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Applications of the MuSIASEM approach to study changes in the metabolic pattern of Catalonia

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ABSTRACT

This document presents an integrated analysis of the performance of Catalonia based on an analysis of how the ***energy consumption*** (measured at the societal level for the Catalan Society) is used within both the productive sectors of the economy and the household, to generate ***added value, jobs, and to guarantee a given level of material standard of living to the population.*** The trends found in Catalonia are compared to the trends of other European Countries to contextualize the performance of Catalonia with respect to other societies that have followed different paths of economic development.

The first part of the document consists of the Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) approach that has been used to provide this integrated analysis of Catalan Society across different scales (starting from an analysis of the specific sectors of the Catalan economy as an Autonomous Community and scaling up to an intra-regional (European Union 14) comparison) and across different dimensions of analyses of energy consumption coupled with added value generation. Within the scope of this study, we observe the various trajectories of changes in the metabolic pattern for Catalonia and the EU14 countries in the Paid Work Sectors composed of namely, the Agricultural Sector, the Productive Sector and the Services and Government Sector also in comparison with the changes in the household sector. The flow intensities of the exosomatic energy and the added value generated for each specific sector are defined per hour of human activity, thus characterized as exosomatic energy (MJ/hour) (or Exosomatic Metabolic Rate) and added value (€/hour) (Economic Labour Productivity) across multiple levels.

Within the second part of the document, the possible usage of the MuSIASEM approach to land use analyses (using a multi-level matrix of categories of land use) has been conducted

Keywords: integrated analysis, societal metabolism, metabolic profiles of countries, energy analysis, multi-scale analysis, sustainability, Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), sustainability indicators

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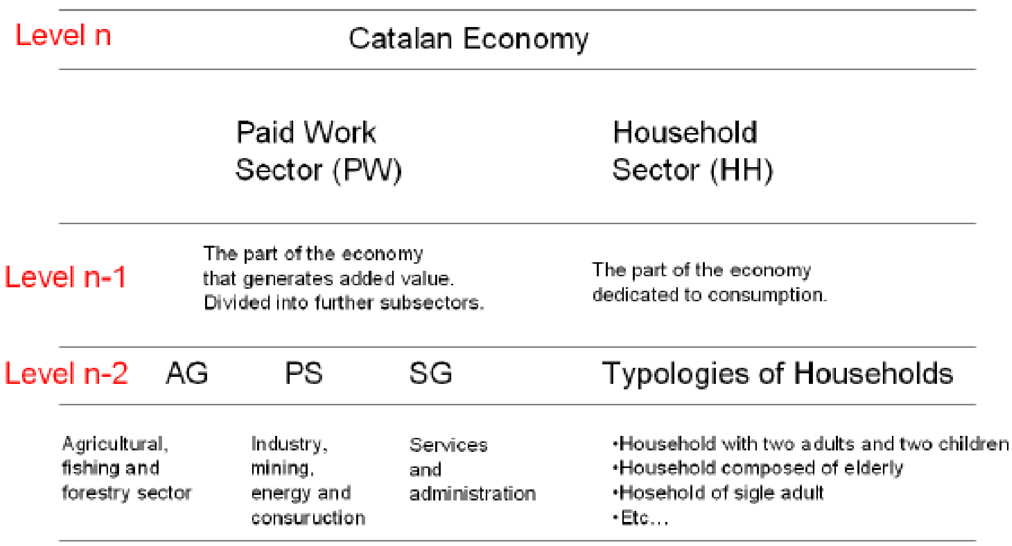
PART 1 - Using the MuSIASEM approach to compare the trajectory of economic development of Catalonia to that of other EU countries

1. The application of MuSIASEM

The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) is a method which allows us to analyze the pattern of production and consumption of goods and services (associated with a given level of economic development) simultaneously across different levels of analysis and in relation to different dimensions of analysis (demographic, economic, technical, ecological).

In particular in this document we focus on the factors determining the energy intensity of an economy and an overall comparison of the changes that took place in the period 1990- 2005 in the metabolic pattern of Catalonia in relation to that of 14 EU countries (the EU15 minus Luxemburg). The European comparison of changes in energy intensity is performed simultaneously across hierarchical levels (the whole, the parts at level n-1, the parts of the Paid Work sector at level n-2). The two factors determining the energy intensities are: (i) energy flow per hours of human activity; and (ii) added value generation per hour of human activity. In relation to the theoretical frame of MuSIASEM, we uses in this analysis as FUND for the multi-level matrix the variable hours of human activity (the flow intensity of both energy and added value are defined per hour of human activity). The two relevant FLOWS considered in the definition of the energy intensity of the economy (MJ/€) are: (i) exosomatic energy (expressed in MJ); and (ii) added value (expressed in €). That is, we characterize the two flows of exosomatic energy (MJ/hour) and added value (€/hour) against a multi-level matrix of human activity - across multiple levels (Fig. 1):

Fig. 1 – The Multi-Level Matrix of the FUND human activity over 3 levels (n → n-2)



As illustrated in Fig. 1 the three different levels considered in this matrix are:
(1) the whole society (with the label SA – Societal Average)– defined at the *level* ***n***;

(2) the hierarchical level at which we divide: (i) the consumption side of the economy – the Household sector (with the label HH) versus (ii) the production side of the economy – the Paid Work sector (with the label PW) – at the *level **n-1***; and
(3) the hierarchical level at which we individuate 3 sub-sectors of the Paid Work in the economy: (i) AG – Agriculture; (ii) PS - Productive Sectors; and (iii) SG - Service and Government – at the *level **n-2***.

By adopting the MuSIASEM approach it is possible to scale-up or down the quantitative analysis of energy intensity (MJ/€) of the economy across these three levels by establishing a link between the values of benchmarks characterizing the performance of these different elements at different hierarchical levels.

In this way, we can explain the characteristics of the whole economy of Catalonia (e.g. total GDP, Total Energy consumption, energy intensity) defined on the focal *level **n*** as determined by the characteristics (e.g. GDP generated by PW, Sectoral Energy consumption, energy intensity of PW) and the relative size of the two lower level compartments (HH and PW) defined at the *level **n-1***. Then, using the same approach we can explain the characteristics of the productive side of the economy – the PW sector – as determined by the typical characteristics (e.g. sub-sectoral GDP, sub-sectoral Energy consumption, sub-sectoral energy intensity) and the relative size of the three lower level compartments (AG, PS and SG) - defined at the *level **n-2***. It should be noted, that when considering the consumption of the flows of energy all the compartments do express a rate of consumption of energy per hour of human activity (both on the consumption side – HH- and on the production side – PW), whereas, in relation to the generation of added value, only the PW sector is performing this activity.

That is, in this system of accounting the generation of added value is considered to take place over three sub-sectors of PW: (i) the Agricultural Sector (including, agriculture fishing and forestry); (ii) the Productive Sectors (including industrial activities, mining, energy and construction); and (iii) the service and governance sector (primarily composed of the public and private services and administrative activities). The household category is not directly linked to the generation of economically added value, even though it is essential in determining the allocation of human activity, and determining the energy flows associated with the activities performed outside the PW sector.

The analysis of Catalonia covers the time period of 1990-2009, whereas the comparison with EU countries covers the time period 1992-2005. The values of the FLOWS variables (added value and energy) is taken from statistics, whereas the multi-level matrix of the FUND human activity is calculated per each year as follows: the total amount of human activity [THA = population x 8,760] is expressed in hours per year, and then this amount of hours is allocated over the various compartments defined across the levels (according to the scheme provided in Fig. 1). The same set of categories is used to account for the flows of energy and added value. In this way, it becomes possible to define "intensive variables" (amount of flow per unit of human activity in each chosen category), which can be used to characterize and study metabolic changes within the Catalan Society. The choice of the categories used for the compartments determining the multi-level matrix is based on different functions associated with human activity. The categories used in the multi-level matrix and the relative assessments of energy and added value flows are illustrated in the scheme given in Fig. 2.

This set of expected categories which does entail a set of expected relations over the numerical values assigned to formal categories is called a "grammar" (see Reports on Environmental Sciences – 2009#1).

Fig. 2 The categories used to define FLOWS over the multi-level matrix of the FUND human activity – the grammar used to characterize the metabolic pattern of society

Acronym	**Variable**	**Explanation**	**Unit & Calculation**
THA ***(FUND)*** (level n)	Total Human Activity	Total Hours of Human Activity for a society	Hours (hrs)/year - Total Population time 8,760 hours
HA_{PW} HA_{HH} (level n-1) HA_{AG} HA_{PS} HA_{SG} (level n-2)	***Hours of Human Activity*** PW in the Paid Work Sector HH in the Household sector AG in Agricultural Sector PS in Productive Sectors SG in Service&Government	The sum of hours spent in the relevant sectors	Hours (hrs)/year - Total hours of work within each sector (Average hours of work per week* number of working weeks per year * number of people in each sector)
TET ***(FLOW)*** (level n)	***Total Energy Throughput***	Total Primary Energy Supply for an economy for one year	Megajoules (MJ) – Total Primary Energy Supply of Catalunya
ET_{PW} ET_{HH} (level n-1) ET_{AG} ET_{PS} ET_{SG} (level n-2)	***Energy Throughput*** PW in the Paid Work Sector HH in the Household sector AG in Agricultural Sector PS in Productive Sectors SG in Service&Government	The sum of all the energy flowing into the relevant sectors	Megajoules (MJ) – Primary Energy Equivalent of energy consumption in each sector
GDP ***(FLOW)*** (level n)	Gross Domestic Product in Constant Prices (base year 2000)	Sum of the value added from the various economic Sectors in constant prices (base year 2000)	Euros or US dollars
GDP_{AG} GDP_{PS} GDP_{SG} (level n-2)	Added Value Generated by agriculture, by productive sectors and by services and government	Added Value generated by each sector	Euros or US dollars

Using the dataset associated with the grammar given in Fig. 2 we can calculate the set of Intensive Variables (Flow/Fund) – which represent the flow intensities specific for the various compartments in relation to both: (i) energy flow per hour of human activity; and (ii) added value generated per hour of human activity. In this way, we get a set of benchmarks which can be effectively used to characterize the metabolic pattern of a society – the list of these benchmarks, defined across different levels, is illustrated in Fig. 3.

Fig. 3 The intensities (FLOW over FUND) calculated for the various compartments

Intensive Variable	Definition	Significance	Unit & Calculation
EMR_{SA} ***(FLOW/FUND)*** (level n)	Exosomatic Rate for Societal Average	the amount of energy used per hour of human time for the whole society in Catalunya	MJ/ hr; TET/THA Total Energy Throughput/ Total Human Activity
EMR_{PW} EMR_{HH} (level n-1) EMR_{AG} EMR_{PS} EMR_{SG} (level n-2)	Exosomatic Rate for sectors	the amount of energy used per hour dedicated to each sector	MJ/hr; Energy Throughput in relevant sector/ total hours worked in sector (ETi/HAi)
ELP_{SA} ***(FLOW/FUND)*** (level n)	Economic Labour Productivity	the amount of added value produced per hour of human time for the whole Catalan Society	€/hr; Total GDP/Total Human Activity
ELP_{PW} (level n-1) ELP_{AG} ELP_{PS} ELP_{SG} (level n-2)	Economic Labour Productivity for Sectors	the amount of Added Value produced per hour of work spent in relevant sectors	€/hr; Added Value by sector/ total hours worked in sector (GDPi/HAi)

After having calculated this dataset – the flow intensity MJ/hour and €/hour for the various compartments across levels – we can calculate the ***energy intensity*** of the various compartments: a set of numerical assessments having the dimension of MJ/€. That is, for each compartment included in the grammar we can divide the two flow intensities per hour: MJ/hour/€/hour. Finally we arrived to the key qualitative difference that the MuSIASEM approach provides compared with the conventional way of calculating the analogous set of intensive variables (energy intensity of the economy). The conventional way of calculating energy intensity divides directly the values found for the two different flows (FLOW energy divided by FLOW added value) for a given compartment – examples are illustrated in Fig. 4.
However, in this way, the resulting numerical values can no longer be considered as a set of "benchmarks" characterizing a metabolic pattern. [= with benchmark we mean a value that can be used to define whether a particular instance of compartment expresses a either high or low value in relation to an expected value]. This is due to the fact that a ratio FLOW/FLOW is not subject to an integrated set of congruence constraints associated with the concept of metabolism (the forced relation over the ratio FLOW/FUND), when balancing the flows across hierarchical levels (a technical explanation of this point is given in the Reports on Environmental Sciences – 2009#1). Briefly, we can say that the values of the benchmarks provided in Fig. 3 have to change all together, in an integrated way, across the various levels, in order to respect the forced congruence of flows across levels, whereas, the values of the variables indicated in Fig. 5 can change independently from each other.

