compared with the trends observed in Figure 0-2. In fact different subsectors of the industrial sectors in China follow different trajectories. The majority of them increase in EMR, a few of them increase in terms of employment (e.g. Machinery, Transport Equipment), other first increase the working hours and then decrease them (e.g. Energy and Mining, Textile), other tend to maintain the original quantity of working hours by increasing the level of capitalization (e.g. Paper and Pulp industry, Basic Metal).

The enlarging of the picture in Figure 0-7 shows the relation of these changes with the changes taking place in the Service Sector. Looking on the lower right part of the graph we can see that the dramatic reduction of working hours in agriculture is directly related to the concomitant increase of working hours in the service sector. This view clearly shows that extremely low level of EMR when considering the 4 sectors: (i) agriculture; (ii) service sector (without transport); (iii) construction; and (iv) textile. Of these four, the service sector and the construction sector have been expanding and the other two shrinking in terms of working hours.

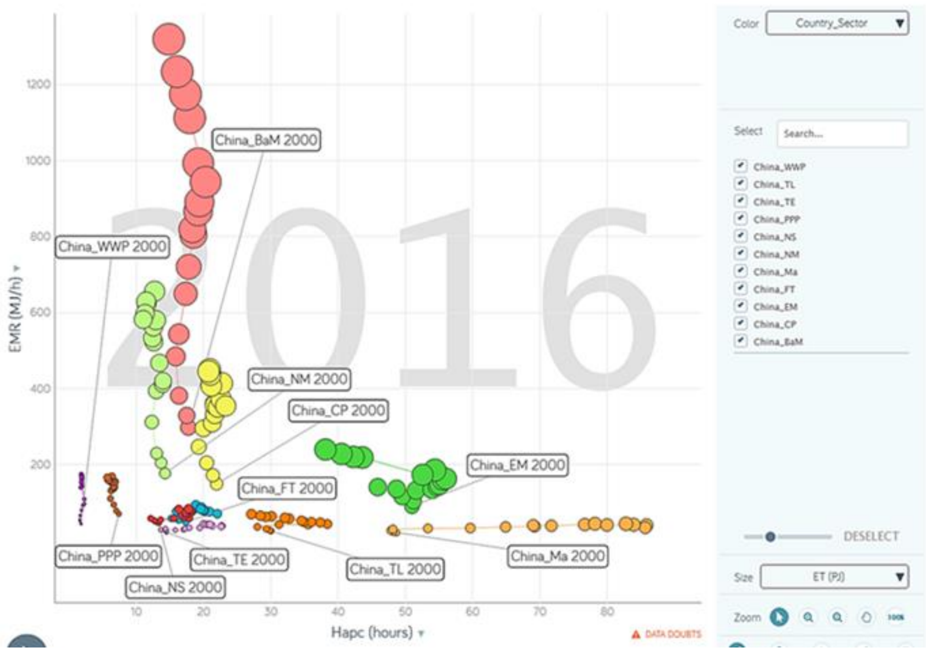


Figure 0-6 An overview of changes in China at level n-3 – EMR$_i$-HAi$_{pc}$ (PW without Services) 2000-2016 (bubble size reflect the value of ET)

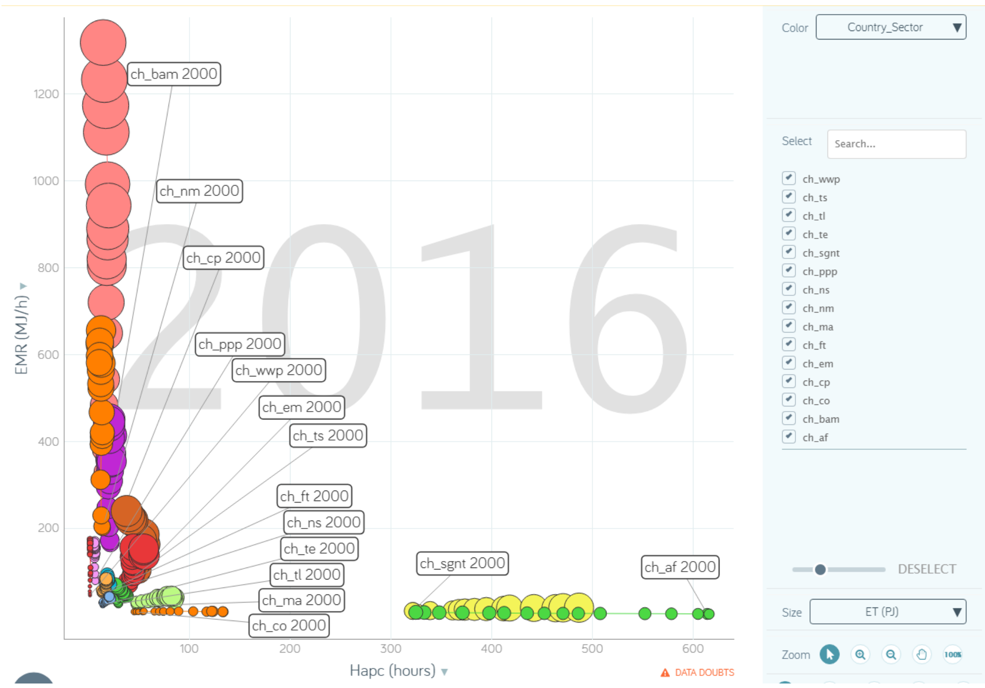


Figure 0-7 An overview of changes in China at level n-3 – EMR$_i$-HA$_{ipc}$ – all the sector together 2000-2016 (bubble size reflect the value of ET)

In the next figure (Figure 0-8) present the economic view of the effect of changes in relation to the same set of sub-sectors of the economy observed in Figure 0-6 and Figure 0-7 at the level n-3. In the case of China, we show a single graph with both the productive sectors and the service sectors, because in China we did not have the inversion of the trends, in the observed period, that took place in EU28.

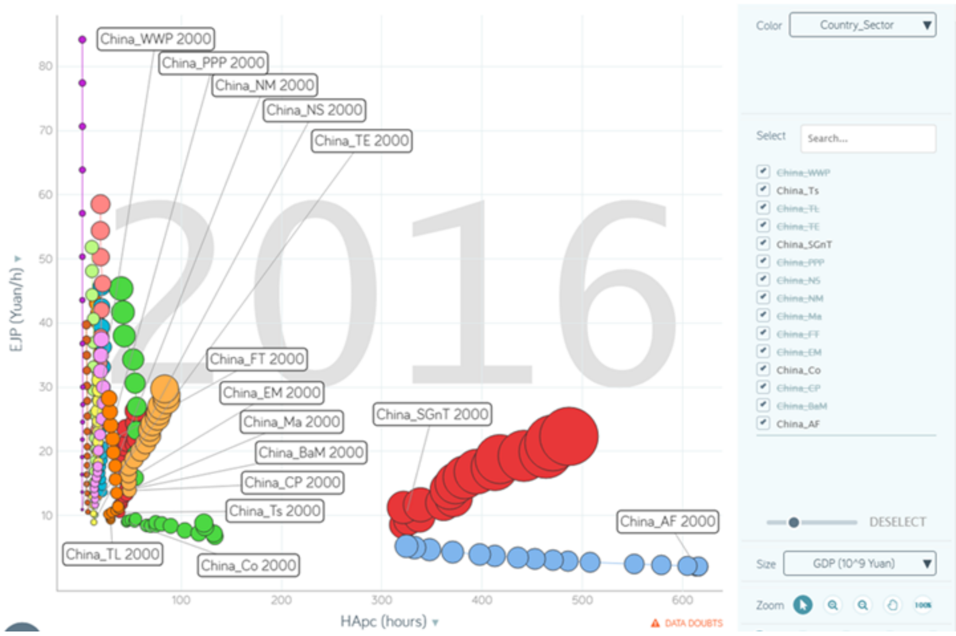


Figure 0-8 An overview of changes in China at level n-3 – EJP-HA$_i$ (PW without Services)

In Figure 0-8 we can appreciate the same a similar trend observed in Figure 0-7. The agricultural sector reduces its size in terms of hours of work to half of the original. Two sectors have a dramatic increase – service sector and the construction sector, whereas all the other sectors maintain their original level of working hours while increasing dramatically their EJP$_i$. It should be noted that the graphs of China have been generated using only three points in time and that the trajectory across the year has been generated by the software (gapminder) used in the visualization.

