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Interlinkages and Forecasting made possible by the use of the DECOIN analytical tool kit

(Deliverable 4.3 of the Work Package 4 – prepared for the EU project DECOIN - No. 044428 FP6-2005-SSP-5A)

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ABSTRACT

This technical report is a document prepared as a deliverable [D4.3 Report of the Interlinkages and forecasting prototype tool] of a EU project – DECOIN Project No. 044428 - FP6-2005-SSP-5A. The text is divided into 4 sections: (1) this short introductory section explains the purpose of the report; (2) the second section provides a general discussion of a systemic problem found in existing quantitative analysis of sustainability. It addresses the epistemological implications of complexity, which entails the need of dealing with the existence of Multiple-Scales and non-equivalent narratives (multiple dimensions/attributes) to be used to define sustainability issues. There is an unavoidable tension between a "steady-state view" (= the perception of what is going on now – reflecting a PAST → PRESENT view of the reality) versus an "evolutionary view" (= the unknown transformation that we have to expect in the process of becoming of the observed reality and in the observer – reflecting a PRESENT → FUTURE view of the reality). The section ends by listing the implications of these points on the choice of integrated packages of sustainability indicators; (3) the third section illustrates the potentiality of the DECOIN toolkit for the study of sustainability trade-offs and linkages across indicators using quantitative examples taken from cases study of another EU project (SMILE). In particular, this section starts by addressing the existence of internal constraints to sustainability (*economic versus social aspects*). The narrative chosen for this discussion focuses on the dark side of ageing and immigration on the economic viability of social systems. Then the section continues by exploring external constraints to sustainability *(economic development vs the environment).* The narrative chosen for this discussion focuses on the dark side of current strategy of economic development based on externalization and the "bubbles-disease"; (4) the last section presents a critical appraisal of the quality of energy data found in energy statistics. It starts with a discussion of the general goal of statistical accounting. Then it introduces the concept of multi-purpose grammars. The second part uses the experience made in the activities of the DECOIN project to answer the question: how useful are EUROSTAT energy statistics? The answer starts with an analysis of basic epistemological problems associated with accounting of energy. This discussion leads to the acknowledgment of an important epistemological problem: the unavoidable bifurcations in the mechanism of accounting needed to generate energy statistics. By using numerical example the text deals with the following issues: (i) the pitfalls of the actual system of accounting in energy statistics; (ii) a critical appraisal of the actual system of accounting in BP statistics; (iii) a critical appraisal of the actual system of accounting in Eurostat statistics. The section ends by proposing an innovative method to represent energy statistics which can result more useful for those willing develop sustainability indicators.

Key-Words: sustainability indicators, multi-scale analysis, integrated analysis, sustainability, Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM), energy analysis, energy statistics, energy intensity, Primary Energy Sources, Energy Carriers,

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DECOIN – Deliverable D4.3 of WP4

Report on the interlinkages and forecasting made possible by the use of the DECOIN analytical tool kit

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1. The purpose of this report (EU project DECOIN deliverable 4.3)

The purpose of the deliverable 4.3 of the DECOIN project is: (1) to illustrate the potentiality of the DECOIN tool-kit for assessing interlinkages between the various trends observed in the current pattern of economic development, especially those relevant for the sustainability issue; and (2) to illustrate how the prototype analytical tool developed within the project kit can be used to improve the use of indicators in the analysis of sustainability trade-offs associated with these interlinkages. In particular, this report uses some of the results obtained in the SMILE project (another European project which follows-up the DECOIN project), in which the DECOIN analytical tool-kit has been used to analyze different sustainability issues in different cases study.

This report backs-up the claim that the DECOIN tool-kit represents a promising approach for the development of innovative analysis of sustainability trade-offs and interlinkages between sustainability indicators. It can be used to organize available data and information in an understandable and comprehensive form both for monitoring purposes and scenarios making. It should be stressed that the information provided by the DECOIN approach ***does not substitute*** the information provided by the conventional sustainability indicators, rather ***it complements*** the existing information by enlarging the perspectives and narratives about sustainability. In this way it boosts the usefulness of the whole package of indicators for decision making.

2. The problems with existing quantitative sustainability analyses

2.1 Typologies of problems associated with quantitative analysis

A theoretical discussion of the epistemological problems associated with quantitative analysis of sustainability has already been provided as a result of WP2 and it is available in the report ***Recommendations for the use of analytical frameworks for monitoring and policy making*** (deliverable D2.2 of this same project). Here we want only provide a few practical examples of the systemic weakness of quantitative analysis, when applied to the analysis of complex systems (= the sustainability of modern societies). These examples are useful to better frame what is presented in the rest of the report.

By definition a complex phenomenon is a phenomenon which can and should be perceived and represented using simultaneously several narratives, dimensions and scales of analysis (Ahl and Allen, 1996; Allen et al. 2001; Funtowicz et al., 1999; O' Connor et al., 1996; Rosen, 1977; 2000; Salthe, 1985; Simon 1962; 1976).

This represents a challenge for the generation of quantitative indicators, since, in order to be able to generate an accurate quantitative representation of an event, scientists must decide, first, to focus only on a limited subset of these possible scales and dimensions (Rosen, 1977; 2000; Giampietro, 2003; Giampietro et al. 2006). For this reason, any quantitative representation of a complex system – which must be based on the use of only a chosen dimension and a chosen scale at the time - entails a dramatic "reduction" in the set of possible useful perceptions and representations. This is to say that quantitative analysis entails an important epistemological trade-off: in order to gain a robust and accurate quantitative representation of one aspect of the investigated system (perceived by using just one dimension and one scale) the scientist must accept to lose the possibility

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of perceiving and representing other aspects, which would be relevant for other analysts having other interests and therefore purposes.

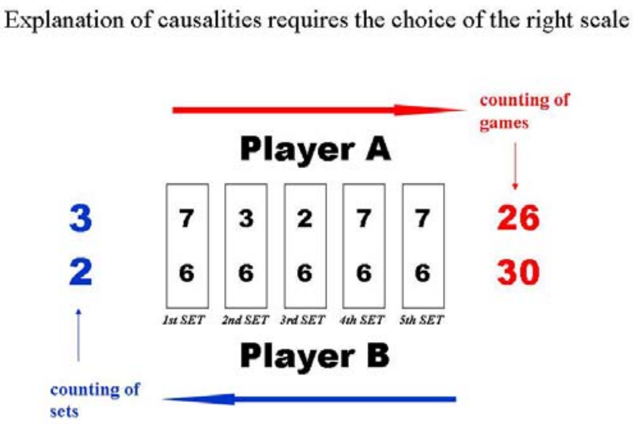
This is to say that when dealing with a complex issue such as the sustainability of modern societies, the power and strength of quantitative analysis may entail also a potential weakness due to the excessive reliance on reductionism, which they require. This point is beautifully explained by Box (1979), under the heading "all models are wrong, but some are useful" he discusses the usefulness of quantitative models as follows: "*For such a model there is no need to ask the question "is the model true?". If "truth" is to be the "whole truth" the answer must be "No". The only question of interest is "Is the model illuminating and useful?"*" (p. 202-203). This consideration points directly at the fact that the pre-analytical definition of the purpose of the analysis - why are we doing this analysis in the first place?, whose problems are addressed by this analysis? - will determine the usefulness and pertinence of the quantitative results.

In the rest of this section we illustrate a few practical examples of typologies of problems associated with this predicament:

2.1.1 Example #1 - Scale issues matter: it is essential to establish interlinkages between events taking place at different hierarchical levels

The example given in Fig. 1 deals with the analysis of a score of a tennis match.
In this example Player A won the match after winning three sets at the tie-breaker (with a score of 7 games to 6 in each one of the three sets). On the contrary Player B won only two sets with a score of 6-3 and 6-2. Let's now imagine that a scientist trying to discover the rules of tennis wants to individuate the winner, looking at that quantitative description (score). If he decides to use an index based on the accounting of the number of games won, he would get a wrong picture of the result of the match. In fact, Player B (who lost the match) won 30 games versus the 26 won by Player A.

Fig. 1 The multi-scale accounting of the score in tennis



This example may seem trivial, but as discussed below, it points at a very dangerous pitfall: one should never rely on statistical information gathered at a given hierarchical level – e.g. the household level, the sub-economic sector level, the whole society level - without having first seen and

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understood the “big picture” – the meaning of the relative numbers in relation to the rules governing the behavior of the investigated system. It is the hierarchical structure of relations across levels, which provides the meaning of the data gathered at different levels.

The example given in Fig. 1 illustrates also that it is not always true that by working more in details, carrying out more accurate measurements, one can always get a more reliable picture (or explanation!) of a given situation. In fact, let’s imagine that two different scientists trying to study this “unknown game” – one counting the “number of games won” and the other counting the “number of sets won” – get into a public scientific controversy about the determination of who is the winner. Let’s also imagine that in order to solve this controversy the scientific community would follow the traditional recipe of reductionism: gathering more accurate data, coming from a more detailed study. This decision may lead to a more accurate analysis of the recorded tape of the match. For example, a new team of scientists can keep record of the individual points won by the two players within each game. This additional check based on an additional dose of reductionism would simply add confusion to confusion. In a tennis match, the number of points won, does not necessarily map either in the number of sets or the number of games won by the two players. There is no escape from the necessity of having first of all a clear understanding of the meaning of the numerical relations found when observing a complex system operating across different levels of organization.