Fig. 4 The energy intensities (FLOW over FLOW) for the various compartments

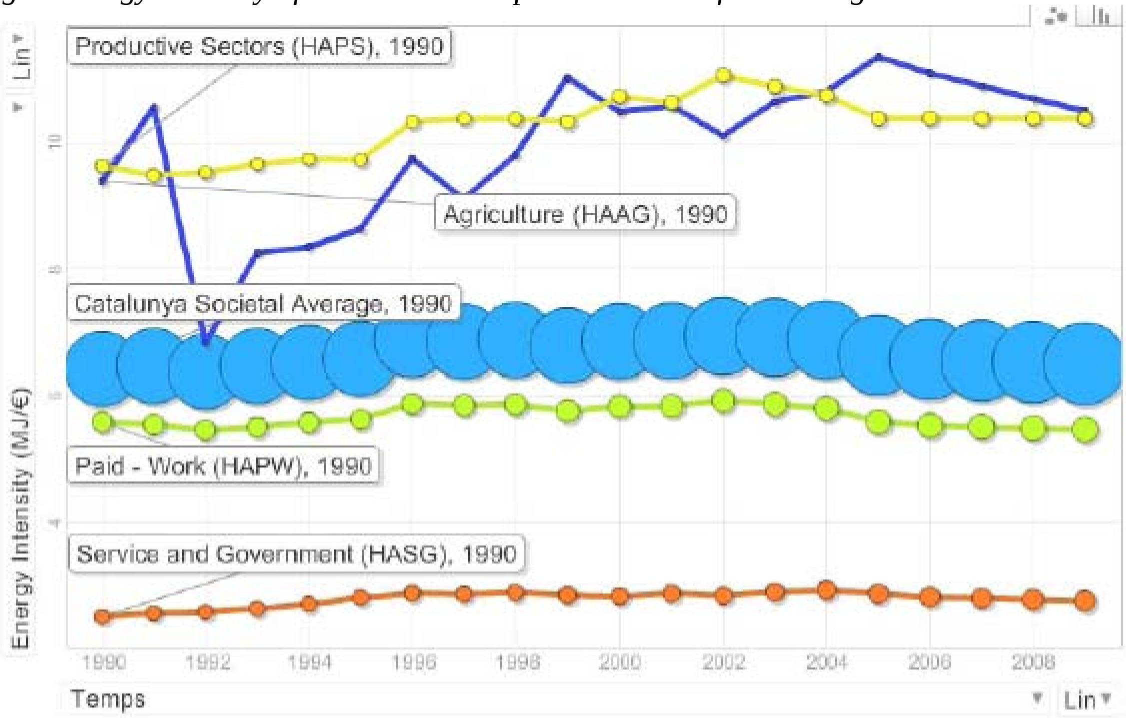
EI_{SA} ***(FLOW/FLOW)*** (level n)	Energy Intensity societal average	Energy Consumed per unit of Added Value generated	TET/GDP
EI_{PW} ***(FLOW/FLOW)*** (level n-1) EI_{AG} EI_{PS} EI_{SG} (level n-2)	Energy Intensity for Sectors	Energy Consumed per unit of Added Value generated for each sector	ETi/GDPi
EE_{SA} (level n)	Energy Efficiency Societal Average	Economic Productivity in energy terms	GDP/TET
EE_{PW} ***(FLOW/FLOW)*** (level n-1) EE_{AG} EE_{PS} EE_{SG} (level n-2)	Energy Efficiency of Production for sectors	Added Value generated per unit of Energy consumption	GDPi/ETi

2. Looking at changes over time of energy intensity

An overview of the changes of the values of energy intensity – expressed in MJ/€ - for the whole Catalonia (at level n), the Paid Work sector (level n-1) and the three subsectors – AG, PS and SG (level n-2) is provided in Fig. 5.

When representing changes in Energy Intensity over time we can check the amount of Primary Energy Sources required, at different points in time, to produce one unit of added value (€), in the various compartments chosen for the analysis. When we carry out this analysis we discover "standard" differences among the considered compartments. For example, the Productive Sectors (at the level n-2) lead by the industrial and construction sectors in Catalonia has the highest energy intensity (starting from 9.63MJ/€ in 1990 and rising up till 10.38/€ in 2009). The following sector in the ranking of energy intensity is the Agricultural Sector (at the level n-2) in which 9.39MJ/€ were consumed per € of production value in 1990. This value is 10.5MJ/€ in 2009. The third sector to be defined at the level n-2 is the Service and Government. This sector has a flow of Primary Energy per unit of added value produced quite low. The combined effect of the characteristics of these three sectors determine the energy intensity of the Paid work sector, which, reflecting the relative importance of the three subsector is lower than the values of PS and AG, but much higher than the value of SG. Finally, moving up to the level n - the Societal Average Value – we find a value of energy intensity higher than that of PW, since at this level we have to add the flow of energy going into the Household Sector, which does not generate any added value, and that therefore results into a net increase in energy intensity.

Fig. 5 Energy Intensity of the various compartments as defined in Fig. 4



3. An analysis of the changes in the metabolic pattern of Catalunya

3.1 The representation of the metabolic pattern

With the expression "analysis of the metabolic pattern" we want to indicate the simultaneous characterization of the integrated set of values assigned to the grammar described in Fig. 3 and Fig. 4 (FUND – HA_i - and FLOWS – both GDP_i and ET_i - and FLOW/FUND – both ELP_i and EMR_i). In order to obtain this representation we will use a more sophisticated graphical representation which makes it possible to handle 4 variables at the same time:

(1) on the vertical axis the Exosomatic Metabolic Rate of the compartment i: EMR_i

(2) on the horizontal axis the Economic Labor Productivity of the compartment i: ELP_i

(3) the size of the disk representing the compartment is proportional to the size of the compartment expressed in hours of human activity per year: HA_i

(4) the various disks connected to the first one, represent the value taken by these three variables in different years, over the period 1990-2009.

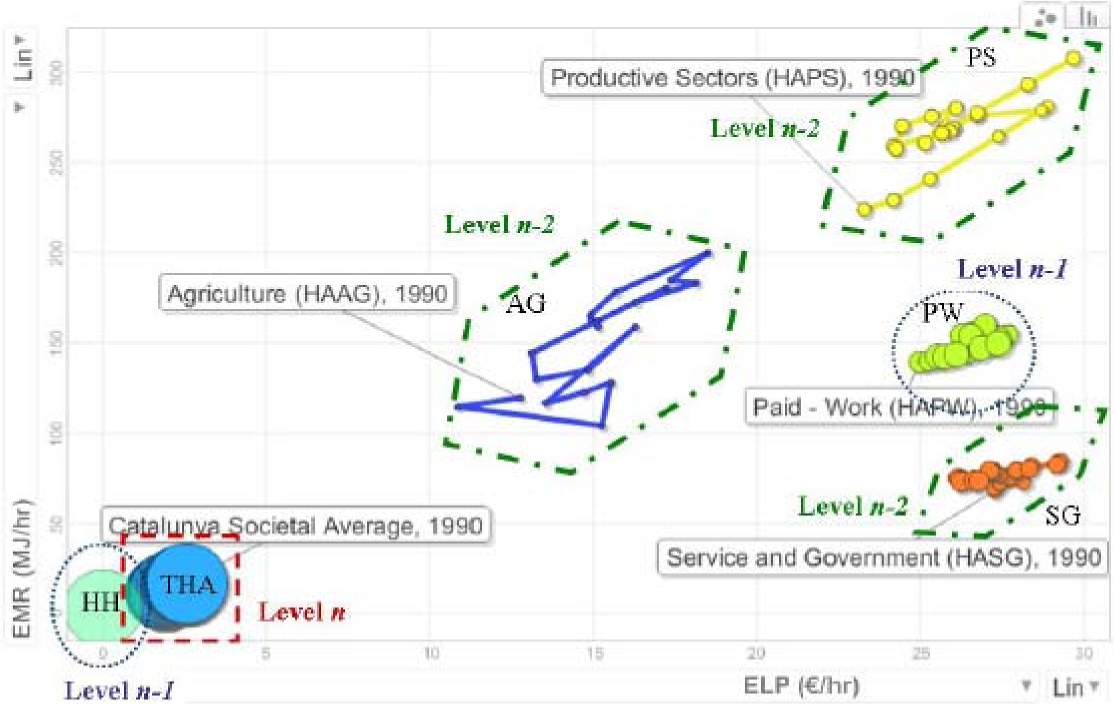
To make this more challenging we represent the 6 compartments referring to different hierarchical levels, all in the same graph. The resulting characterization of the metabolic pattern is illustrated in Fig. 6. In this figure we can observe:

**** at the level n*** - the disk referring to the energy intensity of the whole Catalonia (it is indicated in the red box) which provides a value expressed in MJ/€ (the total energy throughput of the society divided by the GDP per year). The size of this disk represents the amount of hours of Total Human Activity (population x 8760) in a year;

**** at the level n-1*** - we have two disks representing the two compartments of production (HH) and consumption (PW). It should be noted that the disk of HH does not generate any added value and therefore is indicated as a ghost disk. The HH compartment affects the

overall energy intensity because of its changes in size (affecting the rate working non working hours in the society). However, to avoid jamming the figure, the changes in size of the HH compartment are not represented in this graph;
**** at the level n-2*** – we have three disks representing the 3 chosen sub-compartments in which we divided the hours of PW: PS, AG, and SG.

Fig. 6 The metabolic pattern of Catalonia represented across hierarchical levels



Looking at the figure we can see that the societal average of energy intensity of Catalonia is generated as a combination of the consumption of energy of HH and the energy intensity of PW, which have to be weighted over the relative size (expressed in hours of human activity) of these two compartments. In the same way, we can observe that the energy intensity of the PW sector – defined at the hierarchical level n-1 - is determined each year by the combination of the characteristics of the energy intensity of the three subsectors - PS, AG, and SG – defined at the hierarchical level n-2. Again for each year the scaling from the value of the energy intensity of the three subsectors – at level n-2 - and the value of the PW sector – at the level n-1 – has to be calculated by weighting the relative intensity values (intensive variables) over the relative size (extensive variables) expressed in hours of human activity.