1.16 The two different strategies behind the different changes: anticipating potential troubles

After having observed the differences between the directions of changes of the various functional elements of the metabolic pattern of EU28 and China we can try to reflect on the implications of the evolutionary trajectory followed by the two economies.

1.16.1 China represents a kicking economy facing a tough reality but looking at the future

During the considered period, after joining the WTO, China had the option to enter the world competition with other economies trying to use as much as possible its comparative advantages – the supply of hours of work, a millenary skill of social organization and disciplined labor. When coming to economic growth, the size of China can represent a blessing, both in the short term as a buffer against external perturbations (guaranteeing a certain level of redundancy in the network of flows) and in the long term, when they will be capable of expressing a strong internal demand. However, the size of China can also represent a curse, when coming to the requirement of primary sources (energy sources, raw material, land) and primary sinks (problems of emissions and pollutions) because of the huge quantities of resources and environmental services needed to guarantee a continuous economic growth of the economy. In the period considered in this study we saw a standard pattern of economic growth. Priority was given to internal investments in the industrial sector (boosting thee export) while keeping in check the final consumption. This move made it possible to take full advantage of the comparative advantage given by the large supply of working hours in the PW sector while operating inside the WTO. When the economy got enough strength it became possible to play the bonus of credit leverage and expand the internal consumption to guarantee a domestic demand to the growing industrial sector. Looking ahead there are formidable challenges for the continuous growth of the economy. The boost to the work force obtained by the one-child policy will back-fire by generating a wave of old people in the economy, and for this reason the strict demographic control has been relaxed. The search for natural resources is on and China is trying to expand as much as possible its activities across different areas of the world (especially Africa and South America).

1.16.2 EU28 seems to be trapped in the past and not looking at the future: how smart is the idea of EU knowledge economy?

If we try to give a definition of knowledge economy we can say that it represents an economy capable of remaining ahead of the competition by preserving favorable terms of trade (selling products or services of high added value by limiting the stress on its own workers and on its own environment). This solution makes it possible for that economy to guarantee to its own citizens a material standard of living and a quality of the environment higher than the one experienced in other countries. However, the results presented here show the existence of *a dark side of the knowledge economy*. An economy specialized and exporting services, especially financial services, becomes more and more dependent on import for the energy, the food, and the products it consumes. Looking at existing megatrends (generated by the change in world population still growing and level of consumption per capita also growing) we should expect for the year 2050 an increase of 60% in the consumption of energy carriers and an increase of 50% of food products, and analogous increases in the categories of durable and consumable goods, without considering the skyrocketing requirement of services associated with improved welfare. Looking at the internal competition for production factors to be allocated both to produce and consume more in developing countries and to the fact that the availability and accessibility of primary resources is reducing quickly ("peak everything") it is very likely that the surplus of food, energy and consumable products that so far has guaranteed to EU the option of importing cheap commodities will disappear. Moreover, Europe is not a superpower in military terms that can guarantee to itself the access to resources with the force (as done during the time of colonialism). So far the solution to this growing challenge has been obtained with a strategy that has been called "Ponzi scheme economics". To illustrate this concept we can look at the data from a McKinsey report (McKinsey Global Institute, 2015) illustrated in Figure 0-9.

In the period going from 2007 (just before the starting of the first financial crisis) 2014 the increase of the GDP of the world was 38 trillion of USD whereas the increase of the credit leverage was 57 trillion of USD. In the list of countries with the largest external debts (obtained by summing private and public debt) 8 of the first 10 countries (the other two being USA and Japan) are historic members of the EU.

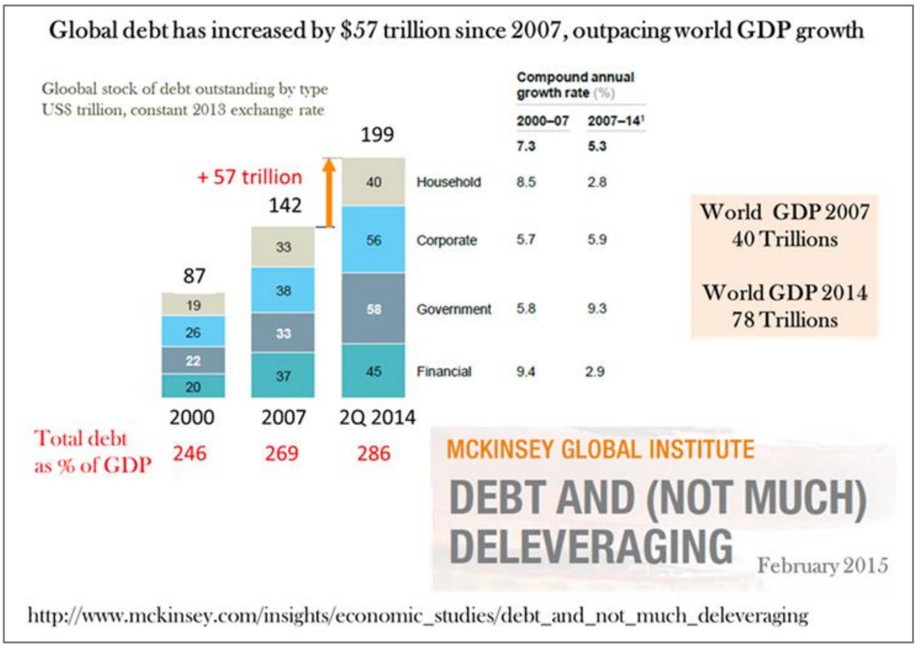


Figure 0-9 Changes in the level of credit leverage at the world level – 2000-2014 (McKinsey Global Institute, 2015)

As illustrated in the historic analysis of changes in Chapter 3 when looking at the economic variables the EU28 was able to avoid the biophysical effects of the 2009 crisis (the reduction of energy and use shown in Figure 0-12). So the "knowledge economy" concept delivered so far. However, this result was obtained by relying on a massive injection of "virtual money" (credit leverage and quantitative easing) helping the vitality of the economic process by boosting the activity of the financial sector. The possibility of using credit leverage to handle the effects of punctual crises is one of the major advantages associated with the constitution of the EU. However, it is obvious that this solution cannot be used to stabilize economic growth forever. Moreover, if prolonged in time this solution may imply dangerous side effects. Printing money is certainly easier than generating added value, but the consequent autocatalytic loop tends to amplify the activity of the financial sector (where the surplus of money can be handled easily) while shrinking the activity of the productive sectors (where biophysical constraints slow down the speed at which the money supply can be converted in a source of added value).