In the example given in Fig. 1 the three relevant rules to be considered for gaining understanding are: (i) how the winning of points within a game translates into the winning of games; (ii) how the winning of games in a set translates into the winning of sets; and (iii) how the winning of sets in a match translates into the winning of a match. In technical jargon this entails to develop a grammar capable of addressing the issue of scale: how to scale the analysis performed at one level to the next one. In fact, the challenge posed by complex systems is generated by the fact that, within different levels, one should expect to find different rules. That is, we cannot understand the emergent behavior of the whole if we do not establish first interlinkages between the various represented events referring to different hierarchical levels.

This problem can be described using various concepts such as: non-linear behavior, emergent properties, the need of using hierarchy theory. To make things more difficult, we have to note that determining the winner of the match – using a variable defined on the highest hierarchical level “number of sets won” - is not the only information which may be relevant when studying and characterizing a tennis match. If we are also interested in the duration of the match, then the variable we have to consider is the “number of points played” (defined at the lowest hierarchical level). Finally, by looking at the games won within each one of the various sets one can get an idea of the typology of the match. For example, a score of 6-0, 6-0, 6-0 indicates a overwhelming triumph in a match played over 5 set; whereas, a score of a 7-6, 6-7, 7-6 indicates a very tight win in a match played over 3 sets. This to say, that when compressing the information gathered about a complex system by reducing it to just a number – a single indicator - referring to just one of the hierarchical levels, we are losing a lot of potential information. For this reason, it would be wise to keep as much as possible the gathered information organized over different “variables” – categories – referring to different hierarchical levels.

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2.1.2 Example #2 – assessments per capita (using variable at higher level) miss important qualitative differences between societies (= the importance of demographic variables – referring to a lower level)

Economic development entails both quantitative and qualitative socioeconomic changes, which can be missed when adopting quantitative assessment "per capita" (e.g. GDP per capita, energy consumption per capita, number of teachers per capita). For example, the very same assessment of 'per 1,000 people' (equivalent to a 'per capita' assessment) can imply quite different supplies of work hours per year into the economy depending on the demographic and social structure of society. This difference is illustrated in Fig. 2.

In 1999, Italian population supplied 680,000 hours of work to the economy per 1,000 people, while Chinese population supplied 1,650,000 hours of work per 1,000 people (2.46 times more!). In China, 1 out of every 5 hours of human activity was allocated to paid work, while in Italy this was only 1 out of every 13 hours (Table 1).

Figure 2 *Relation between demographic structure and supply of work hours at the level of society (adapted from Giampietro, 2009)*

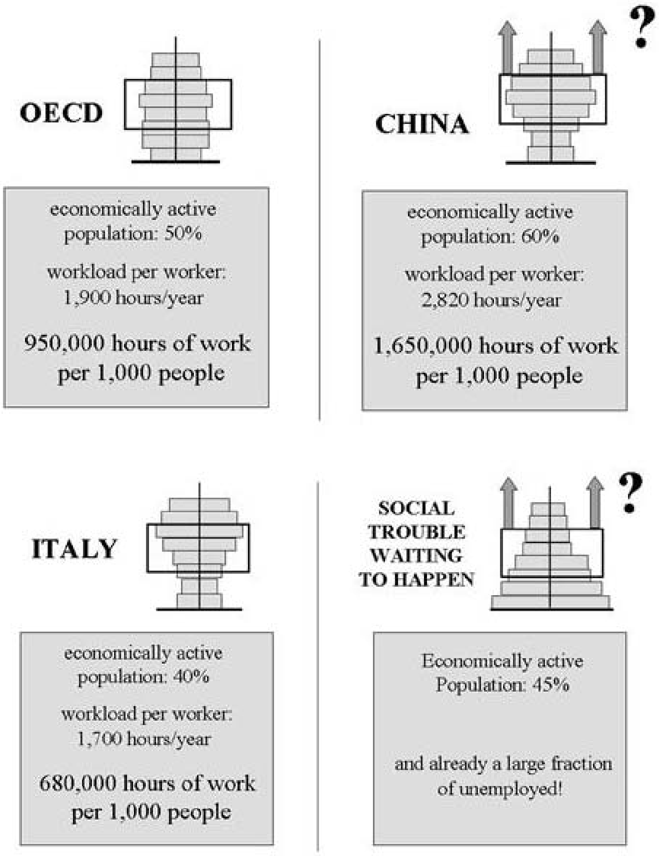

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Table 1 *Allocation of human activity (HA in hours) to paid work (PW) and household (HH) sectors for Italy and China in 1999 (per 1000 people per year); THA=1000 people x 8,760 hours/year, and* $THA= HA_{PW} + HA_{HH}$

	Italy	China
Total Human Activity (THA) in hours/year	8,760,000	8,760,000
Paid Work sector (HA_{PW}) in hours/year	680,000	1,650,000
Household sector (HA_{HH}) in hours/year	8,080,000	7,110,000
Ratio Paid Work/Total Human Activity (HA_{PW}/THA)	1/13	1/5
Hypothetical level of GDP (20,000€/year per capita)	**20,000,000**	**20,000,000**
Flow of added value to be generated in Paid Work!	**29.4 €/hour**	**12.1 €/hour**

This difference can be easily explained: more than 60% of the Italian population is not economically active, including children, students and elderly (retired). The human activity associated with this part of the population is therefore not used in the production of goods and services but allocated to consumption. Furthermore the active population, the 40% of the population included in the work force, works less than 20% of its available time (yearly work load per person of 1,700 hours).

The economic implications of this qualitative difference (per 1,000 people) on economic variable are illustrated in Table 1. If we imagine that these two countries were operating at the same level of GDP per capita – e.g. assuming a common value of 20,000 €/person/year – this difference in work supply would imply that in order to be able to generate the same level of GDP per capita, the amount of GDP produced per hour of labour in Paid Work in Italy would have to be 2.4 times higher than in China (29.4 €/hour versus 12.1 €/hour). This qualitative difference is at the root of one of the trade-offs linked to progress that will be discussed later on and it is completely missed if we adopt indicator of economic performance based on the "per capita" basis.

2.1.3 Example #3 – assessments of any variable at higher-level (the whole society seen as a black box) must be combined with assessments of variables at lower-levels (qualitative differences within economies) by looking inside the black box

The I = PAT relation - introduced by Elhrlich in the 80s - can be used 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

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effectively counteract the effects of increasing population (P) and affluence (A). That is, 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. However, 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" at the level n. This comparison is given in ***Table 2***.

Table 2. 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. 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?

To test the robustness of this result we can use a multilevel system of accounting proposed by the MuSIASEM approach. In this way we can "open up" the black box and move down the analysis through three hierarchical levels:

- **level *n*:** the "whole society"
- **level *n-1*:** the "Paid Work sector"; and
- **level *n-2*:** individual compartments within the economy (e.g. socio-economic sectors)

After opening the black-box we look for benchmark values referring to the proxy variables chosen to characterize the semantic categories A and T at level ***n-2***. That is, in this way we can look for indicators of performance referring to the level ***n-2***.

This characterization can be done both in economic terms (e.g. *extensive variable*: sectorial GDP; *intensive variable*: pace of added value generated per hour of labor) and in biophysical terms (e.g. *extensive variable*: energy consumption per sector; *intensive variable*: exosomatic energy spent per hour of labor in the sector). In this way, we can generate a different – richer – view of the key characteristics (expressed at a lower hierarchical level) generating the overall level of CO2 emission