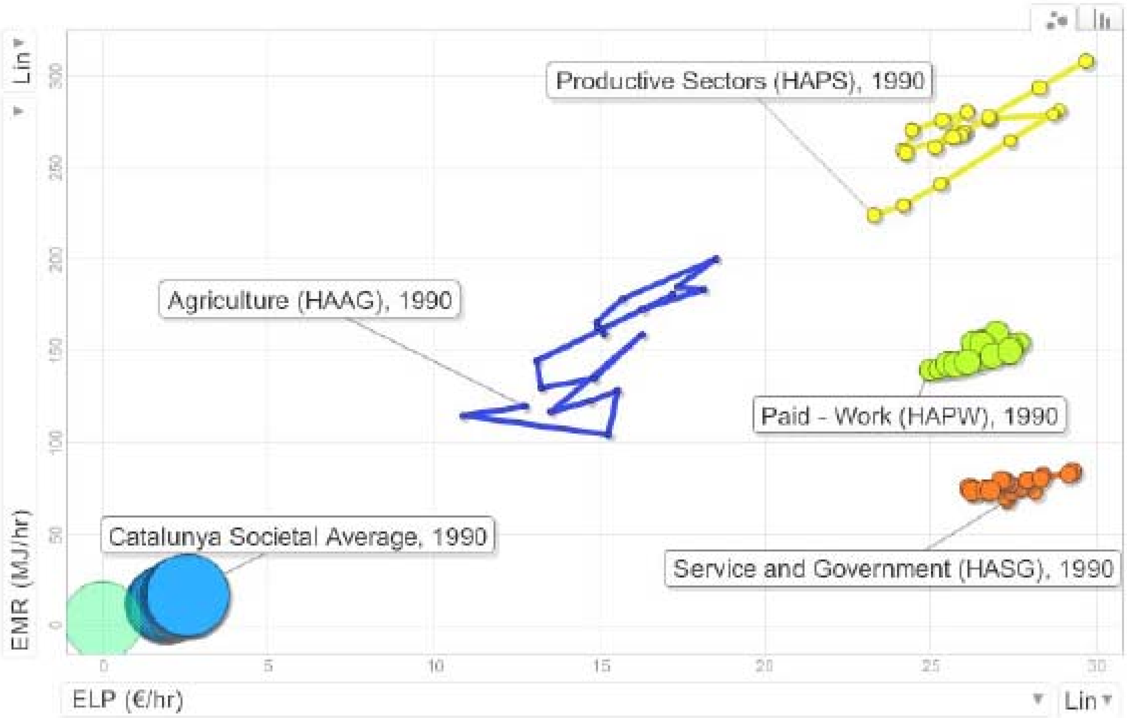
3.2 Describing the evolution of Catalonia on the plane EMRi vs ELPi

The adoption of this visualization makes it possible to study the changes in the flows of commercial energy per hour of work, an assessment which can be associated with changes in the level of biophysical capitalization. In fact, the different sectors do express different values of added value produced per hour of work and different requirements of energy. Changes in this metabolic pattern can only be studied by taking in account differences in intensive variables (i.e. the energy intensity of the various sectors) and extensive variables (i.e. the relative size in hour of human activity of the various sectors). Looking at the relative size of the disks (Catalonia Societal Average disk represents the Total hours of

Human Activity available within the Society) we can notice that the majority of the hours of human activity are found within the household compartment (represented in light green). The remaining hours are distributed among the sectors of production in paid work. We have to remind the reader that within the multi-level matrix of human activity the overall number of hours must remain constant across the levels. This implies: THA (level n) = HA_{HH} + HA_{PW} (level n-1); and HA_{PW} (level n-1) = HA_{PS} + HA_{AG} + HA_{SG} (level n-2);

The household sector in the chosen system of accounting is not seen as a sector contributing to the generation of added value within the economy, thus its Economic Labour Productivity value appears to be zero. However, this does not in any way mean that "work" is not taking place within the household compartment. As a matter of fact an important fraction of the hours spent within the household (taking care of household chores such as cleaning, hopping, cooking, nursing, personal care) are indeed domestic modes of production. However, these activities are invisible to macro-economic figures. This is an important advantage of the MuSIASEM approach, which makes it possible to include these activities in the representation of the overall metabolic pattern. In fact, even though the Household Sector does not generate a flow of added value, it requires an important flow of energy (in general around 30% of the total flow of Primary Energy sources in developed countries). A detailed analysis of the energy flows in Catalonia divided by compartment, type of primary energy sources and type of energy carriers is given in the document B of this case study – authored by Ramos-Martin et al. Whenconsidering the Exosomatic Metabolic Rate (MJ/hour) we can see that the value for the HH is very low when compared with the values of EMR achieved in the Paid Work Sectors, in which human activity handle intense modes of production of goods and services.

Fig. 7 The metabolic pattern of Catalonia characterized on the plane EMR – ELP



Let's now describe the changes in the metabolic pattern of Catalonia illustrated in Fig. 7. Note that the graph in Fig. 7 is the same as in Fig. 6, we just took out the different labels referring to the different hierarchical levels to increase clarity.

** Changes at the Level n-2*

AG sector - the Agricultural Sector in Catalonia shows significant changes in EMR and ELP over the years. In 1990, it was producing 12.8 €/hr while consuming 120 MJ/hr of primary energy equivalent, whereas, in 2009 the economic labour productivity has risen to 15.1€/hr together with the energy flows per hour to 159MJ/hr. However, the historic series does not show any clear trend over the period. Actually, the graph shows quite the opposite case. This seems to indicate that the evolution of the agricultural performance in Catalonia has been quite irregular, probably heavily affected by external causes – the continuous change in the criteria used to regulate the economic subsidies that drive changes in the agricultural sectors in the countries of the EU. This analysis of the performance of the agricultural sector indicates also the relative high energy intensity of this sector. This point is especially important when considering that the energy intensity calculated in this graph refers only to the fuels and electricity consumed in agriculture. This direct energy inputs is only a small part of the total consumption of fossil energy in agriculture, which is largely used to produce fertilizers and pesticides (accounted as fossil energy consumed in the industrial sector!).

SG sector - the Service and Government Sector shows a relatively stable trend, even though it went through some fluctuations and inversions of trend. In the year 1990, it was producing 27.3€/hr while consuming 68MJ/hr of Primary Energy sources, whereas in 2009 the ELP value has dropped to 26.8€/hr and the consumption of energy per hour increased slightly to 74MJ/hr. This can be explained by the energy intensification of the services sector, in particular the transport sector and the continuous increase in the use of primary energy equivalent for electricity. The decrease in the ELP can be explained by the increase in the hours of work flowing into the services sector for assistance of elderly and other low paid jobs (immigration). Thus, it can be said that the pace of the increment of hours of work in the services sector has not been as high as the pace of incremental increase of the overall value of added value provided by the services sector. Thus, ELP (€/hour) has dropped over the years.

PS sector - the Productive Sector composed of industrial activities with a high material requirement and energy demand has by far the highest level of Exosomatic Metabolic Rate per hour, whereas it produces a relatively low amount of added value (very close to that of the services sector). In 1990 the EMR was 224MJ/hr to produce 23.3€/hr. In 2009 the energy consumption per hour of work (EMR) arrived to the level of 308MJ/hr, while the added value generated has increased only to 29.7 €hr. As discussed in the Reports on Environmental Sciences – 2009#1, this fact explains the strong tendency found in developed countries to externalize the production of industrial goods to developing countries, decreasing in this way the energy intensity of their economies.

** Changes at the Level n-1*

PW sector – changes in the characteristics of the Paid Work sector are determined by changes in the characteristics of the three sub-sectors weighted together. In order to decrease the energy intensity of the PW sector we should increase the Labour productivity of each sector (added value generated per hour of work) while keeping the level of energy flow per hour, as low as possible. However, this idea works well only in the text-books of neoclassical economics. In fact many economists (e.g. Georgescu-Roegen) and biophysical analysts (e.g. Hall, Cleveland) have clearly demonstrated that there is a strict link between economic growth and energy consumption. As a matter of fact, Robert Ayres has provided an empirical analysis that can explain almost entirely the differences between total energy consumption and GDP, by considering: (a) the different mix of Primary Energy Sources (1 GJ of natural gas is better than 1 GJ of oil, that is better than 1 GJ of coal); and (b) the different mix of Energy Carriers (the continuous increase in the fraction of electricity in the energy mix correlates very well with increases of energy efficiency in relation to energy carriers). Much more important than changes in the technical coefficients (EMR) and ELP of the individual sector is a change in the mix of economic activities – the relative size of the three subsectors – for changing the overall characteristics of PW. In particular (as discussed in the next section) two systemic adjustments do explain the changes in overall characteristics of PW: (i) a continuous reduction in the fraction of hours of human activity and sectoral GDP associated with the Agricultural sector (steadily decreasing toward 2% in the richest countries); (ii) a continuous increase in the fraction of hours of human activity and sectoral GDP associated with the Service and Government sector (steadily increasing well above 60% in richest countries).

4. Comparing the evolution of Catalonia to that of other EU countries

The figures presented below are based on a dataset referring to the grammar illustrated in section 1 (Fig. 1, Fig.2 and Fig. 3). The analysis refers to fourteen EU Countries – that is, it started with EU15, but then it was decided to exclude Luxemburg – since this country represents a clear outlier. Actually, this fact seems to confirm the validity of the approach. When adopting an integrated characterization of its metabolic pattern Luxemburg does not exhibit a metabolic pattern similar to that of the other countries. We did not investigated further the issue, but the obvious hypothesis is that the majority of the human activity taking place in that country is performed by people, which are continuously crossing national borders (either people resident there and working outside of Luxemburg or *vice versa*). As a consequence the set of economic activities (economic functions) performed within the borders does not cover the entire requirement of economic functions associated with the metabolism of a country. In the economy of Luxemburg it is very likely that imports and exports play an overwhelming role in guaranteeing the supply of goods and services needed to cover the needs of the population.

In conclusion, in the series of figures presented below, the dataset describing a historic series of the metabolic pattern for the EU 14 countries has been coupled with the dataset developed for Catalonia (presented in Fig. 7). In this way, we can visualize and compare changes in the performance of the metabolic patterns, across the various compartments defined at different hierarchical levels of European Countries and Catalonia.