Looking at the trends of changes taking place in the metabolic pattern of EU we can simply observe that the actual strategy of economic growth is consistently dismantling all the economic activities related with biophysical processes –the actual production of energy carriers, food products and durable products- to move to what is called the knowledge economy. But looking at the future how smart is the move to the smart economy depending more and more on import for its consumption of food products, energy carriers and durable products? Even more important, do the EU policy makers have a clear picture of the amount of resources that what would be required to be self-sufficient?

1.17 The analysis of the metabolic pattern of social-ecological systems: future lines of research

The end use matrix developed and presented in the various deliverables of this work package is not a tool that can be used for checking the external constraint limiting the production of the secondary inputs used in the economy. The end use matrix can only identify, inside the metabolic pattern, who is using the various secondary inputs, why, how much and how. However, this information is essential in relation to two goals: (1) checking the internal constraints associated with the ability of establishing a dynamic equilibrium between (i) the required investment of human activity in consuming (the welfare of the households) and guaranteeing services; and (ii) the required investment of human activity in the productive sectors (the supply of energy carriers, food products and durable and consumable goods). The characterization given by the end use matrix provides a key input of information to study the viability of the dynamic equilibrium as illustrated in Figure 0-10. The requirement of hours in the dissipative parts of the society is determined by demographic characteristics and by the level of welfare associated with the size of the Service Sector and the mix of activities carried out in it (showed in the upper part of Fig. 5-10). When combining the two requirements of hours for the HH and the SG we can define an overhead of hours of human activity and other end uses that the socio-economic characteristics impose on the economy. This overhead implies that the rest of the economy (MC, AG and EM) have a limited endowment of hours of human activity (in the lower part of Fig. 5-10) to express the end uses needed to supply the requirement of energy carriers, food products and durable and consumable goods. The analysis of this constraint can be carried out using the tool of end use matrix.

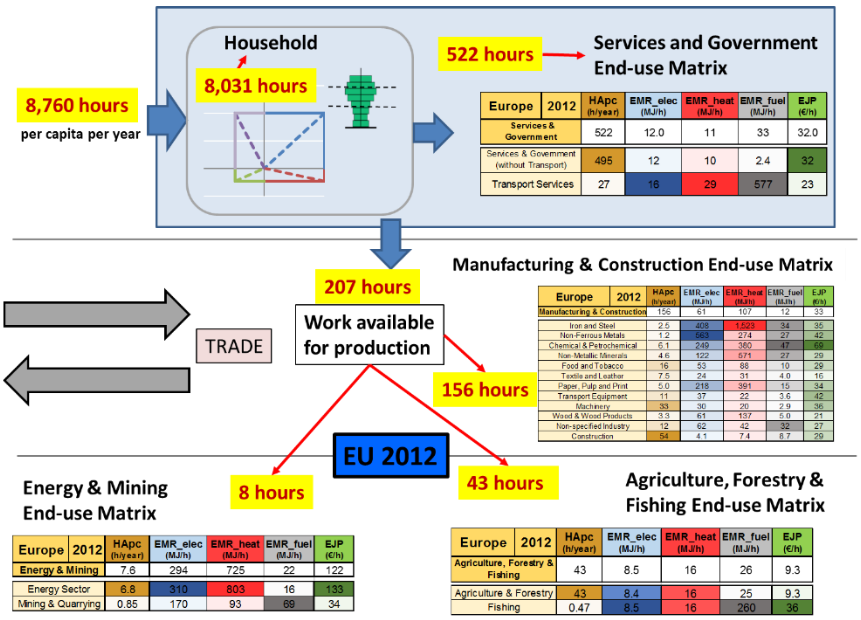
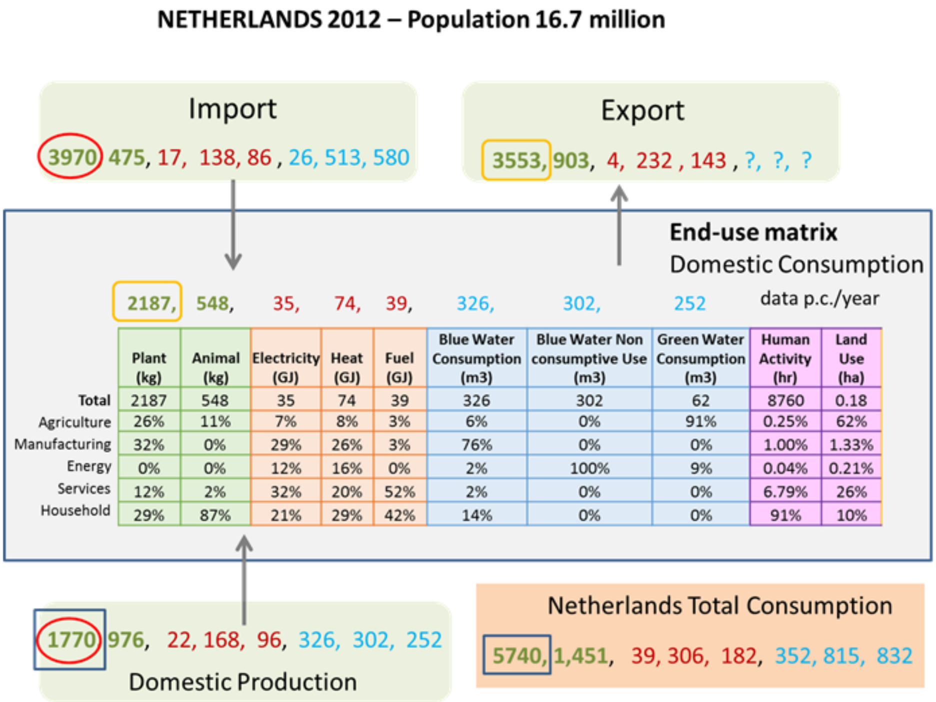


Figure 0-10 The factors determining the dynamic equilibrium of end uses in the dissipative sectors (upper part) and the productive sectors (lower part) in EU

(2) checking the external constraints associated with the availability and accessibility of the required primary sources of energy, food, water mapped in spatial terms. These primary sources are needed to guarantee a stable supply of these secondary inputs. This analysis needs a conceptual bridge capable of translating the information about the internal end uses of quantities of energy carriers, nutrient carriers, water carriers (described both per hour and per hectare of land use) into information about the different types of environmental pressures: the various requirements of primary sources and primary sinks. An example of this conceptualization is given in Figure 0-12. In this way it becomes possible to check the feasibility of proposed metabolic patterns both on the supply and the sink side of the economic process: the existence of external biophysical limits. This line of research is carried out at the moment in the EU project MAGIC - http://magic-nexus.eu/. It should be noted that if we adopt this type of analysis then we get a picture of "what is used by a given economy" (a combination of primary and secondary inputs) and "what is produced by a given economy" (what is the final use of the internal production) that is quite complex. This complexity is due to the high level of openness modern economies.