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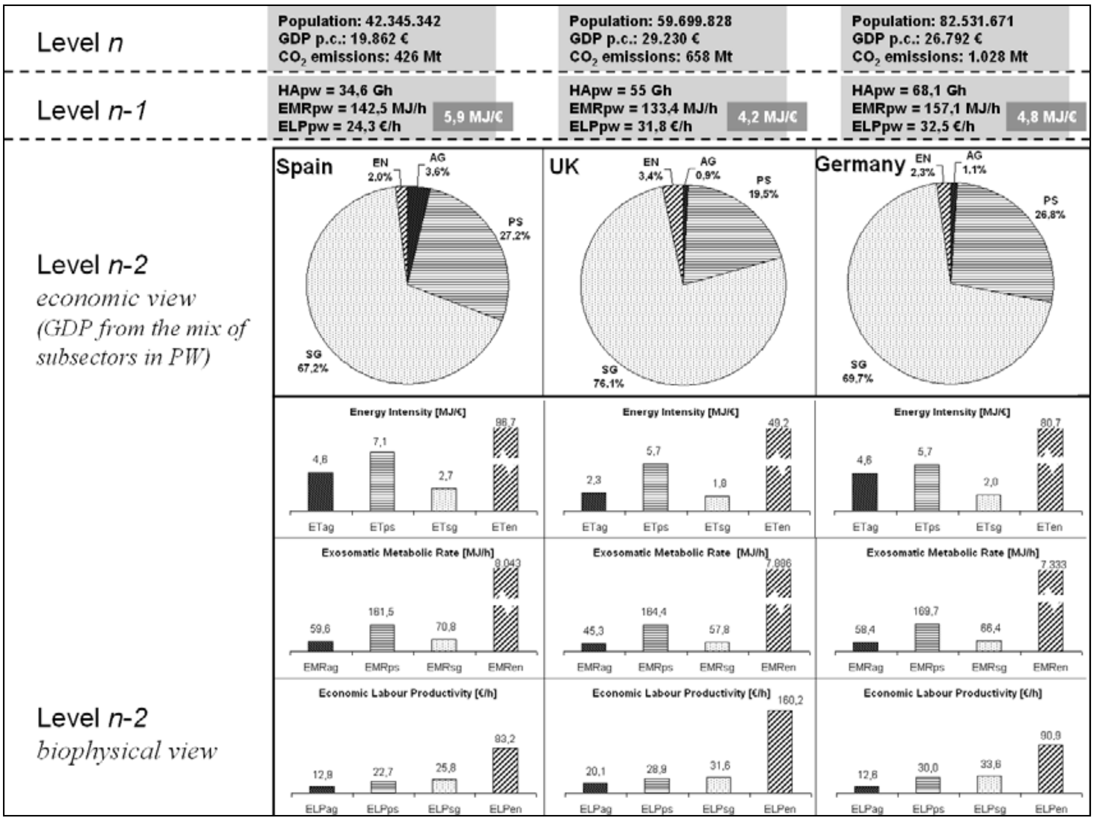
per capita and of the overall energy intensity (MJ of primary energy consumption/€ of GDP) – measured as aggregated value for the whole country.

Figure 3. Opening the "black-box": what is behind the "I=PAT" relation (Data source: Eurostat).



An example of what we see after opening the black boxes is given in ***Fig. 3***.

After moving to a lower hierarchical level (that is, the "Paid Work sector" inside the black box [level ***n-1***]), we can check for differences and similarities in sub-sectors of the Paid Work sector (i.e. socio-economic sectors at level ***n-2***) between the three considered countries. The three sub-sectors considered in this example are:

(i) **AG** = agriculture;
(ii) **PS** = Productive Sector (Building and Manufacturing, plus Energy and Mining);
(iii) **SG** = Service and Government.

For these three sub-sectors we can now compare benchmark values referring to both economic, demographic and energy related variables:

- Economic variables: Sectoral Gross Domestic Product per hour of Human Activity – GDPi/HAi – measured in €/hour (data from Eurostat EEA);

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- Demographic variables: Human Activity in the Paid Work sector (HAPW) and Human Activity in the Production sector (HAPS), Human Activity in the Service and Government sector (HASG), Human Activity in the Agricultural sector (HAAG) (data from ILO), and
- Energy related variables: Sectoral Energy Throughput per hour of Human Activity in the sector *i* – ETi/HAi – measured in MJ/hour (data from IEA).

As observed earlier, in order to be able to read the system across levels, the MuSIASEM approach uses assessment of energy and added value flows "per hour of human activity" instead of using values "per capita/per year".

As soon as one look at the integrated characterization (based simultaneously on economic and biophysical data) across the levels given in

Figure 3, we can make the following observations.
(1) the differences in the aggregate value of CO2 emission intensity (Table 1) have very little to do with the values of individual proxy variables used to characterize the semantic categories I, A, T at the level n-2. That is, the lower level of CO2 emission of the UK (Table 1) is not about a more efficient production of steel or construction than in Germany or Spain. Rather the differences in this value are more related to the different composition of the Paid Work sector in these three countries (UK does not produce the same level of steel and construction, and it has to rely more on import for its internal consumption).
(2) the different economic performances of these three countries depend on their different socioeconomic structures (i.e. different characteristics of the sub-compartments of the whole), that is by the relative importance of the different economic sectors. UK gets a large fraction of her GDP from the service and the financial sector.

Looking at this example we can conclude that the ratio MJ/€ measuring the energy intensity (***which is erroneously labelled as a proxy of*** Technology) either of a whole economy (at the level n) or of an economic sector (at the level n-1) does not have a meaningful external referent. In fact, this emergent property of the whole can be explained by both: (i) differences in technology over the various sectors (detectable only at level n-2 and level n-3); and (ii) differences in the relative profile of sectoral GDPs.

When using the chosen label (Technology) these values could (mis)lead us to think that Spain is using worse technology than UK and Germany. This may be true or not, but cannot be checked using these data. For example, when looking at the amount of fossil energy consumption per hour of work (a proxy of the amount of technical devices used per worker) of the Industry, Building and Manufacturing sector (PS) the three countries present very similar values: 161,5 MJ/h in Spain, 164,4 MJ/h in the UK and 169,7 MJ/h in Germany.

In conclusion looking at the dataset presented in

Figure 3 we can say that the differences of values in energy intensity (or CO2 emissions) found at the level of the whole economy do not necessary imply better or worse technology.

This point will be illustrated with practical examples using data from a SMILE case study, later on, when discussing of interlinkages and trade-offs associated with the strategy of economic development followed by the vast majority of developed countries. This strategy implies a continuous externalization of primary productions to developing countries and a clear priority given to the financial sector for the generation of added value.

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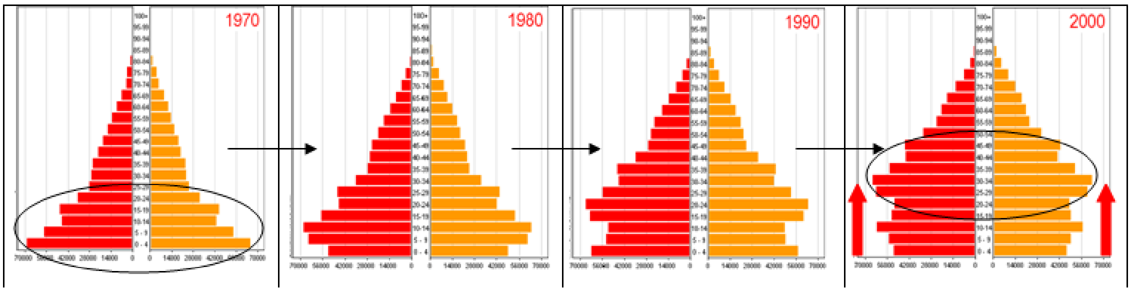
2.1.4 Example #4 – Multiple-scale [short-term vs long-term view] and Multiple-dimensions [steady-state analysis vs evolutionary analysis]

Demographic changes provide an easy example of lag time dynamics that imply a predictable trade-off in economic performance. As observed in Fig. 2 a wave of individuals moving across age class will determine a change in the performance of an economy, which can imply a different effect when considering short-term vs long-term.

Fig. 4 - A view of the changes in demographic structure in China 1970-2000



This effect is illustrated in Fig. 4. What is bad in the short term (in 1980) a high dependency ratio, associated with a baby-boom in the 70s, will become a very positive situation in the year 2000 (after 20 years), providing an incredible high fraction of working population. Needless to say that we can expect that the situation will revert again to bad in another 20 years when the dependency ratio will go up again because of the massive ageing of the population. Therefore, the example in Fig. 4 shows the existence of predictable pattern of qualitative (structural) change in time, which will determine a contrasting performance at different points in time (short term vs long term). But there are other systemic properties that can be associated to sustainability trade-off – or better entailing a sustainability dialectics, a sort of Yin Yang tension.

The first systemic property determining an example of sustainability dialectics can be associated with the tension between ***efficiency*** (improving the technical performance of a society according to existing goals and boundary conditions, through the elimination of obsolete types) and ***adaptability*** (boosting the diversity of possible types even though this implies reducing the overall efficiency by keeping types that are less performing) – Giampietro, 2003. This implies that the more a society is efficient in relation to a given set of boundary conditions (hyper-specialization), the more it will result fragile in the case the conditions will change. The extreme fragility of the livelihood of urban dwellers compared with that of rural dwellers in the case of a long black-out, strike of transportation or a situation of war is well known.

A second example of sustainability dialectics can be associated with the tension between ***an increase in the level of complexity of a society*** and the consequent ***increase in the risk of collapse*** of its organizational structure since the system is no longer able to adapt quickly in evolutionary terms (Tainter, 1988). This is a consequence of the systemic property discussed earlier. A continuous increase in the level of complexity of a modern society translates into the necessity to

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expressing several functions required for the correct working of the whole. One must be very efficient in order to express many functions, and this entails a progressive lock-in. The expression of many societal functions becomes a fact no longer negotiable. For example, within the EU health care is a must for European government. This service must be guaranteed to the citizens even if they do not have income and even if the budget of the government shrinks. In the same way big companies have to be kept alive by national governments, in order to preserve employment, even if their sector of activity is no longer economically competitive (e.g. the car industry in this moment of crisis). In general terms, we can say that the democratic process tends to prevent dramatic changes in the power structure. That is, a rich democracy tends to prevent swift changes and adjustments in their functional and structural organization, even in case of sudden and large scale crises. They prevent the implementation of what would be required to adapt.