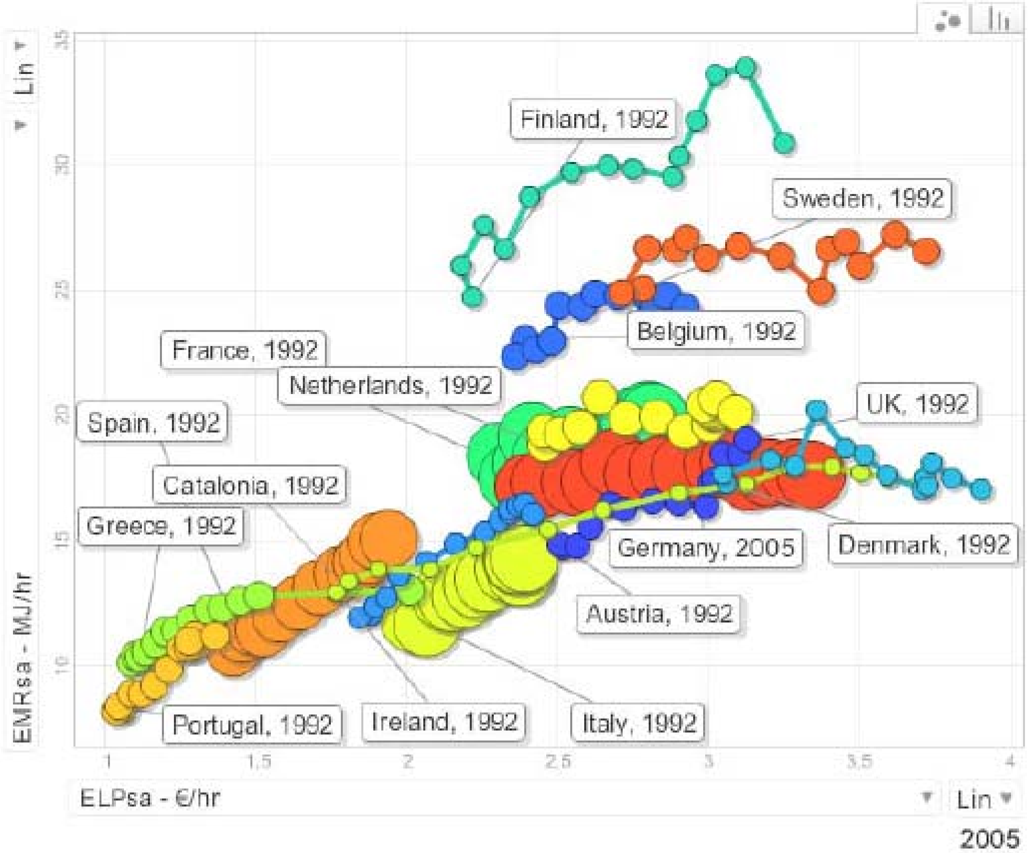
As mentioned earlier, due to availability of data, we could cover for this comparison a smaller historic series referring to the period of years between 1992 and 2005. Because of this fact, we do not have any data reflecting changes due to the recent financial crisis.

4.1 The comparison at the level n (whole countries)

The various trajectories of changes in metabolic pattern for Catalonia and the EU14 countries are illustrated in Fig. 8. The trajectory describing changes in time of the performance of the Catalan Society is indicated by the small disks blues, starting in 1992 just on the left of Italy (the larger yellow disk) and on the right of the trajectory of Spain (the series of orange disks). This means that, in 1992, Catalonia was consuming more or less the same energy per hour as Italy, but producing less added value, and that in relation with Spain (especially making a comparison over the year 1992) Catalonia had a higher level of capitalization (i.e. a higher level of fossil energy consumption per hour) and a much higher pace of generation of added value per year.

In the period considered – 1992-2005 – Catalonia reached the same level of generation of added value per hour of Italy, but this result was achieved by a higher consumption of fossil energy (the economic mix includes economic activities more energy intensive). In relation to Spain, Catalonia maintained the relative position on the plane basically constant. This means that Spain and Catalonia have been evolving (pattern of evolution of structural changes in the economy) in a very similar way.

Fig. 8 - The performance of Catalonia vs EU 14 – societal average (level n)



In more general terms, looking at the general trend over the whole sample of countries, we can confirm the correlation propose by many bioeconomic analysts (e.g. the studies of Ayres) between energy utilization and increase in added value generation. It is quite obvious that in spite of all the lip service about the implementation of the Kyoto protocol, the decoupling of the economy and the green revolution, the general trend of all the countries included in this sample is toward the right upper corner of the graph.

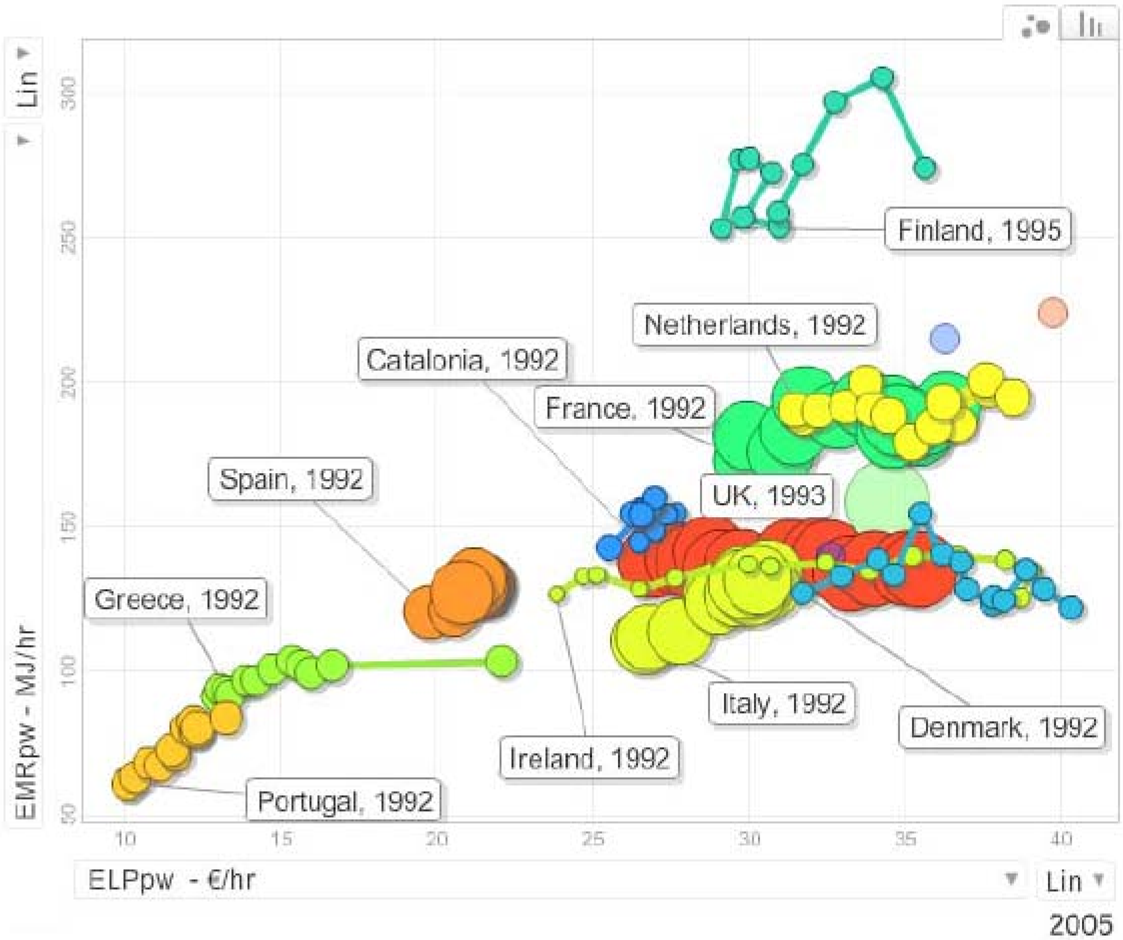
The second observation that can be made looking at Fig. 8 is that we can distinguish two typologies of trajectory for countries. The countries with a lower GDP per hour (on the left of the horizontal axis) show a parallel increase of energy use and added value generated. This group includes Portugal, Greece, Spain, Italy, Catalonia, Austria. The countries with a higher GDP per hour increase the pace of added value generation per hour without increasing the pace of consumption of fossil energy per hour as much. In this second group we can include the Netherlands, Denmark, UK (may be also France). Belgium, Sweden and

Finland are in between these two types, expressing a higher energy intensity per hour than the EU average. When dealing with data referring to the level n (very aggregated and reflecting different lower level specific characteristics) it is important not to drive many conclusions. In fact, the same numerical value can be generated by a lot of different combinations of lower level factors. For this reason it is important to analyze changes in the sectoral performance of the various countries, in order to be able to explain the overall trajectory at the level n.

4.2 The comparison at the level n-1 (the Paid Work sector)

The first point to observe is that the values of EMR_{PW} in the side of the economy dedicated to economic production is much higher for all the countries considered. That is EMR in the Paid Work sector is in the order of hundreds MJ/hour, whereas is in the order of tens MJ/hours when considering the Societal Average (and it is in the order of single digit MJ/hours when considering the HH sector). In fact the activities performed in the paid work sectors are much more energy intensive than the activities performed in the household sector.

Fig. 9 - Catalonia vs EU 14 – the Paid Work sector (level n-1)



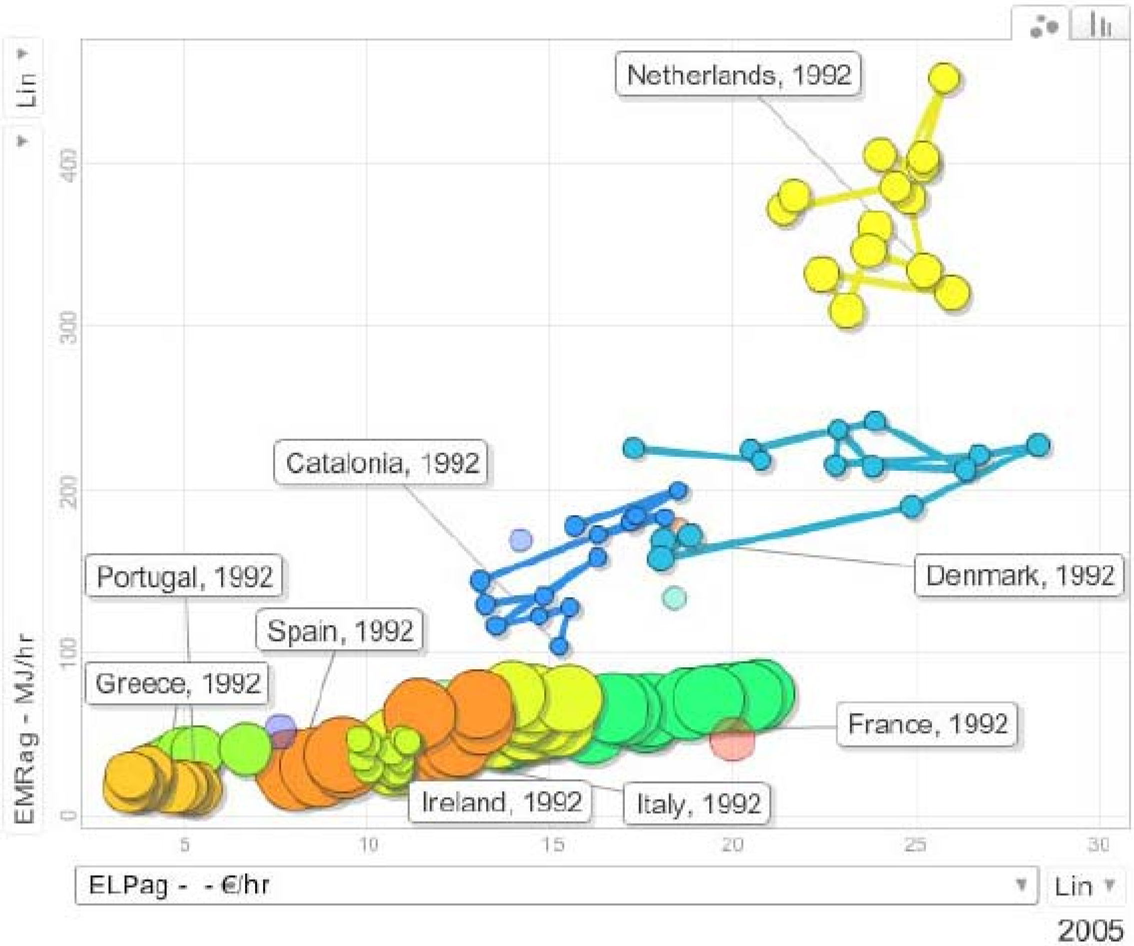
When looking at this graph we can observe again the difference in trend between the two groups of countries, with a stabilization of the EMR for the PW of the countries generating a higher pace of added value per hour of work in PW. But again, at this aggregate level we cannot explain which changes at the lower level (of the subsector defined at level n-2) are determining this trajectory, detected at the level n-1. At the level n-1 we can only detect the effect of changes in demographic variables, determining a different size (due to changes in the dependency ratio – the hours spent in the Paid Work sector by those belonging to the economically active population and the hours spent in the Household sector by those not belonging to the economically active population) between HA_{PW} and HA_{HH}, within THA. Changes in the mix of economic activities – for example the mix of sectoral GDP considering Agriculture, Services and Industry – and changes in technology – for example changes in the EMR of the different sectors cannot be analyzed at this level.