	Plant (kg)	Animal (kg)	Electricity (GJ)	Heat (GJ)	Fuel (GJ)	Blue Water Consumption (m3)	Blue Water Non consumptive Use (m3)	Green Water Consumption (m3)	Human Activity (hr)	Land Use (ha)
Total	2187	548	35	74	39	326	302	62	8760	0.18
Agriculture	26%	11%	7%	8%	3%	6%	0%	91%	0.25%	62%
Manufacturing	32%	0%	29%	26%	3%	76%	0%	0%	1.00%	1.33%
Energy	0%	0%	12%	16%	0%	2%	100%	9%	0.04%	0.21%
Services	12%	2%	32%	20%	52%	2%	0%	0%	6.79%	26%
Household	29%	87%	21%	29%	42%	14%	0%	0%	91%	10%

Figure 0-11 The end use matrix of the Netherlands - flows (food products, energy carriers and water uses) and funds (human activity and land uses) – and its relation to domestic consumption and production and imports and exports (Ripoll-Bosch and Giampietro, 2018)

In the case illustrated in Figure 0-11, the Netherlands in the year 2012, when considering only the plant food flow, we find that the Dutch economy: (i) consumes (in domestic consumption + export) 5,740 kg per person per year. That is more than 3 times what is produced in domestic production: that is 1,770 kg per person per year; (ii) exports 3,553 kg per person per year, twice more than it produces; (iii) imports 3,970 kg per person per year, more than twice what it produces. For each of the other flows (in the categories of food, energy and water) we can find a similar situation. How to calculate the efficiency of its economy when considering simultaneously this combined set of inputs and outputs? What if each one of the considered flows are affecting each other in an impredicative way? The use of the end use matrix makes it possible to combine information about: (i) the internal constraints associated with the dynamic equilibrium between end uses invested in consuming and in producing (Figure 0-10); (ii) the external constraints associated with the requirement of primary sources and primary sinks in the production processes generating the secondary flows (Figure 0-11); and (iii) the effect of trade on the feasibility, viability and desirability of the metabolic pattern by externalizing to other social ecological systems either the requirement of end uses or the requirement of primary sources and primary sinks (Figure 0-12).

The material presented in this deliverable suggests that an approach based on the analysis of the metabolic pattern can provide additional pieces of information to the discussion over sustainability. This alternative supply of useful information can be used to complement the information generated by Computable General Equilibrium models, when coming to the analysis of: (i) desirability (in relation to the material standard of living); (ii) viability (in relation to technical and economic aspects); and (iii) feasibility (in relation to external constraints outside human control).

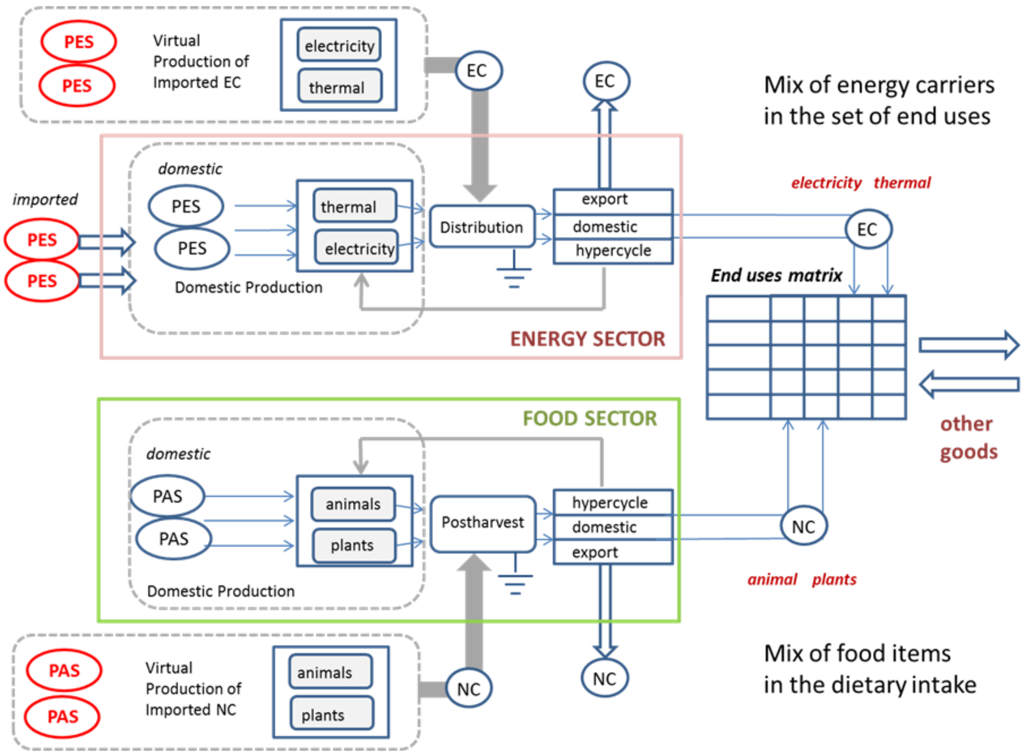


Figure 0-12 A scheme tracking the requirement of primary and secondary inputs embodied in the secondary inputs consumed in the end use matrix (PES – Primary Energy Sources; PAS – Primary Agricultural Sources)

1.18 Final reflections on the results of this deliverable

The authors of this deliverable are convinced that the adoption of the type of biophysical analysis of the economic process presented here –what Georgescu-Roegen called an analysis of the biophysical roots of the economy - would be very useful in complementing the information provided by more conventional approaches, such as Computable General Equilibrium Models. However, analysis based on the observation of biophysical characteristics of the functional parts of the economy (what Georgescu-Roegen calls fund-flow relations) has never been included in the modeling used for informing decision makers. Evidence based sustainability policies are still based on quantitative analysis generated by models that only look at flow-flow relations using prices.

As noted by many economists in the field of Ecological Economics – e.g. Herman Daly (Daly, 2017) - this type of models studying relations over heterogeneous flows cannot compare the size of the economy with the size of the resources required both on the supply side and the sink side of the metabolism. Therefore, according to Daly, these models, by default, cannot properly address the issue of sustainability. In relation to this point Daly explains also that the systemic avoidance of the use of biophysical analysis in the study of sustainability can be explained by ideological reasons. According to Daly, using bio-economic analysis would entail the infringement of three taboos influencing the production of scientific inputs to be used for governance in relation to the issue of sustainability. These three taboos are:

1. *avoid any analysis indicating the need of redistribution* – if one admits that there are biophysical limits to the expansion of the economy and that therefore perpetual growth is not possible, then with globalization we are dealing with a zero-sum game in terms of the use of available primary sources and primary sinks. This acknowledgement should be followed by a discussion on re-distribution of wealth: (i) within developed countries; and (ii) between developed and developing countries;

2. *avoid any analysis addressing the issue of population* – if one admits that we moved from an empty world to a full world (as suggested by Daly (Daly, 2005)) it is extremely important to develop narrative about sustainability in which the implications of the factor population - both in relation to the size and the demographic structure - should always be considered. This is an issue extremely complex in practical, political and ethical terms. However, ignoring the issue will not improve our ability to handle it;

3. *avoid any analysis indicating that the level of welfare enjoyed by urban dwellers in developed societies is not sustainable* – if one admits that there are biophysical limits and that the material standard of living promised by consumerism *is not achievable by the whole population of this planet*, and it may not even be maintained in the future due to peak everything (we arrived to what Daly calls a "full world"), we should start re-discussing our definitions and policies about the quality of life.

We believe that the results of the analysis provided in the previous chapters support the point made by Daly about the urgency of complementing the conventional modeling approach based on economic narratives with alternative approaches based on biophysical narratives. According to what presented in this deliverable addressing the three issues missed by the conventional approach to energy modeling would be essential for deliberating more effective policies in relation to sustainability.