These tensions associated with sustainability dialectics are obviously extremely relevant for sustainability analysis. But, they can only be analyzed when adopting an evolutionary narrative of sustainability. However, an analysis of evolutionary change poses an extreme challenge for quantitative analysis. In fact, evolutionary change implies that the society in the future will ***become something else***. Put in another way, it is not possible to make predictions using quantitative models and set of indicators of performance, which are based on the current picture of the society.

That is, when looking at existing indicators of performance and demographic dynamics one can guess a situation of instability. For example, we can develop an analysis that says: when the economy of China will reach a dependency ratio similar to that of Italy now, it is very unlikely that it will be able to generate a flow of added value of 29.4 €/hour of labour, since the large population would make quite unlikely the accumulation of a huge amount of capital per capita (required by this performance). However, such a model can only predict instability (lack of viability) due to demographic changes, but it cannot predict if this instability will translate into wars, riots, massive emigration, or rather in a positive transformation determining a new form of organization of social activities, which will make it possible for the society to work in a desirable way, in presence of a much higher level of dependency ratio. Such a model can only point at the existence of critical bottlenecks and at forced transformations to be expected in the future.

In relation to this tension between the “steady-state view” and “evolutionary view”, it should be noted that, so far, the development of sustainable indicators has been focused only on indicators of performance referring to the steady-state view. These indicators necessarily reflect a PAST => PRESENT definition of performance. That is, a definition which is based on the existing identity of the society (= what has been learned by society according to the known option space and boundary conditions). However, the tensions associated with sustainability dialectics suggest that a society which does well according to a given set of sustainability indicators, which are valid now, not necessarily will keep doing well when boundary conditions will change.

The very concept of sustainability should imply considering the fact that both the identity of the society and the boundary conditions will change in the future! Otherwise, if we imagine that the problem of governing the economic development of EU is only about governing a continuous improvement of all indicators, within a situation of perpetual steady-state, we should drop the label sustainability indicators. Looking for improvements in a situation of perpetual steady-state is something conceptually distinct from the idea of sustainable development.

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2.2 Looking for a wiser simplification of complexity: learning how to go beyond the narrative of the perpetual steady-state

The recent debate over degrowth (*décroissance* – Serge Latouche) can be seen as the resurfacing of a historic debate about the sustainability of modern progress which took already place in the 70s. At that time the debate was carried out by two sides called:
(i) "*cornucopians*" – those fully endorsing the ideology of neoclassical economics, maintaining that technology, human ingenuity and market will always be able to avoid biophysical limits to a continuous economic growth (e.g. authors such as Solow, Julien Simon). For these cornucopians perpetual growth is not only possible but the reality in which we live;
(ii) "*prophets of doom*" – those framing the issue of sustainability using biophysical and ecological analysis (e.g. authors such as Georgescu-Roegen, Ehlrich, Odum), claiming that natural resources and the fragility of ecological processes will impose limits to the idea of perpetual growth.

The result of the confrontation between "cornucopians" and "prophets of doom" is well known. Neoclassical economists stuck to a simplified vision of social development that had worked in the past - the richer, the better – a solution that worked well so far. In this simplification, the only important goal was to maintain momentum by adopting policies aimed at getting richer (maximizing GDP) at maximum speed. No quality control was ever applied to the validity of this narrative in the long term, since nobody but the powerless losers in the economic battle complained about it. The prophets of doom, on the other hand, did not deliver any valuable predictions. On the contrary, they rang alarm bells too early suggesting policies that were not welcomed by anybody. No wonder that cornucopians won the ideological battle!

The problem is that this win of the cornucopians has left an enduring legacy in the way modern society (especially developed countries) frames the issue of sustainability, which in turn determines the way we select sustainability indicators.

In fact, even if, in recent times, modern society learned about the importance of complementing economic indicators with ecological and social attributes of performance, the basic narrative about progress and development remained associated with the idea of steady-state. That is, additional attributes have been included in the set of sustainability indicators expanding the targets that have to be monitored, and this addition generated the concept of "sustainability trade-offs". That is, after having introduced different types of indicators referring to different dimensions of sustainability [the classic triadic distinction over ***the three E***: Economics, Ecology and Equity in social affairs] one can see the existence of "trade-offs" (improvements in relation to one target entail a worsening in relation to another target). Actually, the analysis of "sustainability trade-offs" is a key ingredient of conventional sustainability discussion (it is included in the title of this deliverable!).

The point to be made here is that the very concept of "trade-offs" is based on two heavy assumptions: (i) that the different changes associated with the concept of sustainability can be measured and compared exactly against each-other. This concept, in turn, is based on the assumption that the identity of the society "remains the same" through the sustainability ordeal. This requires assuming that the representation provided by the chosen set of sustainability indicators will remain perfectly valid also in the future; and (ii) that the existing situation of steady-state is stable and can be adjusted through smooth linear adjustments. The hypothesis of catastrophic events (wars, social unrest, ecological collapses) is never considered within the option space. May be, this is why

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climate change represents such a scaring hypothesis in the debate of sustainability. For the first time an event belonging to the category of catastrophes has been officially admitted in the option space associated with sustainability.

Unfortunately things are not that simple. This is an important point that we want to challenge in this report. Sustainability analysis is not about characterizing a given steady-state using a set of indicators and then measuring deviations (above or below the original targets) in terms of trade-offs. Rather sustainability analysis should be based on a characterization of an evolutionary process, in which: (i) both the observed system – the society – and the observer – the scientists studying it - change their own identity, in relation to the evolution of different tasks and priorities associated with the concept of sustainability; (ii) there is the possibility to be hit by perturbations in the current boundary conditions or in the internal set of functional and structural relations, which can push the system outside the viability domain.

To analyze an evolutionary process, the system of indicators used for such a characterization should be based on: (i) a semantically open representation (e.g. the use of multi-purpose grammars illustrated at the end of this document) and not just on a given dataset (a set of measurements over proxy variables) to be compared with the relative set of targets. This is required in order to be able to adjust to the fact that the system is becoming in time; (ii) an integrated set of viability constraints, capable of detecting unsustanability trends and risks of collapse across different hierarchical levels (at the micro, meso and macro level) and across different dimensions (economic, ecological, social, technical, demographic dimensions).

Since the main concept of this discussion – how to deal with the representation of real change - is quite elusive, we provide a short discussion - in Box.1 – of a practical example about the problematic use of indicators related to study of the effect of changes in energy efficiency. The box discusses the conceptual difference between the two labels: *“Jevons’ Paradox”* and *“Rebound Effect”*, used to indicate the effect of increases in efficiency in evolutionary terms. This topic is dealt with in chapter 3 of the book “*The Jevons’ Paradox and the myth of resources efficiency improvements*” (Polimeni et al. 2008). Mario Giampietro is the first author of this chapter, written within the activities of the DECOIN project.

Box 1 - The conceptual difference between “Jevons’ Paradox” and “Rebound Effect” when using the indicator “energy efficiency” to assess the effect on economic growth

The deep implications of Jevons paradox (= increasing energy efficiency will generate in the long term an increase in energy consumption rather than a reduction) are nowadays becoming more and more popular in the discussions over how to achieve sustainable development. However, there is an important confusion about the basic concept of Jevons’ paradox. In fact, economists refuse to adopt the expression Jevons’ paradox (= you cannot win against complex adaptive systems, their representation is necessarily elusive to formalizations) and they prefer to perform an analysis of this phenomenon under the framing of “rebound effect” (= you can describe changes determined by increase in efficiency in formal terms by using the ‘ceteris paribus’ assumption). Giampietro and Mayumi (in Chapter 3 of Polimeni et al. 2008) explain why “Jevons paradox” is not equivalent to “rebound effect”: a short resume’ of their discussion is given below.

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In the 80s the discussion of sustainability addressed the distinction between "growth" and "development". The difference was framed as follows: growth is about doing more of the same; whereas development is about becoming something else – it indicates evolutionary changes. The same distinction can be maintained in relation to the epistemological difference between "rebound effect" and "Jevons paradox".

When dealing with "rebound effect" the chosen characterization (the set of variables used to represent the system and the relative system of accounting) used to quantify changes remain the same. Therefore, those measuring the rebound effect represent change using a single parameter (an increase in efficiency) defined somewhere in the system (using a simple ratio over two numbers) and then, under the "ceteris paribus" assumption, they describe the resulting changes on the performance of the whole. This implies assuming that the same formal identity of the system remains valid "*before and after*" the change. That is, assuming that the initial quantitative representation of the semantic behind the analysis remains valid: technological changes can only generate "more" or "less" of "the same" pattern.

On the contrary, the concept of Jevons paradox should be associated to the phenomenon of structural and functional change – emergence of new features - due to evolution. Put in another way a change in efficiency entails a change in the identity of the system. Therefore this makes it impossible to measure, *using the same set of variables and attributes*, the relative change in performance – before and after. For example, let's imagine that we want to characterize the consequences determined by a change in the energy efficiency of cars. History teaches us that after achieving major improvement in efficiency, "old cars" became different models or "new cars". Modern cars can afford air conditioning – which is now available even in small cars. However, those studying the rebound effect over a given set of variables (e.g. "liters of gasoline consumed" over "miles of driving") can only study the well-known trade-off: more efficient cars are driven for much more miles. Such quantitative analysis misses an important part of the story: the increase in efficiency makes it possible not only to drive more with the same gasoline but also to change the identity of cars and the meaning of "driving". The miles driven before and after the change (the number measured when looking for the rebound effect) are apples and oranges! Since "cars" have changed their meaning in time, the quantitative comparison entails comparing miles referring to driving without air conditioning in primitive, unsafe and small cars versus miles referring to driving with air conditioning in fancy, safe and spacious cars. The identity of the attribute of performance (the driving of the car) has changed its meaning and this would require a different definition of variables. This is to say, the two situations – before and after – are not comparable using the chosen system of quantification.