4.3 The comparison at the level n-2 (the integrated changes of AG, PS and SG)

At this level of analysis, we can finally look at the effect of structural changes of the economy, since we can check: (i) the relative size of the compartments, and therefore detect the effect of changes in the mix of economic activities; and (ii) the specific performance of individual compartments by checking changes in both ELP (€/hour) and EMR (MJ/hour).

4.3.1 Changes in the AG sector

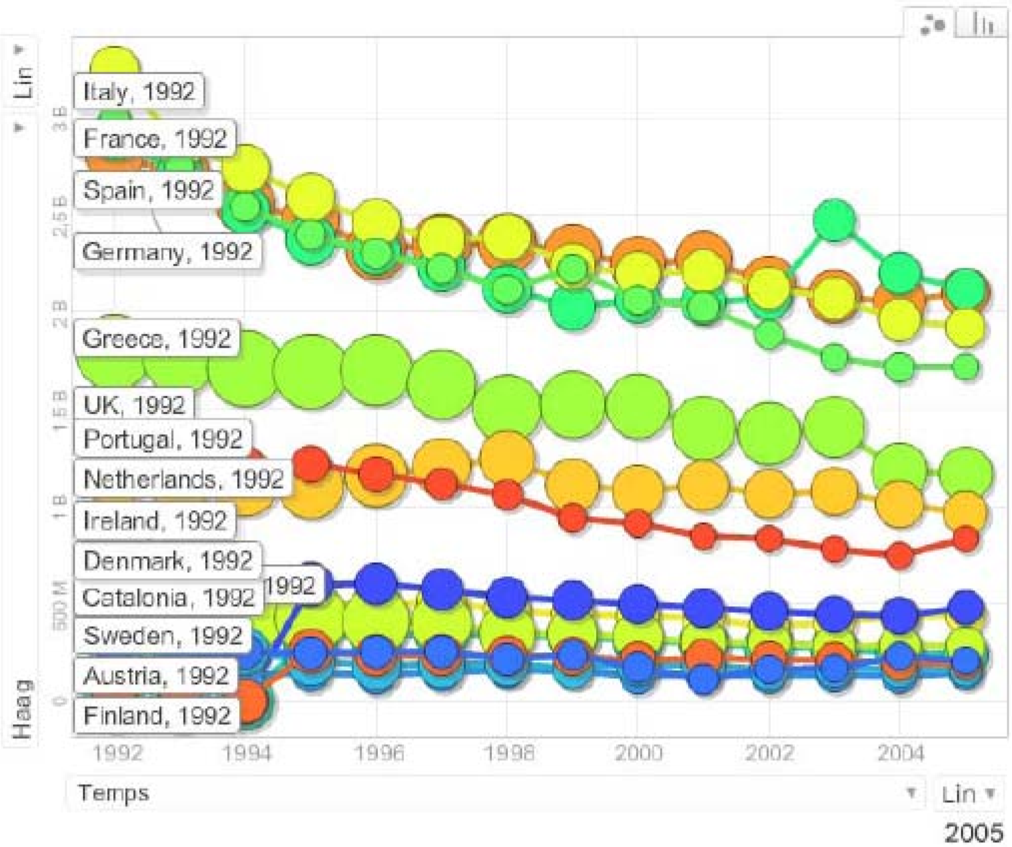
Fig. 10 - Catalonia vs EU 14 – the Agricultural sector (level n-2)



As observed earlier, trends of agricultural energy use are quite erratic. The Netherlands, renown for its fame in agricultural products has a very high energy throughput, and a high pace of added value per hour (this can be explained by the heavy reliance on green-houses). However, changes in this sector have been very difficult to explain. For example, in 1992 in the Netherlands, the energy throughput per hour of work in the agricultural sector was 321 MJ/hr generating 26€/hour; however in 2005 the energetic consumption per hour increased to 381 MJ/hr while the added value produced dropped to 21.7 €/hr. The relative values for Catalonia are quite different: in 1992, the energy throughput in Agriculture was 104 MJ/hr with a return of 15.3€/hr, and in 2005 the energy throughput was 178MJ/hr to produce 15.7€/hr. In both cases, we have an intensification in energetic terms the EMR growing much faster than the ELP (which in some cases decreases).

The energetic intensification in the agricultural sector (growing EMR intensity per hour, but also per hectare, when the data are calculated using categories of land uses) in EU is linked to the increase of use of machineries, electricity and greenhouses. To this one should add also a simultaneous increase in fossil energy consumption to produce fertilizers and pesticides. This combination of increase in energy intensity (not fully represented in the trajectories given in Fig. 10) raises serious doubts on whether it is worth investing such a high amount of energy in a sector in which the added value per hour worked is decreasing or just remaining constant. It should also be noted – Fig. 11 - that the hours worked in total in the agricultural sector for every country seems to be on the decrease over the years.

Fig. 11 - The reduction of hours in the Agricultural sector (level n-2): Catalonia vs EU 14

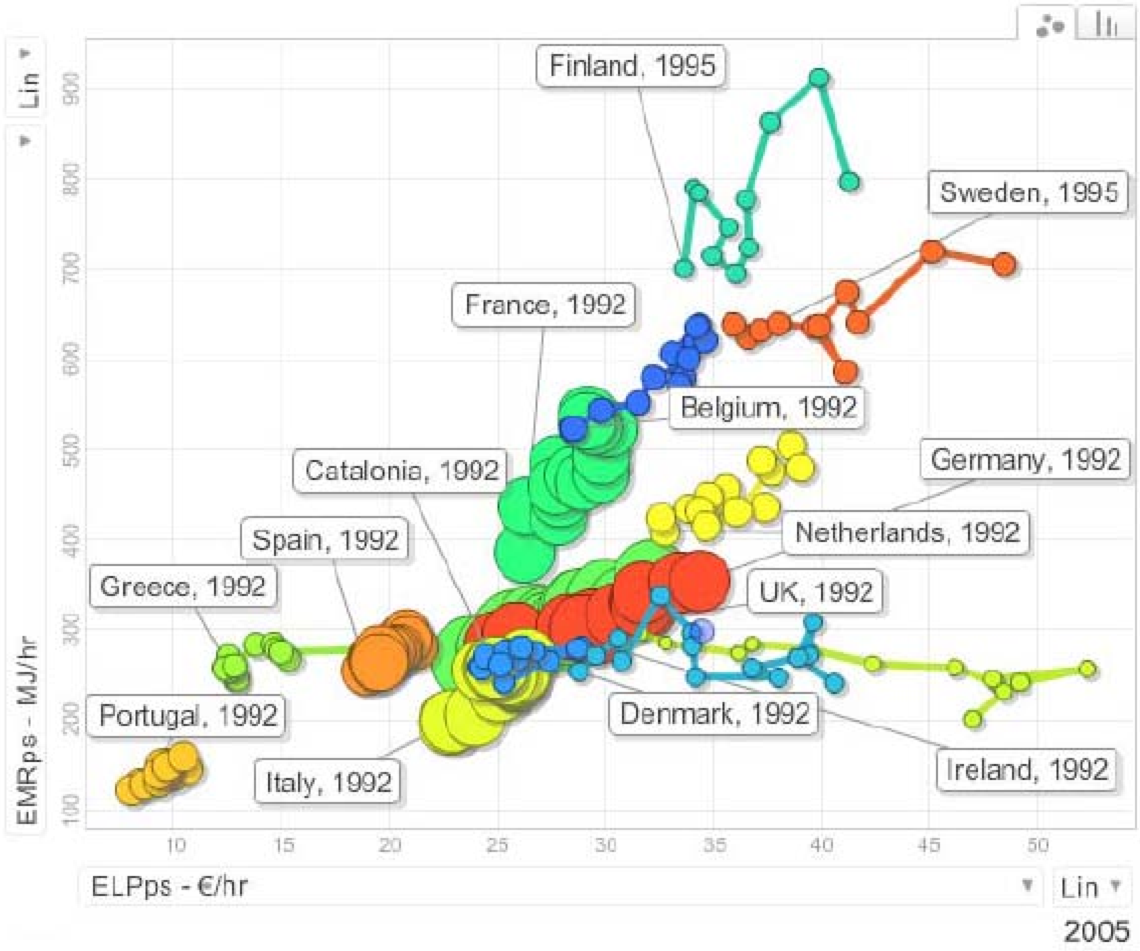


The graph in Fig. 11 shows a continuous decrease in the overall hours spent in the agricultura ector. The graph has: (i) total hours of work in agriculture, on the y-axis; and (ii) the years between 1992 -2005, on the x axis); and (iii) the size of the disks shows the percentage of added value contributed by the agricultural sector to the national GDP. This percentage did also get smaller in size over the considered time period, indicating that, the contribution of the agricultural sector to the GDP of the economy decreases over the years.

4.3.2 Changes in the PS sector

The productive sector of modern economies forms the backbone of the industrial activities often divided in building and manufacturing. These activities entail a much higher throughput of energy per hour of work, nearly four times as much as that of the agricultural sector. It should be noted, that the intensity of the energy throughput does not depend only on the type of activity involved (making tunnels is more energy intensive than selling insurance) and on the technology used (one can make tunnels using more or less energy), but also on the system of prices and subsidies enforced by different countries. The cost of different energy forms will affect the mix of Primary Energy Sources and Energy Carriers used in the economy. For example, as of 2007, electricity prices for industrial consumers (in euro per 100 kWh) in the EU-15 (without tax) appeared to be the lowest in Finland, France and Sweden in order.[1] Thus, a high use of electricity for example in the industrial sector can be linked with the high energy throughput per hour in these countries that appear to have the highest energy throughput in the productive sectors, but also a high pace of generation of added value. This is a point that deserves more attention in the following analysis.