There is an additional point explaining the resistance to the adoption of new forms of bio-economic analysis suggested by Guimarães-Pereira and Funtowicz (Guimarães Pereira and Funtowicz, 2015). Acknowledging the complexity of the set of relations operating in the metabolic pattern of economies would imply rejecting the Cartesian dream of prediction and control associated with science. When considering the nexus between energy, food, water, land uses, ecological services, across different scales and dimensions, both for individual countries and for the whole planet, there is no possibility of even dreaming the finding of optimal solutions (optimal for whom?, for how long?, at which cost?, who will pay?). Unfortunately, in the existing institutional settings it is simply not possible to admit that we do not know how to deal with the existing sustainability predicament. It is simply not possible to say that our societies will undergo "*a radical transformation of their metabolic pattern that will end up in "something" that we cannot imagine now and that we can only control this transformation in a minimal par*t".

The result of this impossibility is an official story telling that it will be possible to have in less than 30 years "*a transition toward a society functioning exactly like this one in relation to the consumption pattern, but with lower emissions, more justice and peace*". In order to try to support this story telling with models it becomes essential to use models capable of totally missing the complexity of the issue.

Even after acknowledging the unavoidable existence of a strong institutional inertia, we firmly believe that it would be important to expand the set of scientific analytical approaches used to inform policy. The current models based on economic narratives are useful for identifying optimal strategies for reaching future states selected because of their desirability. However, it would also be important to complement these models with other types of quantitative analysis capable of checking whether the proposed desirable states are both feasible (according to external constraints) and viable (according to internal constraints). The quantitative analysis presented here belongs to this second family of models.

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Appendix 1: Complementation between Linda model (D8.2 and D8.4) and MuSIASEM in the energy analysis of China: the link between WP4 (D4.4) and WP8

In this section we present a reflection on the complementarity of the analysis of the energy efficiency of China developed in WP8 applying the LINDA model and in WP4 applying MuSIASEM.

As discussed in previous deliverables several systemic epistemological challenges can be associated with the analysis of the energy efficiency of an economy (Velasco-Fernández et al., 2018). One of the crucial issues is the distinction between the structural and the technological effects over the total energy consumption in an economy. This issue requires the adoption of an accounting method capable of detecting the different influence of; (i) changes in the mix of economic activities (e.g. the relative contribution to the GDP of agriculture, industry or services) and (ii) changes in the performance of technologies (e.g. the specific technical coefficients of specific production processes) – on the overall energy consumption of the economy. This is crucial when using the economic energy intensity (a simple ratio of two quantities: Joules/GDP) as an indicator of energy efficiency – the approach used in WP8. In the deliverables 8.2 *Impacts of Main Economic Sectors on Energy Efficiency in the period 2015-2030 in China* (Chen et al., 2016) and 8.4 *Provincial energy efficiency analysis in China* (Vehmas and Alexeeva, 2017) the China-LINDA model is applied to a five-sector division for analyzing the structural shift towards service-oriented economy. The same model is also applied to 24 sectors realizing a structural decomposition analysis looking for isolating the effects of technological improvements over the total energy intensity of the economy. Additionally, in D8.2, the analysis at the provincial level provides a regional analysis capable of capturing lower effects on the energy performance of China.

MuSIASEM analysis has been applied to China at similar sector levels: n-2 considering 5 economic sectors (agriculture, industry, construction, service & government and transport); and at n-3 considering 11 subsectors (see figure xx). Unfortunately, MuSIAEM accounting could not disaggregate so much in geographic terms due to lack of data required and it has been just applied to country level. However, MuSIASEM analysis bring an alternative epistemic conception of the performance of the economy that complement the structural and technological effects observed in WP8. While China-LINDA model considers the size of the sector by the relative size of their GDP, MuSIASEM accounting look the size of fund elements (human activity in this case). From both analysis, one can see that Chinese economy has experimented a structural shift to service sector activities increasing GDP and human activity per capita in this sector. Additionally, MuSIASEM analysis shows that this structural change has been done with a great capitalization of the industrial sector (EMRs increase) that have nothing to do with the efficiency of the economy ("better" technology) but rather with the replacement of work by machinery. Thanks to the decomposition analysis, one could see how this structural shift affects the total energy consumption.

On the other hand, MuSIASEM analysis avoid the use of economic energy intensity as indicator of efficiency due to the poor quality of the information that this indicator brings at the country level (Fiorito, 2013). The problems with the energy intensity indicator as a measure of efficiency rely on the strong correlation between energy consumption and value-added generation. Consequently, we can find similar economic energy intensity values when analyzing one process consuming a lot of energy and generating a lot of value-added and another consuming little energy and producing little value-added. In order to avoid these misinterpretations, MuSIASEM use the fund-flow scheme introduced by Georgescu-Roegen (Georgescu-Roegen, 1971). In this way, MuSIASEM analysis can identify the capitalization effects and contextualize the energy performance of an economy accordingly (see more details in Data and Methods, section 2).

In relation to energy accounting, China-LINDA model distinguishes between Total primary energy supply (TPES) and Final Energy Consumption (FEC). On the contrary MuSIASEM accounting distinguish between: (1) Primary Energy Sources (PES) out of human control; Gross Energy Requirement (GER) expressed in virtual joules of thermal equivalent through the partial substitution method, (2) when coming final energy consumption MAGIC uses an account based on Energy Carriers (EC) maintaining an accounting differentiated by energy qualities (electricity, process heat and fuel); and (3) Energy End Uses (EU), which indicates useful tasks generated by the consumption of energy carriers. Thanks to this distinction, MuSIASEM accounting maintain information in relation to the availability of resources (feasibility), the process generating energy carriers in the energy sector (viability) and consuming them in the other compartments of the society (desirability) that is crucial when developing energy policies (Giampietro et al., 2013). However, in the current study we just analyze energy in GER, EC and EU form. On the other hand, in 8.2 and 8.4 there is an analysis of CO_2 emissions, while in the application of MuSIASEM presented in this deliverable we do not assess emissions.

Finally, in the current study we also address the externalization (outsourcing) effects that trade generates over the energy performance of a country (section 5). For doing that, we have accounted the embodied resources (human activity and energy carriers consumption) associated with imported and exported products between China and Europe. It should be noted that the same approach could be extended to the assessment of externalized GHG.

As one can see, the complementation between LINDA and MuSIASEM brings pluralism to the efficiency narrative conception. In that sense, while LINDA model follows decomposition analysis based on energy intensity as efficiency indicator, the MuSIASEM approach identifies different problems of this conception and develops a set of tools for addressing these issues: the End-use Matrix, the fund-flow decomposition and externalization accounting.

Appendix 2: embodied energy carriers in trade

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1.19 Embodied quantities of Energy Carriers, divided by type, in the bilateral trade between EU and China – at the level of the whole economy

In the case of ET, there are no data on the energy carriers' consumption of Rest of the World. Thus the results don't include imports and exports of RoW, even though the exports to RoW could be included. This way, the only analysis in this section will be that of the relation between EU and China. It has to be taken into account that the EC to produce electricity are not included in the accounting.