The same reasoning applies to the use of monetary values to measure the effect of structural and functional changes in the economy. For example, when looking at the energy intensity of an economy, using the ratio between: (1) the aggregate consumption of resources; and (2) the total GDP of a country – e.g. energy and emissions per € of GDP. One should be aware that a given amount of € of GDP has a different meaning in different types of society. Therefore, one should be first of all able to characterize how similar or how different (in structural and functional terms) two countries, having different levels of GDP, are. This point is recognized even by the economists to a point that this point is at the basis of the epistemological patch that they often adopt when using PPP (Parity Purchasing Power), in order to compare the GDP of different countries. The problem is that this patch does not address explicitly how relevant are the criteria used to define the PPP factors (just an

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econometric analysis on the differences in price over a set of goods and services). That is, this patch is based on empirical data (their validity is PAST → PRESENT), which do no carry any robust information when discussing of future structural changes of future societies . . .

As a result of this lock-in on the steady-state view of sustainability (sticking with a formal identity used to represent a country at a given point in time), we assisted in the last decade at an incredible proliferation of indicators of sustainability. New relevant attributes and targets are continuously added - as required patches to the original selection of sustainability indicators - with the goal of covering more and more possible aspects of sustainability in relation to each one of the three dimensions: economic, social and ecological. However, this continuous flow of indicators does not seem to address in systemic way the implications of qualitative changes (implications of functional and structural adjustments on systemic properties of the society) versus quantitative changes.

We believe that it is necessary to get out of the narrative of steady-state (an unwanted legacy of the ideology of perpetual growth) as soon as possible. In fact, this narrative reflects the intoxication of neo-classical economic ideology based on various untenable assumptions:

(i) perfect substitutability of production factors – implying that it is not possible that either biophysical constraints – shortage of natural resources including energy, water or key minerals – or the resilience of ecological process, collapse of biodiversity, soil, biogeochemical cycles – will ever impose a limit on the expansion of global economy;

(ii) rational behaviour and utilitarianism of "individuals - implying that it is possible to optimize welfare for humankind for this generation (intra-generational equity) and also for future generations (inter-generational equity) in a substantive way! This translates in believing that it is possible to find a shared definition of welfare, values, equity which is accepted by men, women, young, adults, elderly, western democracies, Muslims, Buddhists, Jews, including the different native *indios* living in tropical forests.

(iii) possibility to generate a deterministic analysis of the world - implying the ability of making predictions, eliminating uncertainty and ignorance from the predictive power of science, as it would be required for the definition of optimal policies and solutions applied to the entire planet and assessed over a time span of centuries!

A narrative based on these three assumptions is at the basis of the belief that it is possible to define a system of sustainability indicators that is capable of individuating in an uncontested way what has to be considered, in substantive way, as "good" or "bad" for the development of "countries" (any type of country!). This chosen set of indicators and target values could then be used across different cultures, ecosystems types to characterize in quantitative terms the sustainability of the investigated societies, describing trade-offs and quantifying progress using a set of target values.

However, as discussed earlier, such a set of sustainability indicators, even if existed, could only reflect a PAST => PRESENT definition of performance. A definition of performance based on a given local story-telling about the sustainability of human society. A story-telling reflecting the given perception of risks and aspirations of a given social group (defined at a given point in space and time), which may not necessarily: (i) reflect the perception of risks and aspirations of other social groups (operating in different places in the planet); and let alone (ii) predict what will happen in the future (nobody can predict with reliability what will happen in the future!).

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Let's use again another simple example to illustrate the hidden danger of the steady-state narrative about sustainability. Let's imagine that we want predict the evolution in time of the fever of a person experiencing a quick increase in temperature. Starting with a first measurement of 37.5 C after a hour we get a reading of 38.5 C. Then after another hour we measure 39.5 C and again 40.5 C in another hour. The fever is increasing at a pace of 1 degree per hour. Obviously, starting from this dataset nobody would extrapolate that in the next 24 hours that person will reach a body temperature of 64.5 C. We know that there are biophysical limits to the possible increases in the temperature of a human body. This example teach us how important is to have a sound biophysical understanding, which is independent (non-equivalent) from the information obtained by the measurement scheme.

Let's now consider the expectation of a sustained economic growth of 2 or 3% per year typical of modern economies.

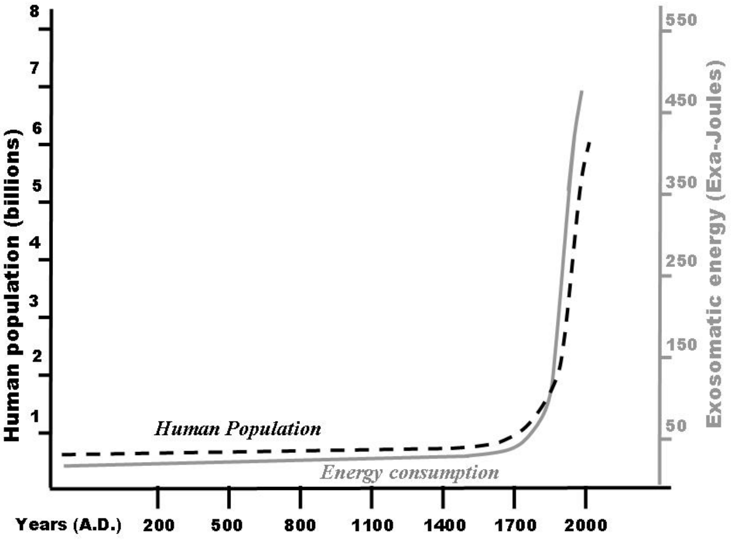

Fig. 5a – Trends of world population and energy consumption

Looking at Fig. 5a - we can see the trend of human development on this planet in the last three centuries as a dramatic and abrupt increase of both population and energy consumption per capita. An abrupt change determined by the industrial revolution. The phenomenon of globalization supported by the plundering of natural resources (made possible by fossil energy) and an increased stress on ecological processes has made possible, so far, this exponential expansion for more than 200 years.

However, the tale of the kernels of rice doubled over the chessboard reminds us of the incredible power of exponential growth. It is very unlikely that an exponential growth – which must be associated with biophysical flows - can last for a long period of time, in a finite context.

Therefore, the steady-state view of a sustained economic growth - tacitly assumed as possible in many discussions over sustainability - seems to have totally missed the biophysical view of this process. This point is visualized in Fig. 5b.

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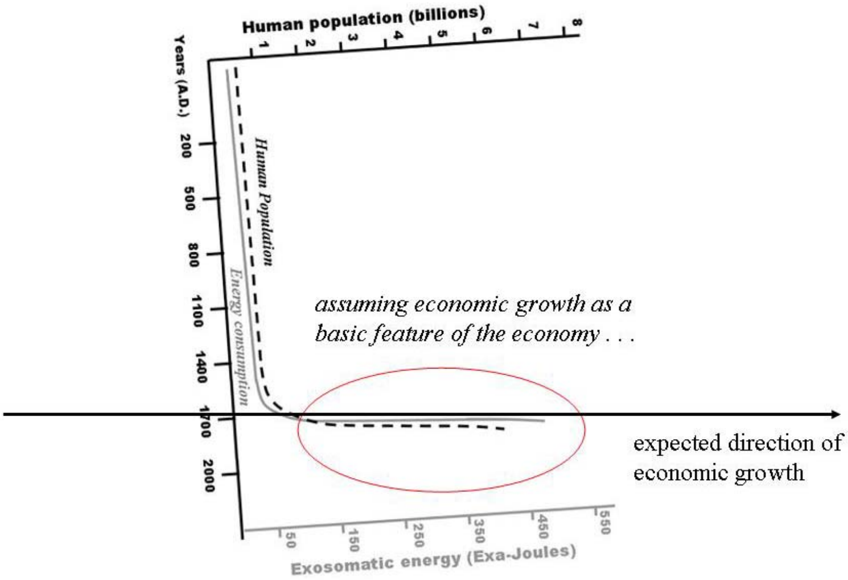

Fig. 5b – The narrative of steady-state of perpetual economic growth

The 200 years of continuous economic growth – more than 3 generations - have convinced the majority of people that it is “natural” to have a rate of economic growth of 2%-3% for developed economies. Actually, according to the theory of globalization of the economy it is also natural to expect an even higher rate – e.g. 7% - for developing economies (to catch up with richer economies, in the process of globalization of the economy) for ever. No government will ever say to its own voters that economic growth should be below 2% per year. As illustrated in Fig. 5b, this idea seems to be based on a ideological rotation of the axes of the graph given in Fig. 5a in order to get a perception of the reality in which, what those making biophysical analysis perceive as a very unnatural peak - something described by the exponential growth in the value of the two variables (total population and total consumption) - is considered by others as the baseline at which the world economy is supposed to work forever!!!