Fig. 12 - Catalonia vs EU 14 – the Productive sector (level n-2)



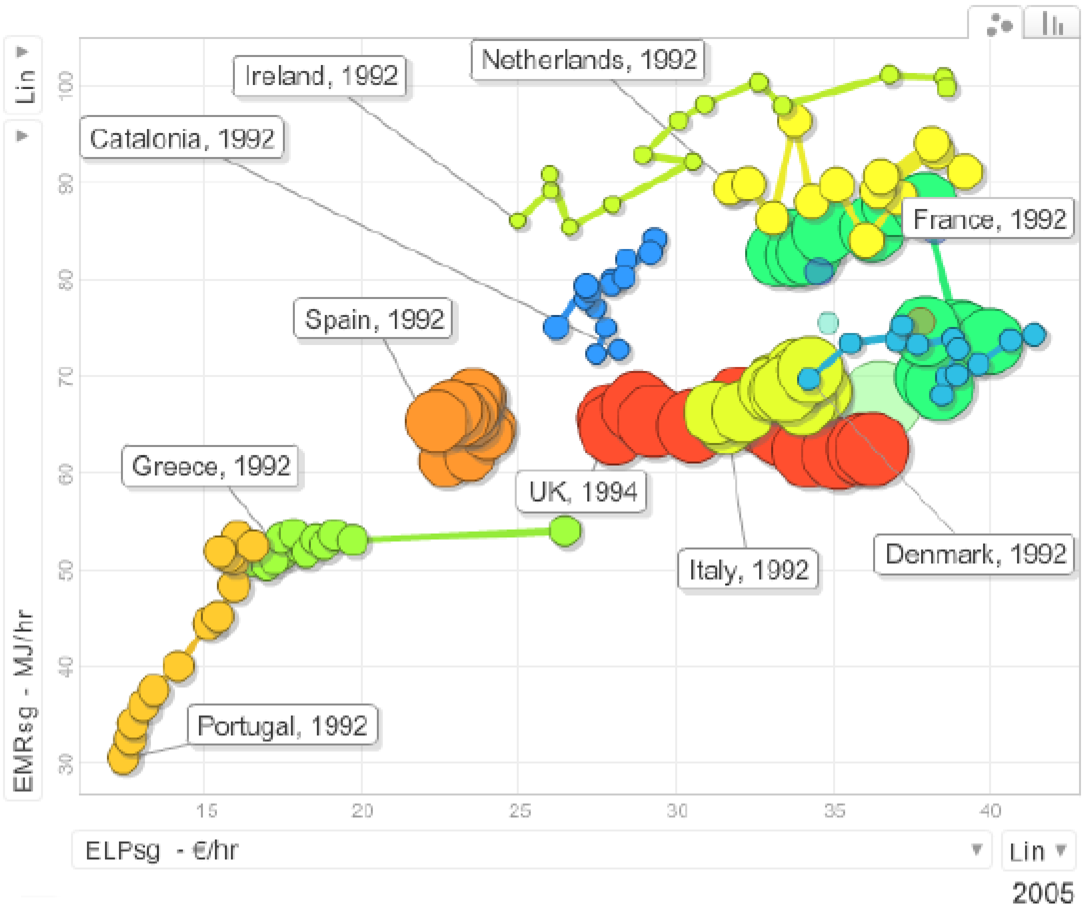
[1] Electricity prices for EU households and industrial consumers on 1 January 2007, Available for download http://epp.eurostat.ec.europa.eu/portal/page/portal/product_details/publication?p_product_code=KS-SF-07-080

Catalonia seems to have a similar EMR as that of Spain with a higher pace of generation of added value (ELP), which indicates a better performance. The energy throughput has remained quite constant while solely increasing its € generated per hour of work. Negative consideration for both Catalonia and Spain is that the "worm" made up by the different disks reflecting different position in time (over the considered years) seems to be coiled on itself. That is, even if Spain and Catalonia had an increase in their GDP over this period of time, this increase was obtained by doing more of the same, and not through a qualitative change in the structure of the economy. That is, this comparative analysis shows a worrying lack of evolutionary changes in the economies of Portugal, Spain, Italy and Catalonia.

4.3.3 Changes in the SG sector

The services and Government sector is the sub-sector within PW, which has the lowest EMR and the lowest energy intensity. As observed, the values of EMR are nearly as half of those of the Agricultural Sector and less than one third of the Productive Sector. None of the countries included in the sample has a EMR of SG which exceeds the value of 100 MJ/hr. Ireland is the country with the highest EMR in SG (yet still is very moderate when compared with the energy throughput of other sectors). Referred to as the Celtic Tiger, Ireland is well known for its fast economic growth in the 1990s, during which the added value of the services sector rose immensely. As seen in the graph, there has been a great increase of ELP over the years, so this may have reduced the priority of investing in energy efficiency in this sector (also because of the intrinsic low level of EMR).

Fig. 13 - Catalonia vs EU 14 – the Service and Government (level n-2)



Again, with this preliminary study carried out at the level n-2 we can only formulate hypotheses. These hypotheses can be checked by moving the analysis down to another hierarchical level: by representing the metabolic pattern at the level n-3.

4.4 Discussion of these results

It is impossible to study changes in the energy intensity of an economy without first observing the changes in its metabolic pattern across levels.
For example, the Environmental Kuznets' Curve hypothesis says that richer countries reduce the energy intensity of their economy because of "better technology". A famous way to discuss this point is to use the I = PAT relation - introduced by Elhrlich in the 80s - to explain the main point we want to make in this example. The 4 terms of this relation are:
(I) standing for the Impact on the environment; which is determined by the combination of other three terms: (P) Population; (A) Affluence; and (T) Technology. Within this relation (T) Technology is individuated as the key factor that makes it possible to decouple economic growth and environmental degradation. According to the traditional gospel about the positive effect technical progress (e.g. the Environmental Kuznets' Curve hypothesis), improvements in Technology can effectively counteract the effects of increasing population (P) and affluence (A). That is, even though the two factors (P) and (A) have the effect of increasing the amount of goods and services which have to be produced and consumed in a given society, technical progress, by improving the performance of technology (T) can reduce the impact per unit of goods and services produced and consumed by society.

Can we check the validity of this hypothesis using empirical data?

Again, in order to be able to answer this question it is crucial to be careful in handling in a wise way the set of possible assessments of performance referring to different hierarchical levels. Let's start by comparing the characteristics of three European countries (Spain, the UK and Germany) adopting the rationale of "I=PAT" using data referring to the level n (the whole economy level). This comparison is given in ***Table 1***.

Table 1. Indicators relevant for the I=PAT relation and the "black-box level"(level n)

	Spain	Germany	U.K.
I - CO_2 Emissions p.c. (ton/year)	352	897	558
P – Population (millions)	42.3	82.5	50.1
A - GDP per capita (€/year)	**17,900**	**26,800**	**27,000**
T - CO_2 Emission Intensity (kg/€)	**0.46**	**0.41**	**0.35**

Looking at this dataset (using values per capita to eliminate, for the moment, the effect of the size: P) it seems that the data back up the hypothesis of the Environmental Kuznets curves. That is, the Affluence A (estimated in this case using the proxy GDP p.c.) seems to explain the differences in emission intensity (estimated using the proxy CO_2 emission per unit of GDP). UK with a higher GDP per capita than Spain has a lower energy intensity of its economy. According to this hypothesis the variable Technology (T) is explaining this difference, since, according to this analytical framework Technology is "better" where the GDP is higher.

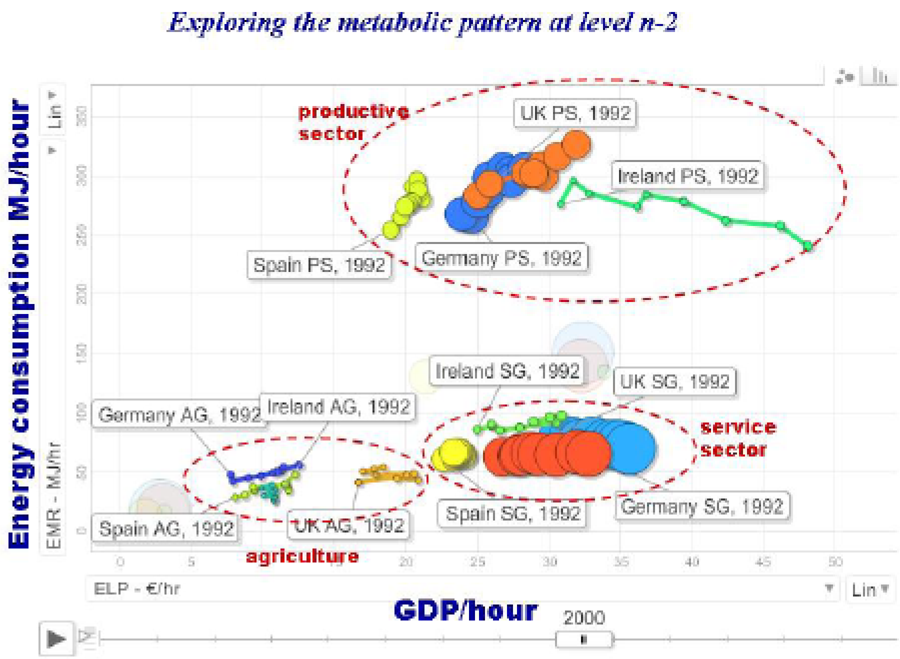
But how robust is such an analysis if we check the same data set across different hierarchical levels?

When we observe the characteristics of these three countries at a different hierarchical level we can get a quite different picture. We provide a comparison between these 3 countries (plus Ireland included b ecause of its peculiar pattern of economic growth) across the compartments defined at level n-2 in Fig 14.

From this figure it is easy to see that the differences ***across typologies of sectors*** over the three countries (e.g. energy intensity of PS sector versus energy intensity of AG) are much higher than the differences, ***within the same sector over the three countries, due to gradients in technological performance***.

In particular, we can notice that: (i) the PS sector is much more energy intensive than the others; and (ii) the energy consumption per hour of work in the PS sector is increasing in time everywhere (but in Ireland . . .). On the contrary the intensity of the service sector is much lower and decreasing in time.

Fig. 14 – Characteristics of the metabolic pattern of sub-compartments of the economy of Germany, UK, Spain and Ireland (level n-2)

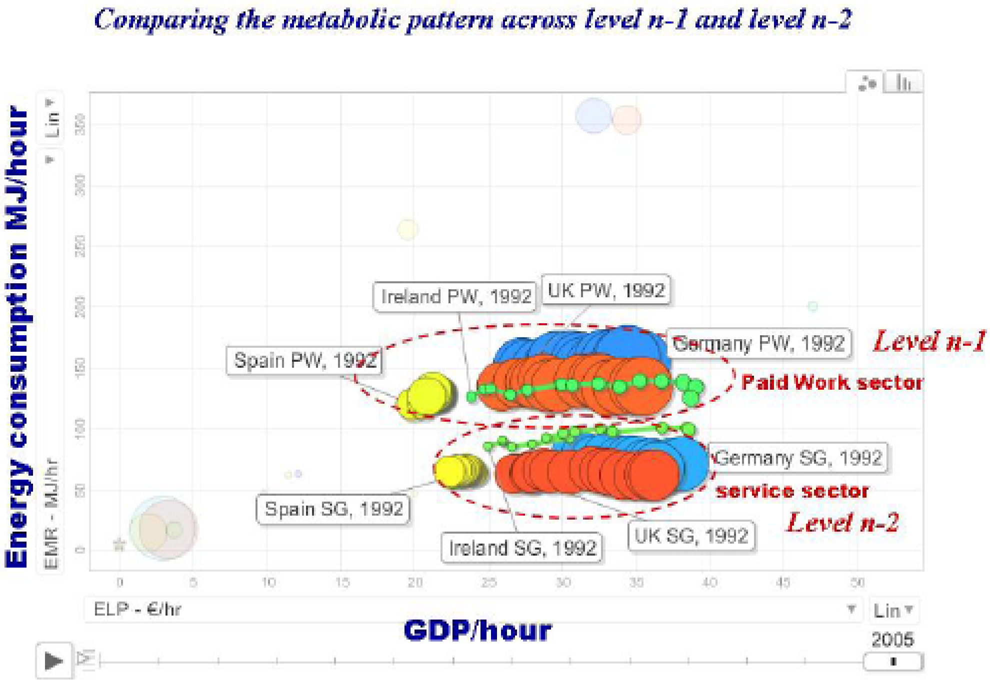


Therefore, we can observe two important points: (i) technical changes are not generating a reduction of energy flow getting into the PS sector; (ii) the overall reduction of energy intensity of PW is due to a progressive reduction of the weight of the PS sector in determining the average in PW. In fact, we know that both in terms of hours of working time in PW and in terms of relative proportion of the sectoral GDP the SG sector is continuously increasing its share in the PW sector. Again this confirms that developed societies change their metabolic pattern allocating more time and energy to the final consumption sector (HH) and within the PW sector they are allocating more working time and energy to the Service and Government sector (SG). But this is possible only because of a continuous externalization of the function of production of goods to developing countries (e.g. China and other Asian countries).