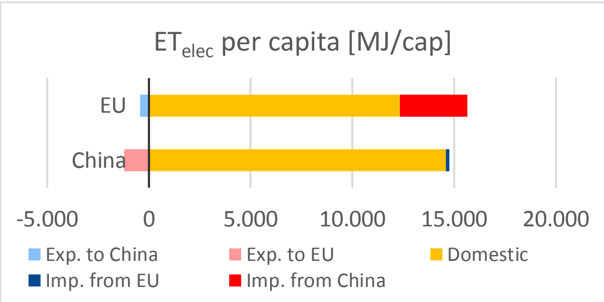

Figure 0-1 $ET_{electricity}$ per capita embodied in trade for EU and China in 2012 [MJ/cap]

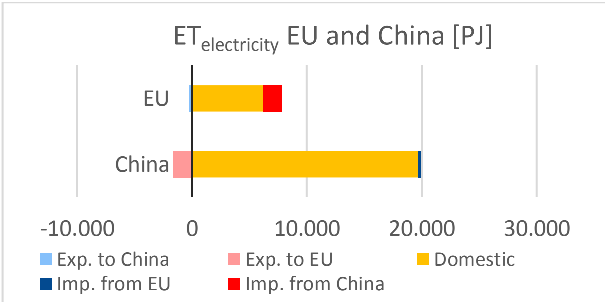

Figure 0-2 Total $ET_{electricity}$ embodied in trade for EU and China in 2012 [PJ]

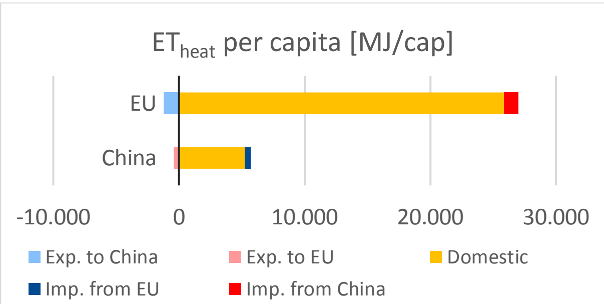

Figure 0-3 ET_{heat} per capita embodied in trade for EU and China in 2012 [MJ/cap]

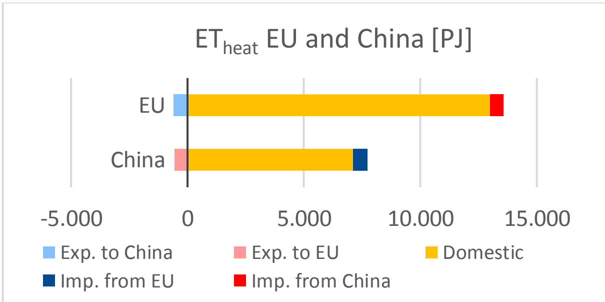

Figure 0-4 Total ET_{heat} embodied in trade for EU and China in 2012 [PJ]

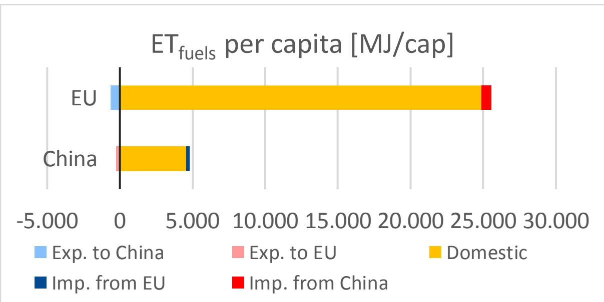

Figure 0-5 ET_{fuel} per capita embodied in trade for EU and China in 2012 [MJ/cap]

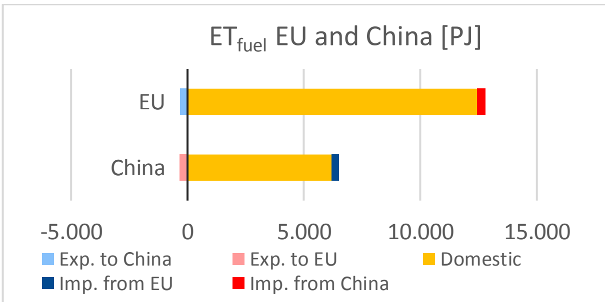

Figure 0-6 Total ET_{heat} embodied in trade for EU and China in 2012 [PJ]

At the first sight, we can see that EU consumes more ET_{heat} and ET_{fuel} both in absolute numbers (Figure 0-4 and Figure 0-6) and per capita (Figure 0-3 and Figure 0-5), while China consumes more $ET_{electricity}$ overall (Figure 0-2), but not per capita (Figure 0-1). Imports and exports are not very significant, the higher % of embodied ET in the consumption is that of $ET_{electricity}$ for EU

(21.1% of the ET_{elect} of consumption of EU is embodied in Chinese exports). The other values lie between 1.1%, $ET_{electricity}$ for China (1.1% of the $ET_{electricity}$ of consumption of China is embodied in European exports), and 7.8%, ET_{heat} for China.

Table 0-1 Share of the ET embodied in Imports to China and EU in relation to their respective domestic production ET consumption for the 3 EC [%]

	Electricity	Heat	Fuels
China	1.1%	8.5%	5.0%
EU	26.7%	4.4%	2.8%

When analyzing per sub-sectors, we can see that the largest share of $ET_{electricity}$ embodied for EU comes from imports from Chinese Industry (37.5% of the consumption of $ET_{electricity}$ for EU in Industry is embodied in exports from Chinese Industry). The largest difference in the two regions is that the share of $ET_{electricity}$ consumed in Services without transport is way lower in China.

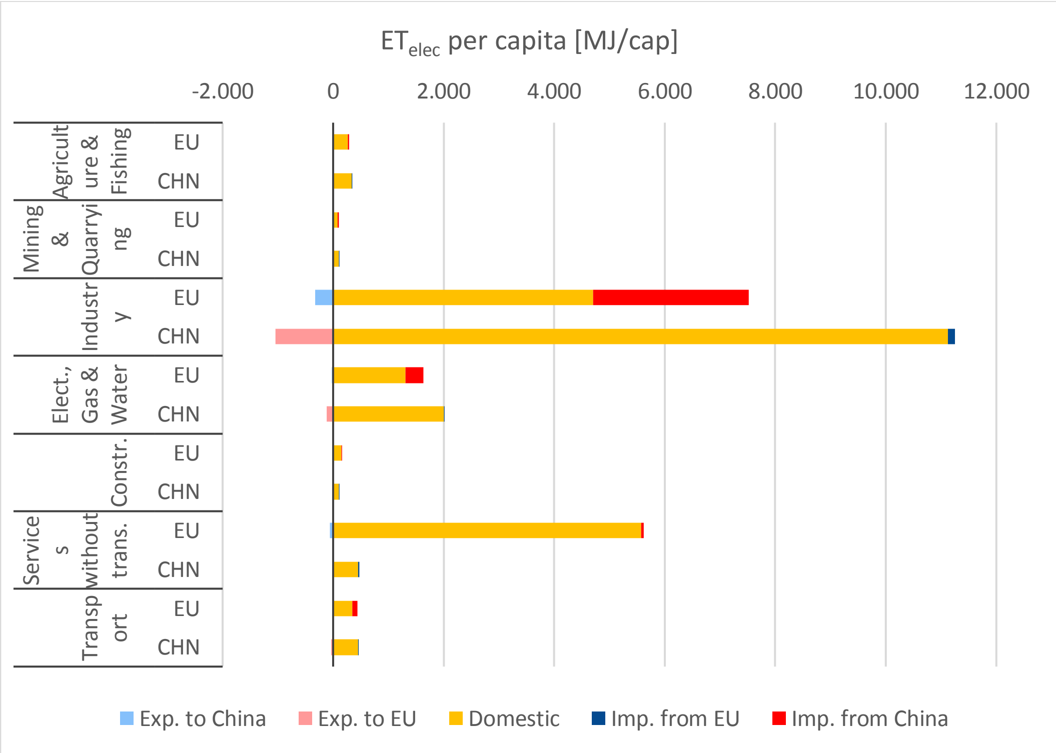

Figure 0-7 $ET_{electricity}$ per capita per sub-sectors embodied in trade for EU and china [MJ/cap]

In the case of ET_{heat}, the EU consumes more in Industry and Services without transport even in absolute numbers. Industry is the sector with the more significant trade of embodied ET. However, the balance is almost negligible.