Obviously, nobody can predict what will happen in the future. However, the growing concern for Peak Oil and “Peak-everything” (an appropriate expression recently suggested by Richard Heinberg) summed to the growing awareness that existing ecological processes cannot be stressed any longer (e.g. collapse of fisheries, dramatic loss of biodiversity, unsustainable rate of deforestation and soil erosion – recently documented by the work of Millennium Ecosystem Assessment MEA, 2005 - casts doubt on the possibility to keep increasing forever, at an exponential rate, both population and the relative consumption of energy and other resources.

The curve of human population sooner or later will have to get out from its current path of exponential growth – Fig. 5c. One can only consider that the number of humans grew in the last 35 years of 3 billions, more than in the last 35,000 year. Obviously, the same pace of growth cannot be expected for the next 35 years.

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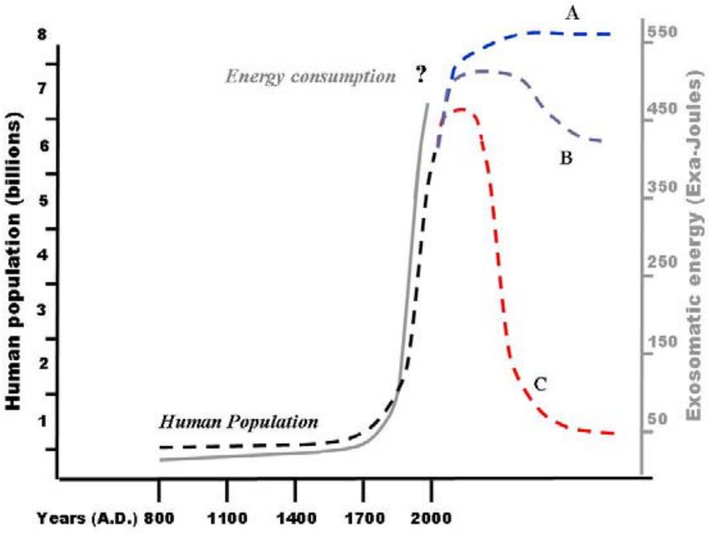

Fig. 5c – What future scenarios can we expect?

But if we admit that an important change must occur on existing trends (either generated by internal dynamics or external constraints), then it is obvious that the possibility of maintaining a large population on this planet at a decent material standard of living ***depends on the ability of readjusting dramatically and quickly the current structural and functional organization of society***.

In turn accepting this point raises the following question: IF swift changes have to be expected in the next 50 years, THEN how useful is the actual selection of sustainability indicators, which is based only on a set of targets characterizing the wellbeing according to the typical functional and structural organization of the founding states of the European Union over the past 50 years? It is obvious that the attributes of performance considered by the existing set of sustainability indicators are very effective in monitoring and representing the type of wellbeing that the EU has known so far, and it wants to maintain. But how useful are these indicators to study the feasibility and desirability of major functional and structural changes in the future of EU?

In relation to this point, we can appreciate the crucial importance of adopting a new system of characterization of the performance of socio-economic systems, which must be capable of catching both quantitative and qualitative changes across different levels when measuring the performance of an economy. Accepting the fact that necessarily - better sooner than later - the trends of population and resource and energy consumption per capita will have to change – it is crucial to explore the implications of the option space described in Fig. 5c. In fact, changing these trends will imply a dramatic readjustment of existing pattern of production and consumption of goods and services in EU. For this task a system of indicators capable only to detect changes in terms of “more or less of the same” can result problematic. When relying only on this set of indicators we will perceive as “a bad change to be avoided”, any change which is moving into the “wrong” direction according to the representation/perception based on the steady-state narrative. But if admit that this type of changes will take place anyhow, then it would be wiser to explore how can we steer the evolutionary process, within the viable option space, toward states that we like better than others.

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For example, getting back to the discussion of the concept of “de-growth”, the chosen label has been proved very effective in catching the attention of the general public. However, the word de-growth, interpreted within the steady-state narrative, suggests the idea of doing “less of what we do now”. Clearly this tends to be associated with something bad. Nobody would recommend policies aimed at reducing the GDP of a country. But this fact just reflects our addiction to reasoning of sustainability in steady-state terms. To avoid this impasse it is crucial to recall the distinction between development (qualitative change – becoming something different) and growth (quantitative change – more or less of the same). Jevons paradox proves that a change in efficiency (either up or down) does not imply either more or less consumption of energy in relation to the old pattern of consumption: the final result depends on the type of changes implemented because of this increase in efficiency. In the same way the ability of consuming more resources does not imply more happiness or progress. One can have indeed “too much” of a good thing (too much economic growth).

This point can be generalized by saying that: (i) it is not necessarily true that by increasing economic growth things will automatically “improve” [or “deteriorate”]; or (ii) it is not necessarily true that by obtaining a de-growth (according to a naïve interpretation of the idea) things will automatically “improve” [or “deteriorate”].

Therefore, the real discussion about sustainability should be focused on the fact that the only option we have to reduce the actual level of energy and resource consumption without reducing our wellbeing and material standard of living is that of changing our definition of performance for the society – our identity as a social system. In practical terms, we have to rethink the actual pattern of production and consumption of goods and services.

But accepting this point entails a severe predicament for the selection of sustainability indicators. In fact, after adopting a different definition of performance – when looking for development rather than for growth – then the previous quantitative characterization of performance (the set of targets used to define the performance of society now) loses its usefulness for evaluating the effect of future structural changes.

In order to explore possible ***alternative definitions of progress*** we cannot rely on a given selection of indicators of development based on current targets (based on the obsolete definition of progress – e.g. the actual model of consumerism).

In technical terms, this impossibility entails that we should no longer rely only on end-of-the pipe indicators of progress – the amount of goods and services delivered to society (the steady-state view focusing on the output of the economic process). We need to complement this picture by developing indicators capable of studying changes in the structural and functional features of socio-economic systems (systemic characteristics of the socio-economic process itself).

As indicated by Georgescu-Roegen (1971) this requires moving from:
(A) a description focusing only ***on the set of products and services*** produced and consumed by a society NOW - a snap-shot picture of ***flows*** in steady-state; to
(B) a description focusing ***on the set of processes (structures and functions)*** required for producing and consuming goods and services in a society – the ***funds*** of that society.

In conclusion, the expression sustainable development should be interpreted as “the ability of becoming something else, something which is desirable to society and compatible with boundary conditions”. Therefore sustainability indicators should focus not only on: (i) the “desirability” of a

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given society – a steady-state view of the perception of welfare perceived from inside the system; but also on (ii) the "ability of adjusting", when needed, by consuming less resources and by reducing the stress on both people and the environment – addressing the evolutionary view. This implies that the integrated set of indicators of sustainability to be developed to guide policy should enlarge their focus. At the moment they only address what has been perceived and represented as good and bad according to the recorded history. For a better discussion about the future they should also include the ***structural-functional view*** of performance required to deal with the evolutionary view.

When becoming something different (either consuming more or less energy resources, producing more or less GDP) what is important, it is to be aware and reflexive about: (i) what we want to become; and (ii) what it is feasible in our struggle for improvement. This second question depends on the option space determined by a combination of internal and external constraints (boundary conditions).

2.3 Implications for the choice of sustainability indicators

Starting with a weak characterization of the sustainability problem, we will be forced to go for a solution of continuous patching (increasing the number of indicators and measurements scheme added to the original characterization), which will not solve the original capital sin. The complexity of the concept of sustainability requires adopting a plurality of narratives and not just continuously increasing the number of indicators developed within the same narrative. Getting out of this impasse requires dealing with the systemic (epistemological) problems listed below.

** an integrated set of indicators cannot be based on a purely formal representation of performance (= a set of proxy variables, which is semantically closed).*
In fact it is impossible to maintain the meaning of "numbers ←→ proxy variables" over a large spatial domain. When dealing with a spatial domain as large as the European Union, it is impossible to find a proxy variable mapping onto the same attribute everywhere, in different contexts. For example if we want to monitor the situation in relation to a given concept – "the diversity of birds in the agricultural landscape" - it is almost impossible to find a bird species which works as a good indicator across all the European countries. Rather it would be better use the semantic behind this choice: "the diversity of birds in the agricultural landscape" as an indicator of the level of stress/health of agro-ecosystems (a semantic variable). Then one should keep the semantic associated with this indicator and focus on systemic properties that have to be formalized using different proxy variables in different typologies of ecosystems. The same reasoning can be adopted when characterizing the level of stress on social minorities in different countries. The problem can be solved by developing a system of accounting based on semantic concepts (the relevant attributes), to which one can assign different formalizations in different contexts (the indicators). It is the evaluation over the semantic concepts that matters not the particular formalization chosen in different contexts.