As a matter of fact, when comparing the trend of change in energy intensity – as observed at the *level n-1* (the characteristics of the PW sector, the side of production of the economy) and the characteristics of the SG sector at the *level n-2* – as illustrated in Fig. 15 - we can immediately observe that it is the slope describing the direction of changes of the SG service which is determining the overall slope describing the direction of change of PW. But again, this implies that someone else must produce the energy and resource intensive products consumed but not produced by post-industrial countries.

In conclusion, by conducting a multi-level analysis of the metabolic pattern one can observe similarities and differences across levels, from the values of these intensities aggregate as societal average to a specific sector of interest. What presented in this case study are just preliminary results. In this exploratory phase the focus was on the development of protocols for the accounting and the generation of a first data set, which would make it possible to visualize and characterize the metabolic pattern. This case study should not be considered as a real detailed study of the performance of Catalonia. As a matter of fact, a more detailed study should be focused to answering a specific set of questions, which were not given in this case study.

Fig. 15 Comparing the trend across levels: PW versus (level n-1) vs Service sector (level n-2)



Some research questions can be formulated by a cursory reading of the graphs presented so far. For example, countries having low industrial electricity prices seem to be utilizing more energy throughput per hour in the in industrial sector, this translates into a large consumption of Primary Energy Sources per unit of Energy Carriers, but it provides also a higher pace of generation of added value per worker (ELP). Other countries, such as the UK for instance, have a lower energetic flow getting into the productive sector per capita. But this does not mean that people in UK consume less products or that the PS sector of UK produces products better than the PS sector of other countries. It only means that the UK economy managed to externalize the productive processes and because of this UK can invest a large fraction of the available hours of works and energy in a very large service sector. In fact, the economic activities performed in the service sector, which is the least energy intensive of the sectors, provide the most energy efficient solution (low energy investment and high pace of generation of added value). This advantage is paid for by a larger dependence of the internal consumption of goods on imports. The Catalan society, in comparison with the other countries, is utilizing more energy per hour of work in the SG sector and to be generating less added value per hour of work.

What we have shown in this application is just a first screening/overview of the metabolic pattern of Catalonia, similar to the set of tests to be performed on a patient undergoing a medical check-up. The patient considered – in this example Catalonia – is tested looking for a set of expected benchmarks (the various values determining the metabolic pattern across levels). This is equivalent to test a patient checking the measured values of blood pressure, weight versus height, cholesterol concentration in the blood, analysis of the urine, etc. etc. Then whenever we find for some of the benchmarks a value different from the expected one we have individuated an anomaly. Then it becomes possible to move to a more detailed and focused analysis of the factors that can determine that anomaly.

PART 2 - Checking the possibility of using the MuSIASEM approach to land use analysis (using a multi-level matrix of categories of land use)

1. Application of the MuSIASEM approach to land use analysis

In part 1 of this document we have been showing the application of the MuSIASEM method for the calculation of ***FLOW intensities per hour*** (where the flows are energy and added value) over a multi-level matrix of the FUND human activity. That is the intensity are defined as the ratio FLOW/FUND over a given compartment – that is: (i) ELPi - the pace of added value per hour; and (ii) EMRi - the exosomatic metabolic rate per hour.

However, as explained in the theoretical documents presenting the MuSIASEM approach, MuSIASEM can be applied using a different multi-level matrix referring to a different FUND – **Land Uses**. When moving to this alternative choice of FUND, we can calculate in the same way ***FLOW densities per hectare***, defined as the ratio FLOW/FUND over a given compartment – that is: (i) the amount of added value generated per hectare: €/ha; and (ii) the amount of exosomatic energy dissipated per hectare: GJ/ha.

The two systems of accounting (FLOW intensities per hour and FLOW intensities per hectare) can be linked by establishing a mapping of the density of hours of human activity in relation to a given set of categories of human activity and land uses (characterizing a giving multi-level matrix using per each compartment the resulting ratio: hours/hectares). A presentation of this approach, with practical examples and a preliminary analysis of the relative problems, is given in the document D of this case study. Therefore, in this section we want only to illustrate the rationale of a quantitative analysis per unit of land and some basic concepts that clearly point at the importance of extending the analysis of the metabolic pattern of society also to the land use side.

2. The importance of going multi-scale also in land use analysis

At this point we do not need to waste too much time to explain the importance to go multiscale also when performing analysis of the metabolic pattern in relation to land use. Two simple examples clearly illustrate this point.

Looking at the density of population in Canada we would classify this value among the lowest values found in the world – Fig. 16. However, looking at the geographic distribution of the population in Canada one finds out that more then 85% of the population lives close to the border with the USA in less than 4% of the total surface of Canada. When considering the density of population in the metropolitan areas, we may be surprised to find that the density found in Canada is comparable with the density found in many other areas of the North-East of USA. This is to say, that it is dangerous to rely on average values for the country, and it would be much more useful to organize our accounting on the expected value of flow density referring to specific categories of land use. This would make it possible to compare the characteristics of “apples” with “apples” and “oranges” with “oranges”.

Just to illustrate how important is this point, we show a map reporting the values of flow density expressed in €/ha/year, in Europe – Fig. 17. Looking at this map it is easy to realize that peak of flow density expressed in €/ha/year coincide with metropolitan areas. On this map we can literally see the various European capitals and major cities, described as blue spots on this map. This is to say, that we can guesstimate a certain density of “added value flow", using this benchmark, to be applied to the hectares of land use belonging to the category "European capital cities" or "European large urban areas".

Fig. 16 Example of the population density in Canada

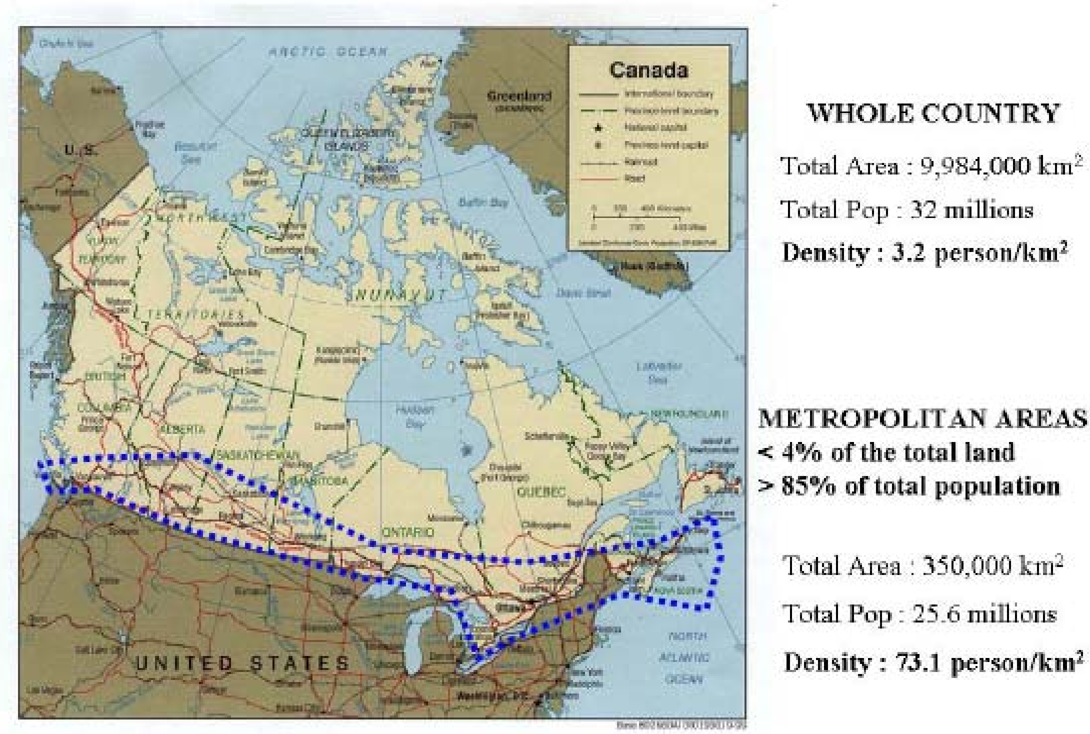
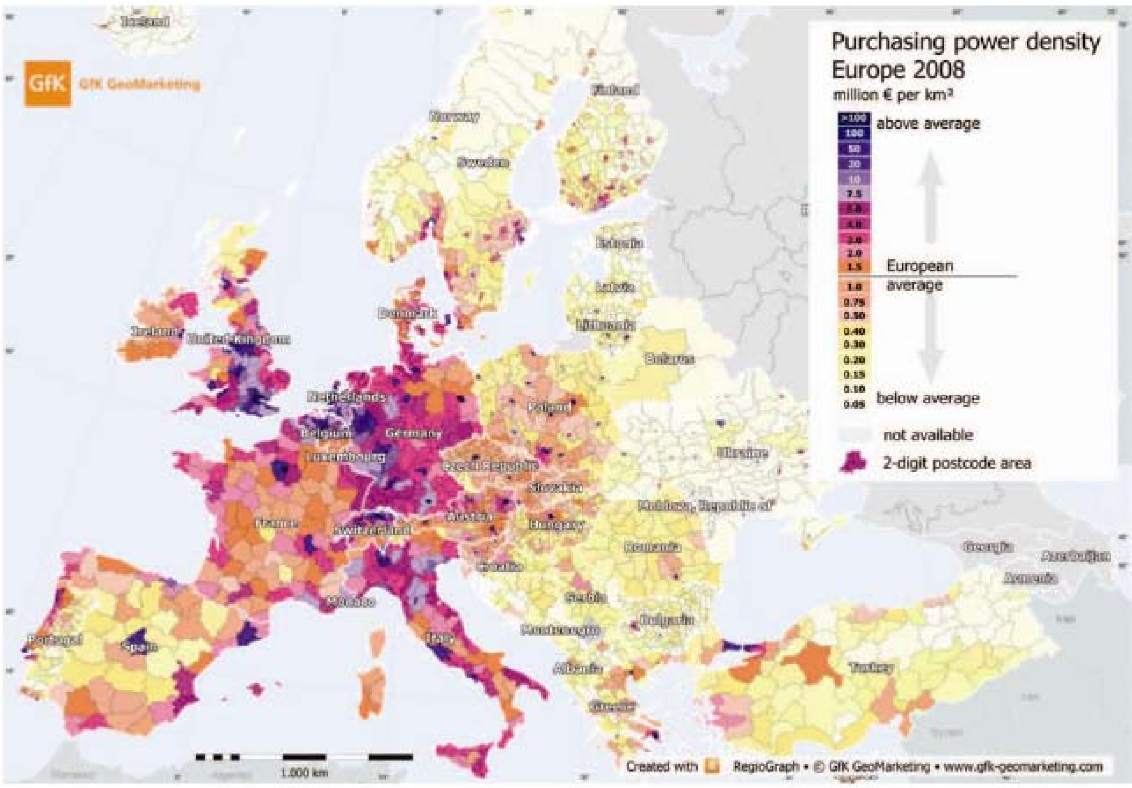