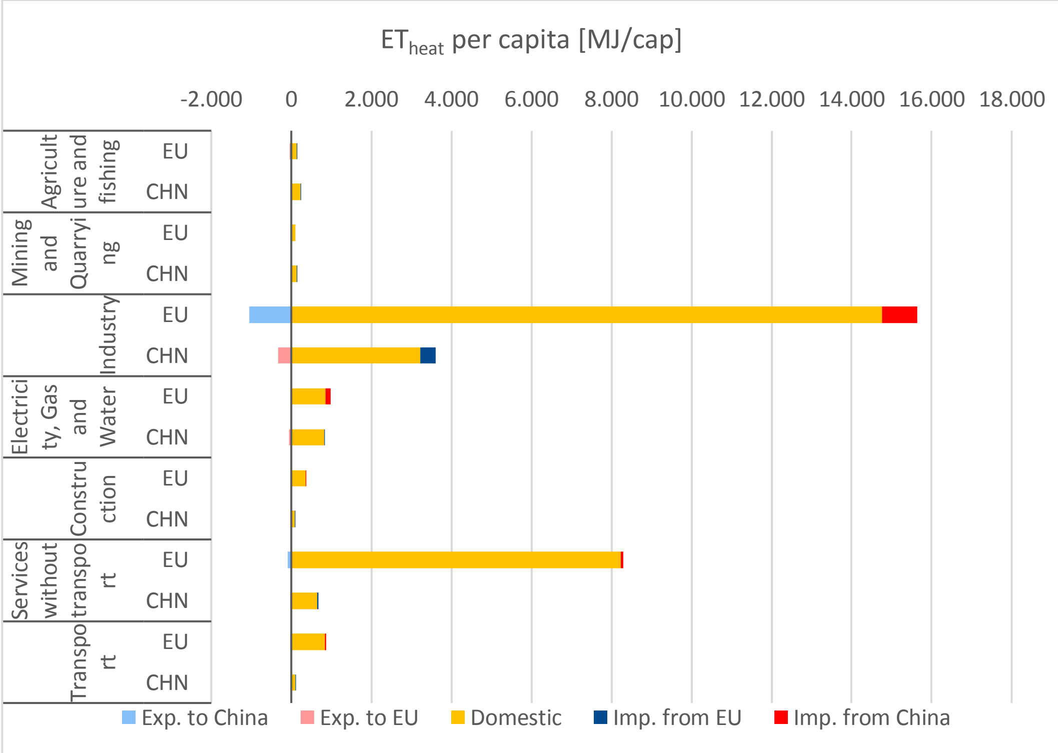

Figure 0-8 ET_{heat} per capita per sub-sectors embodied in trade for EU and China [MJ/cap]

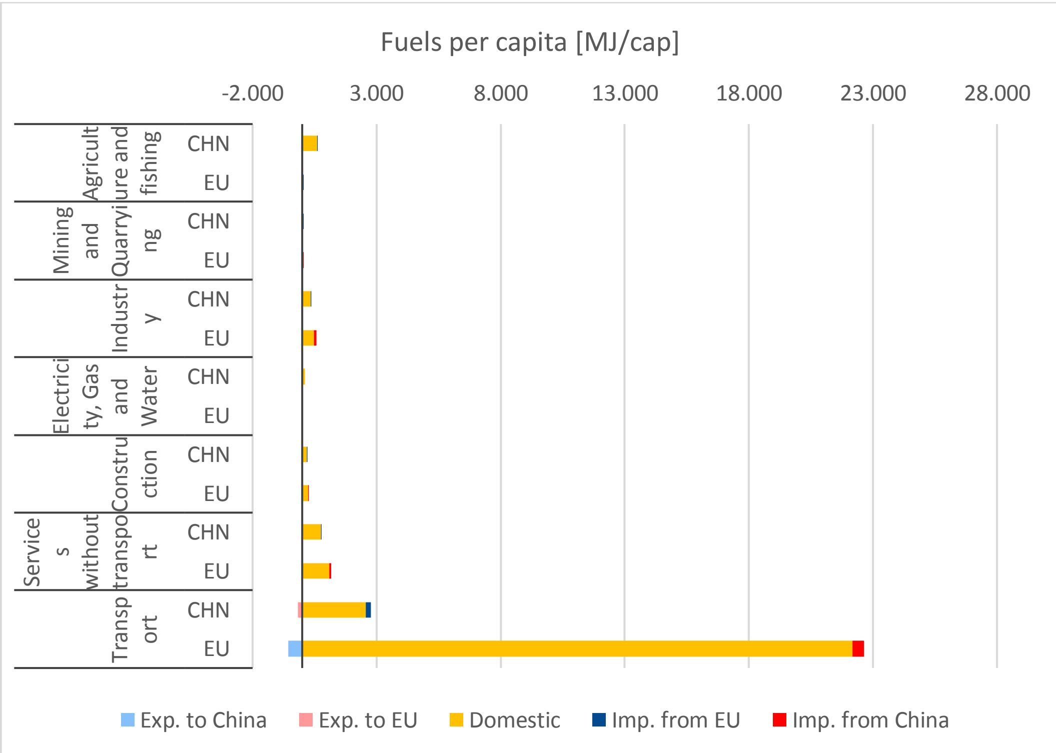

Figure 0-9 ET_{fuel} per capita per sub-sectors embodied in trade for EU [MJ/cap]

1.20 How the various EMR_i would change if we included embodied resources in the accounting

When analyzing the metabolic pattern of societies in the MuSIASEM framework, an important indicator that allows comparison is the Exosomatic Metabolic Ratio (EMR). The analysis of the comparison for China and EU has been extensively analyzed in the chapters 0 and 0. After having analyzed the embodied HA and ETs in trade, we can calculate a virtual EMR with the effective embodied resources used in the consumption, only including trade between China and EU. This is, we are only including part of what would be a consumption-based EMR. The results are shown in Figure 0-10 (EMR_{elect}), Figure 0-11 (EMR_{heat}) and Figure 0-12 (EMR_{fuel}).

EU shows a more energy-intensive pattern for the three energy carriers, relying more on machinery and less on HA. Logically, the EMRs including embodied resources tend to converge, with a general decrease of EMRs of EU. This is, the imports are more important for embodied HA than for ET. The changes in EMR for China are barely visible in general. As we have seen in the last sections, the imports from EU to China both in HA and ETs are not significant, and, thus, the EMRs for China remain practically constant. The contrary happens for EU, for which the imports from China are substantial in Mining and quarrying, and Industry. Therefore, the largest changes in EMR_{elect} and EMR_{heat} are for some of their sub-sectors: Mining and quarrying, Wood and paper, Petroleum, chemical and non-metallic mineral products, and Metal products, electrical and machinery.