** an integrated set of indicators should cover different scales of analysis (= to cover the innate Yin-Yang tension between the steady-state view versus an evolutionary view).*
The steady-state view is certainly essential to make comparison among countries and to describe differences based on the current characterization of performance. Therefore, the existing set of

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conventional indicators is certainly useful and should be kept in use. It reflects the perception of the people living at a particular point in space and time. However, this local and steady-state view – the actual set of sustainability indicators - should be integrated by another type of representation capable of addressing two important components of societal sustainability:
(i) the characteristics determining the internal constraints - how the characteristics and the interactions between internal parts of the socio-economic systems (seen as a black-box) determine the desirability and the feasibility of a given situation; and
(ii) the characteristics determining external constraints - how the characteristics and the interaction of the socio-economic systems (seen as a black-box) with its environment determine the desirability and the feasibility of a given situation.

This more complex representation can no longer be obtained using a set of numbers (associated with the measurement of a relative set of proxy variables), which do not have any systemic relation among themselves, nor any reference to scale and hierarchical levels of organization. Rather the numbers associated with the chosen set of sustainability indicators should be expressed as a set of expected relations between: (i) parts and the whole; and (ii) the whole and its context. As illustrated below, the adoption of a meta-model of representation makes it possible to calculate different benchmarks useful for describing the relations of the parts between themselves, the parts with the whole, the whole with the context. These systemic properties can be used to represent key characteristics relevant for sustainability.

** an integrated representation of the performance of socio-economic systems should establish a link between indicators referring to different levels and dimensions of analysis (= explore the nature of interlinkages among indicators).*
By linking different levels (e.g. household, community, region, country, macroeconomic region, the whole planet) and different dimensions of analysis in an integrated representation it becomes possible to dramatically increase the robustness of integrated analysis of sustainability. For example, as illustrated below one can study how the economic viability is affecting the biophysical feasibility; how demographic structure is affecting economic performance; how changes in the pattern of human activities are driving changes in the pattern of land uses (described more in details in a couple of cases study of SMILE). In fact, the various indicators referring to different representations at different levels of analysis (households, local communities, provinces, nations, macroeconomic regions) and to different dimensions of analysis (economic, demographic, technical ecological) can be combined into a sort of holographic characterization of the interaction society/context. In this way, not only the representation becomes much more robust – e.g. one can double check the reliability of statistical data - but also it becomes possible to study the deep nature of trade-offs - the pros and cons of pulling the “short blanket” in a direction, rather than another.

As illustrated in the next section, a holographic representation of the changes associated with the issue of sustainability is what makes it possible to study the interlinkages across different indicators.

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3. The potentiality of the DECOIN toolkit to study sustainability trade-offs and linkages across indicators – examples from SMILE cases study

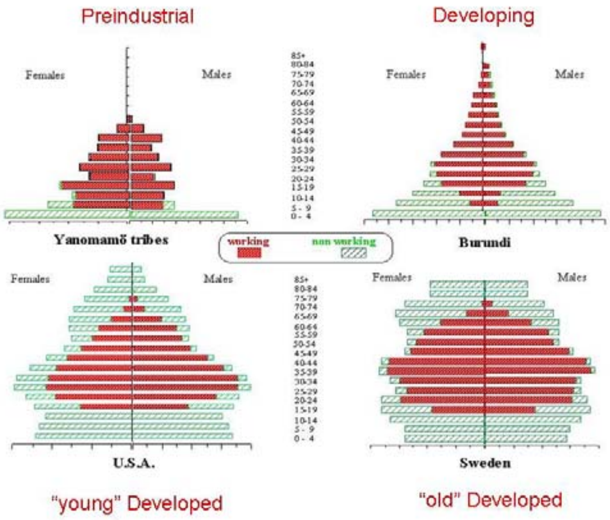
3.1 Exploring internal constraints to sustainability: the dark side of ageing and immigration on the viability of social systems - *economic versus social aspects*

3.1.1 Trade-off: Economic Development vs Economic Competitiveness

<u>Key mechanism</u>

* It is well known that an increase in material standard of living translates into a longer life expectancy. The relation between an increase in material standard of living and adjustment in demographic characteristics of a society is well known (e.g. the theory of demographic transition, the work of 1993 Nobel Prize in Economics Robert Fogel on the implications of demographic changes). Very shortly, we can see in Fig. 6 the differences in population structure between a pre-industrial society, a developing country and two developed countries. (Giampietro and Mayumi, 2000).

Fig. 6 Demographic structure of different societies at different level of economic development



When performing the same analysis within OECD countries, we can still observe a clear difference in population structure between countries at different levels of economic development. As illustrated in Fig. 7 Mexico and Turkey do have at the moment a population structure belonging to the "pyramid type" (associated with developing country), whereas richer countries, such as Sweden and Japan have a population structure belonging to the "mummy type" (associated with developed countries).

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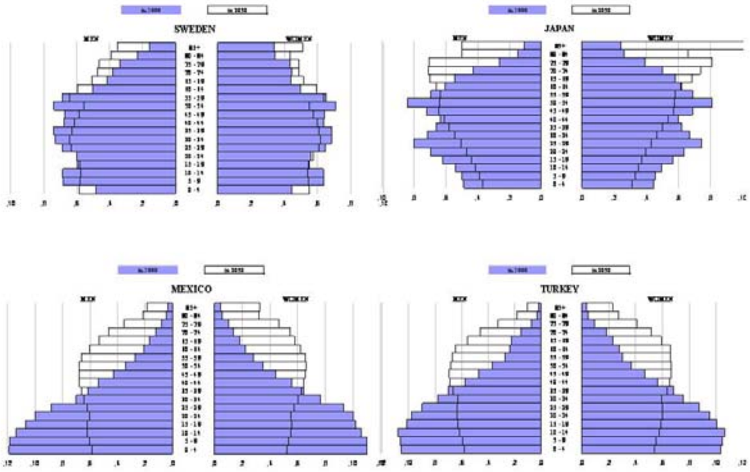
Fig. 7 Demographic structure of different societies in OECD countries



However, it is possible to see, from the projections of population structure, that in the year 2050 Mexico and Turkey, because of their economic development, will get into the “mummy type” shape as illustrated in Fig. 7 by the white bars describing the size of each age class. Obviously, these projections of demographic changes are based on the steady-state assumption of continuous growth of 3% of the global economy . . .

We saw before that population changes may entail a non linear change in the feasibility of the dynamic equilibrium between: (i) the requirement - what is consumed by the whole economy; and (ii) the supply - what can be supplied by the specialized compartments of society in charge for the production of goods and services. In particular the MuSIASEM approach can focus on this dynamic budget in terms of congruence over the flows that are produced and consumed per hour of human activity.

As illustrated in Fig. 8 we can see that there is a standard breakdown in the “expected” profile of human activity across different compartments of the economy, defined at different levels of organization. As illustrated in this example this implies that the amount of hours of human activity per capita available for each specialized task is very limited. In the example of Fig. 8 the task considered is producing energy carriers, but the same constraint applies to other tasks such as producing food, mining, generating an adequate supply of water, activity of doctors, teachers, etc.

In more general terms, we can use the same approach, used by ecologist to study the structural/functional organization of ecosystems, to study the set of internal constraints affecting the metabolism of a modern society. This implies studying the forced relation between what **can be** produced per hour by the different compartments of the economy (on the production side) and what **is required** by the various compartments of the economy (on the consumption side). A systemic discussion of how this set of forced relations can be investigated (more details on applications of “bioeconomics”) are available in Giampietro and Mayumi, 2009 – in Chapter 4 and Appendix II. An example of this type of analysis is shown in Fig. 9.

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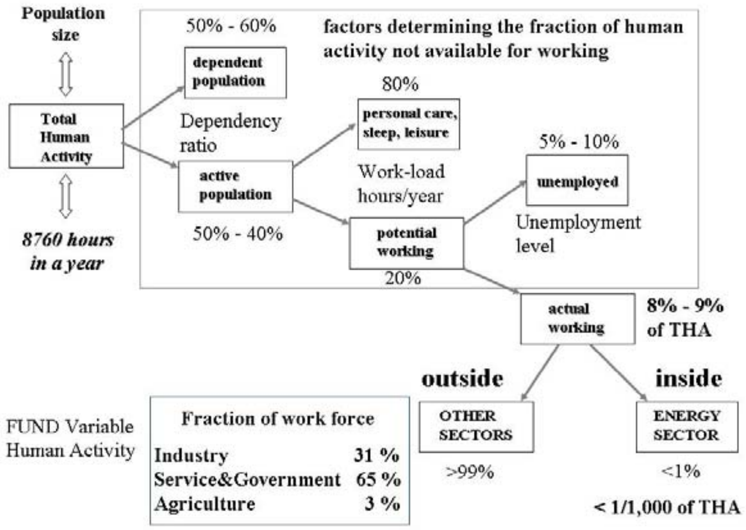
Fig. 8 The standard dendogram of splits of hours of human activity over different compartments of a developed economy (from Giampietro and Mayumi, 2009)



The trade-off between economic development and economic competitiveness can be now explained by the systemic change in internal relations which is associated with economic development.