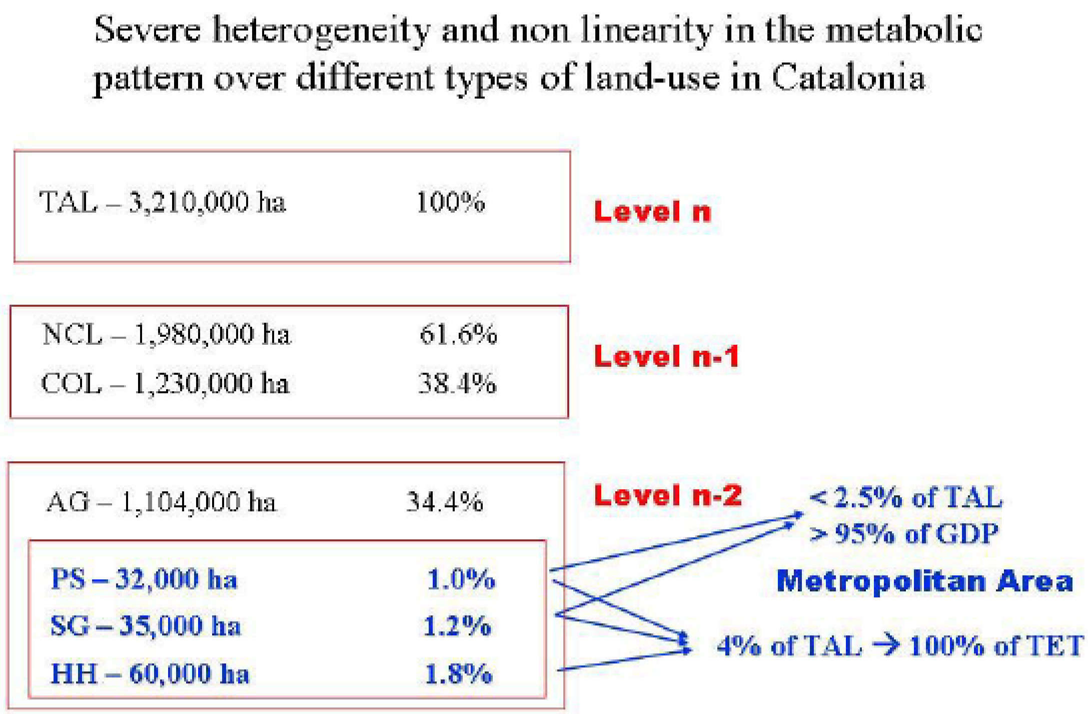
Fig. 17 Benchmarks of Flow Density (€/ha) map onto analogous land use categories



3. A multi-level analysis of the metabolic pattern of Catalonia

If build a grammar to divide the land uses of Catalonia into a multi-level matrix, we should start from the Total Available Land (TAL) which can be split into COL (Colonized land uses) versus NCL (Non Colonized Land). Then the COL sector can be split between: (i) land uses associated with consumption (residential areas – analogous at the category HH in the grammar illustrated in Fig. 1) and (ii) land uses associated with production of added value (the sum of land uses for AG, PS and SG, the equivalent of PW in the grammar illustrated in Fig. 1). If we organize the analysis of land use in Catalonia using this grammar – Fig. 18 – we find out a strong uneven distribution of the flows over the various categories.

Fig. 18 The non-linear distribution of FLOW densities over different FUND categories

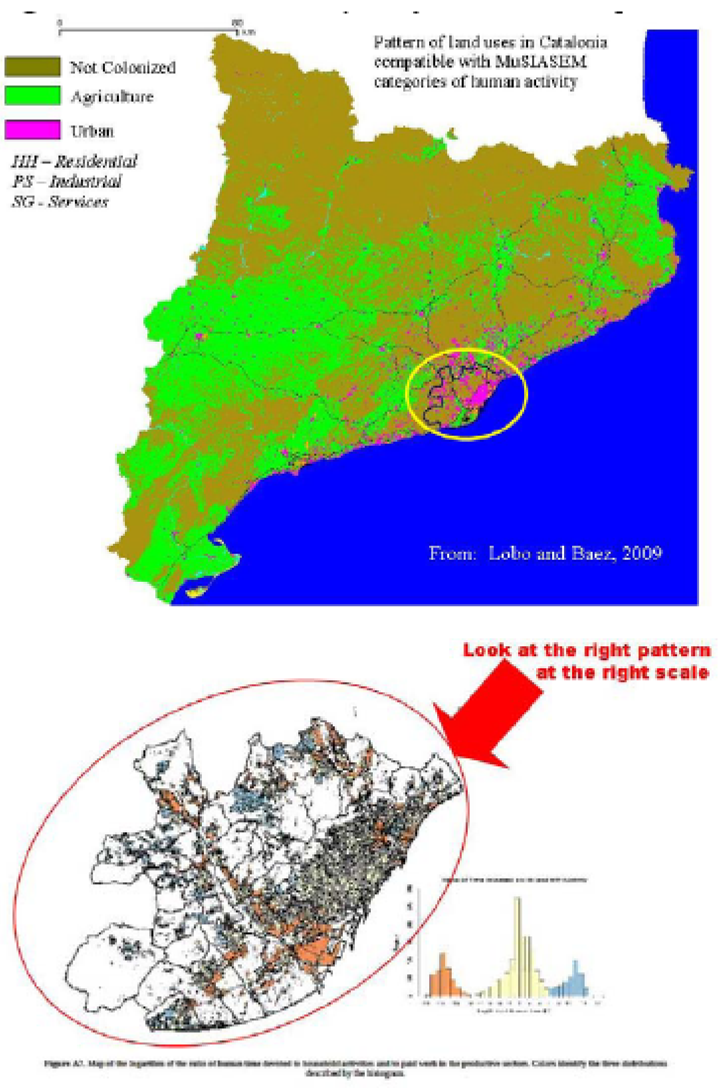


Looking at the data reported in Fig. 18 we can observe that less than 2.5% of Total Land of Catalonia generates more than 95% of the GDP. In the same way the people operating in 4% of TAL are controlling almost 100% of the Total Energy Throughput. This strong nonlinearity in the value of benchmarks (FLOW/FUND ratios) suggests that it is not wise to carry out an analysis of the metabolic pattern of Catalonia, based on the FUND "land use" adopting only a single level and a single scale of analysis. It important to get the big picture in order to be able to deal with ecological processes, natural resources, important geographic features relevant for social, political, economic, and ecological issues. But at the same time it is essential to focus inside the crucial core of 4% of land uses using a different level of resolution for the analysis. This double analysis of Catalonia is illustrated in Fig. 19. We have on the top of the figure a map indicating the relative location of the land uses comprising 96% of the area of Catalonia, and in pink the small spots of those land uses composing the 4% so crucial for determining socio-economic variables. On the bottom of Fig. 19 we have an example of the type of analysis, done at the level of the metropolitan area, in which it becomes possible to analysis pattern of land use associated with pattern of human activities.

At this level it becomes possible to establish a link between the set of societal functions includes in the grammar and the required investments of both: (i) human activity; and (ii) land uses, which are required to carry out these functions.

At this scale and level, it becomes possible to look for data capable of establishing a bridge between the profile of allocation of human time and the profile of allocation of land use within Colonized Land.

Fig. 19 The two levels analysis of the metabolic pattern of Catalonia in spatial terms



From: Lobo and Baez, 2009

4. Future lines of research

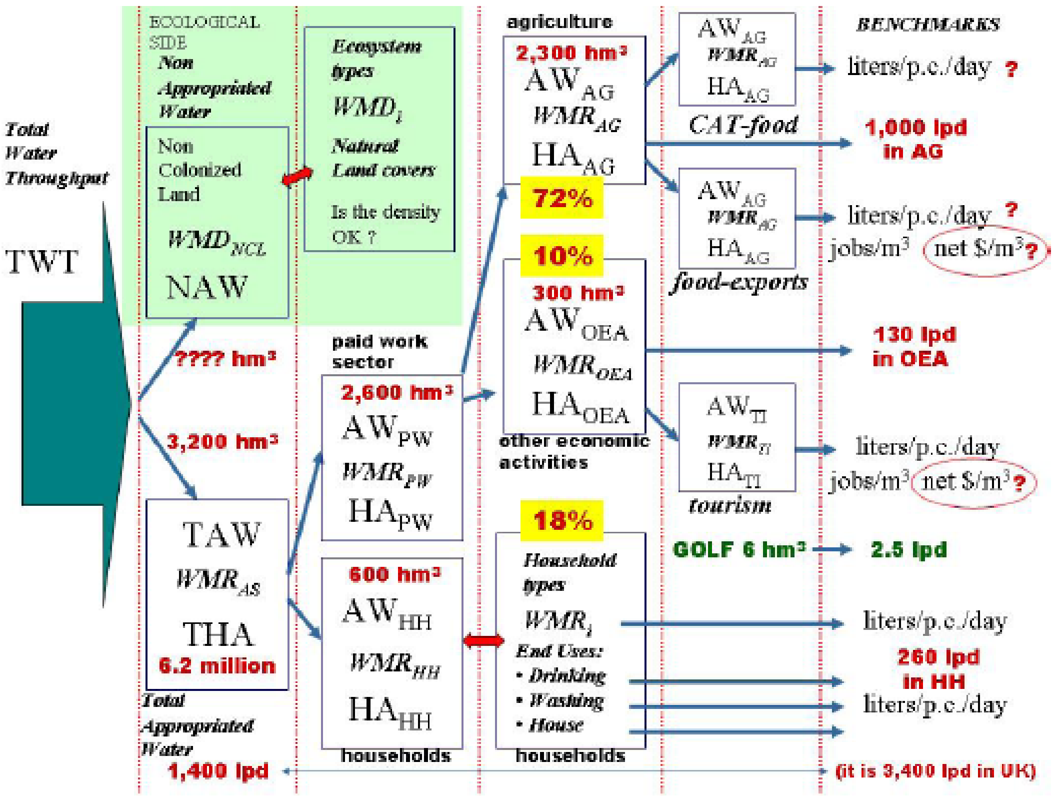
Before closing this section we would like to flag to the reader the extreme flexibility of the MuSIASEM approach. In fact after having established a bridge between the profile of human activity and land use (a bridge over the two multi-level matrices of FUNDS), then we can add several additional FLOWS to the analysis. That is after knowing how many hours of human activity are spent in a given category of land use ***i*** (hours per hectare belonging to this 27 category), then we can calculate the amount of flow per hectare in this category by adopting the simple relation FLOW/ha = Φi x HAi/LUi.

However, this relation can be used for other types of flows. For example:

Φi = EMRi = Exosomatic Metabolic Rate of that activity (MJ/hour)
Φi = ELPi = Economic Labor Productivity of that activity (€/hour)
Φi = WMRi = Water Metabolic Rate of that activity (liters/hour)
Φi = GMRi = Garbage Metabolic Rate of that activity (kg/hour)
Φi = FMRi = Food Metabolic Rate of that activity (kcal/hour or protein/hour)

Just to provide an example, taken from a preliminary analysis of the pattern of water metabolism of Catalonia (data are taken from a study of Prof. David Sauri), Fig. 20 shows an analysis of the metabolic patter of water, organized over a multi-level matrix of the FUND human activity. Starting from this choice of compartimentalization we will try to implement a grammar in which we will handle data with GIS techniques (an example is provided in Reports on Environmental Sciences – 2009#2).

Fig. 20 Analysis of water metabolism per hour and its possible analysis over categories of land uses



Because of its flexibility, the MuSIASEM approach can be applied to other relevant material flows. Beside water, the approach seems to be particularly interesting for the analysis of the metabolism of food, which can be carried out considering different categories of food products (on the supply side) and the requirement of different categories of nutrients (on the demand side), and the metabolism of wastes (domestic wastes from households, or industrial waste or for tracking special materials).