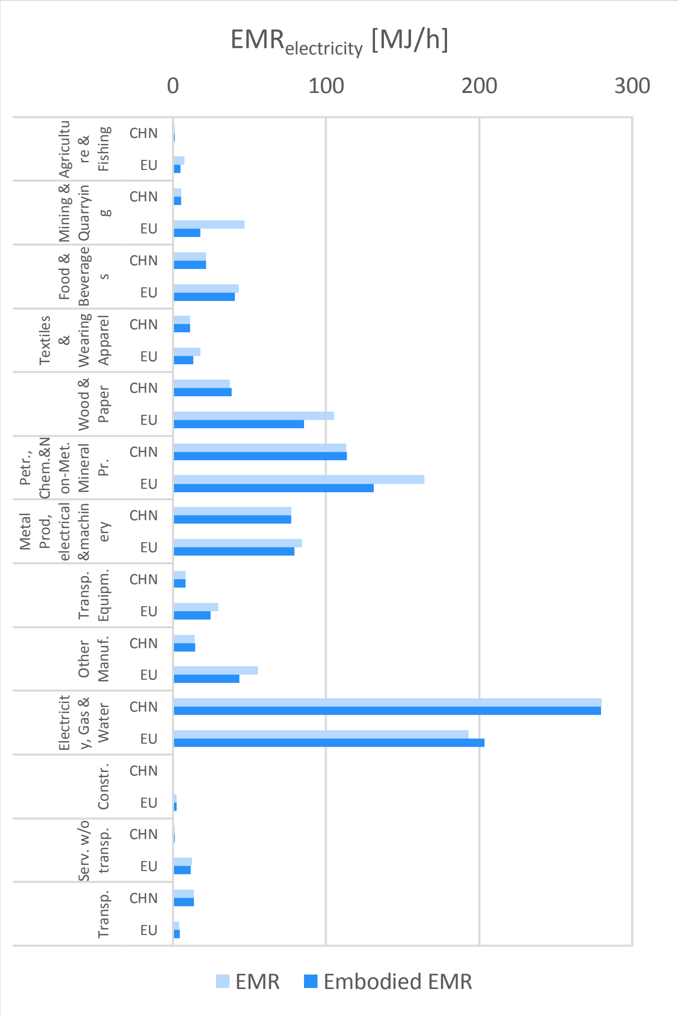

Figure 0-10 EMR_{elect} and embodied EMR_{elect} for China and EU [MJ/h]

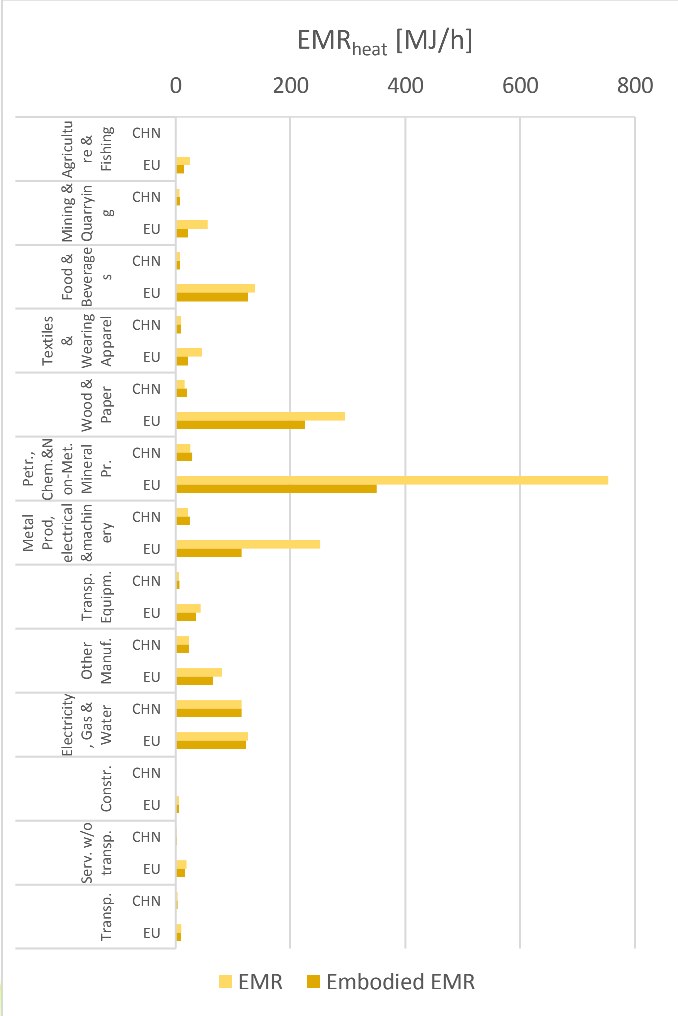

Figure 0-11 EMR_{heat} and embodied EMR_{heat} for China and EU [MJ/h]

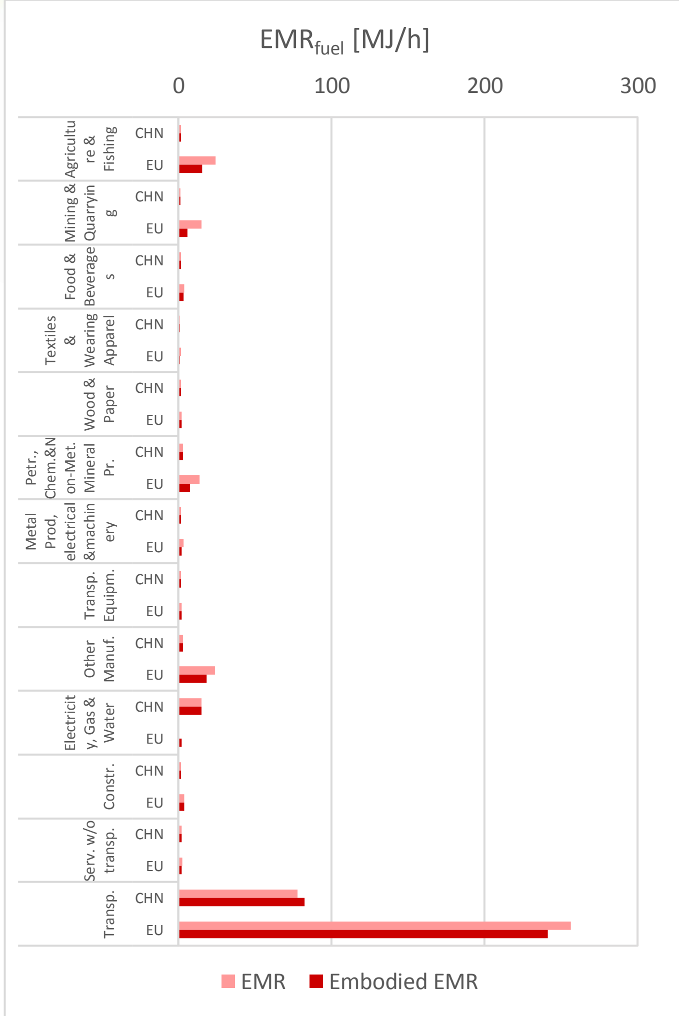

Figure 0-12 EMR_{fuel} and embodied EMR_{fuel} for China and EU [MJ/h]

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