Economic development entails an integrated set of changes in social variables: (i) longer life expectancy = larger dependency ratio; (ii) subsidies to unemployed people = longer periods of unemployment since the unemployed can wait for a desirable job offer; (iii) longer periods of morbidity in the work force; (iv) better level of secondary education = further reducing the economically active population within the work force; (v) smaller work load per year and paid leaves = reducing the actual work supply of the economically active population. The final result of this combined set of changes is an expansion of the size of the Household Sector – the hours of human activity allocated in consuming, by performing activities outside the Paid Work sector. The consequence of economic development is therefore a dramatic reduction of the ratio HA_{PW}/THA – the hours of work in the Paid Work sector versus the Total Hours of Activity of the society. As illustrated in Fig. 9 this value is less than 10% in developed countries.

Another important change associated with economic development is that not only the ratio between working and non-working is continuously reduced, but also that a larger fraction of the shrinking amount of working hours must be allocated into the compartments of services. That is, not only in a developed country per each hour allocated in Paid Work there are 12 hours allocated in final consumption, but also (and this is even more scaring) more than 60% of the working time in Paid Work is allocated in the services. That is when considering the flow of products we consume, in a modern society, per each hour allocated in producing products (in the PS compartment) there are more than 25 hours allocated in consuming them. That is, the more a society increases its level of consumption per capita, the more it reduces the amount of human activity allocated in producing

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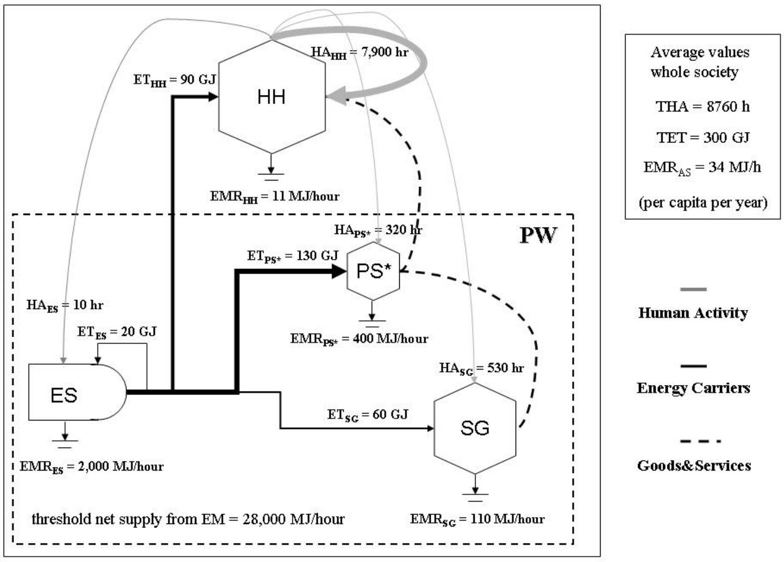
goods. The same phenomenon applies to the activities generating added value. This point is illustrated more in details below, when illustrating the analysis of interlinkages.

Fig. 9 – The forced relation between parts and whole in terms of relative size of funds and flows (the typical metabolic pattern) in a modern society



Implications

The implications of this mechanism are clear and can be visualized as in Fig. 10, where we can see (on the upper right quadrant – whole society level) that the value of ***GDP per hour at the level of the whole country (Spain)*** – 1.8 US$/hour - is determined by: (i) the value of the total GDP (611 billion US$) on the horizontal axis; and (ii) the value of 344 Giga hours (the hours of human activity in a year of 39 million people in Spain). Then on the left upper quadrant we can see the reduction in the value of THA (Total Human Activity) due to the social factors discussed before, leaving only 23 Giga hours (a mere 7 % of THA) available for the Paid Work sector.

This entails that at a given value of the ratio HA_{PW}/THA there is a forced relation between ***the level of GDP per hour of the whole society*** and the rate of ***production of GDP per hour in the Paid Work sector (*****ELP_{PW}*****)***. That is, ***IF*** ageing and other social changes are continuously reducing the ratio HA_{PW}/THA ***THEN*** either the GDP/hour (which is the same as GDP per capita!) will be reduced in the same proportion, or the economy must be able to continuously increase the value of ELP_{PW} = rate of generation of added value per hour of work in the Paid Work sector.

Using the label indicated in Fig. 10 we can write the following relation:

$$GDP/hours_{(societal\ level)} = ELP_{PW} \times HA_{PW}/THA$$

As it will be discussed later on, a continuous increase in ELP_{PW} can only be obtained by continuously re-adjusting the activities across economic sectors with the goal of increasing

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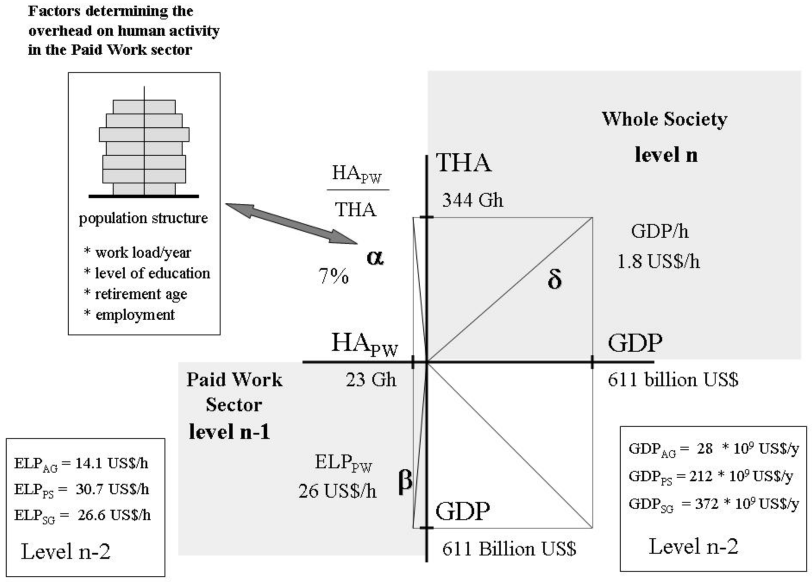
continuously the amount of added value of the products and services produced and consumed per hour of work in PW. One of the most popular solutions to this challenge among developed countries is to: (i) stop producing goods and rather importing them; (ii) use financial leverage to boost the amount of debt in the national economies. That is in developed countries ageing imposes a massive switch from industrial economy to the “bubbles economy”, as predicted more than 50 years ago by Soddy in his seminal book: “Wealth, Virtual Wealth and Debt”.

Fig. 10 The forced relation between the level of GDP of the whole and the rate of production of GDP per hour of the Paid Work sector (Spain, 1999).



A second implication relevant for this report is that economic development implies a systemic increase in the cost of labor (and wages) in developed economies. Goodland and Daly (1992, p. 135) provide a nice example of indirect factors over economic labor productivity. "... *a barber's labor volume and real output have not appreciably increased over the last forty or a hundred years, but his (deflated) income or value added has risen by a factor of four. The barber's increased real income has been generated by activities other than his own*". Clearly this second implication is crucial for the issue of immigration: the same phenomenon applies to a barber moving in space, rather than in time, from New Delhi to Amsterdam. Not only (as discussed in the next section) developed countries need immigrants, but also the gradient in wages, between developed and developing countries, makes emigration very popular among the people living in developing countries. The combination makes almost unavoidable the huge flow of immigrants experienced in this years by the EU.

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3.1.2 Interlinkages: Ageing → immigration

Key mechanism

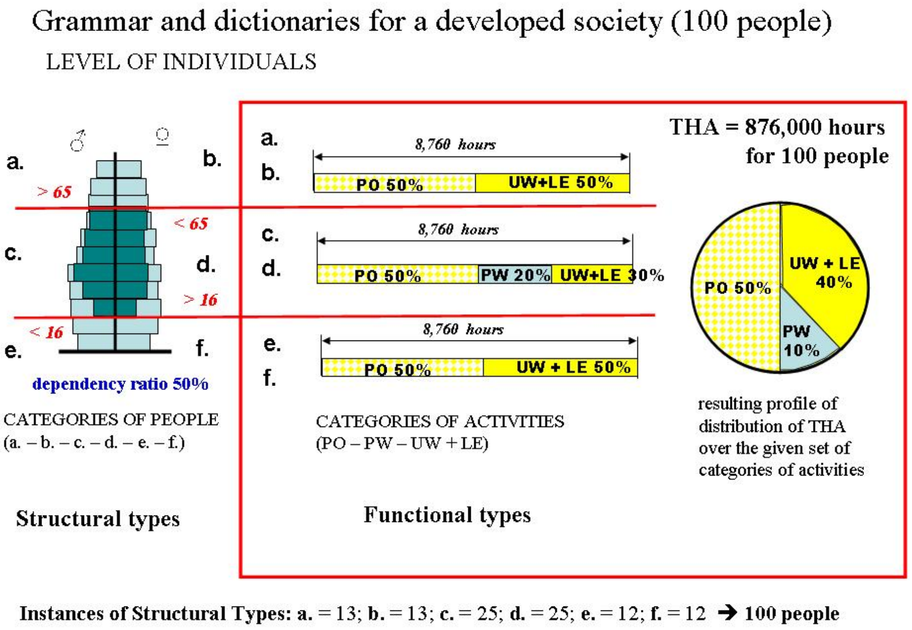
As observed in Section 2, in order to be able to understand the mechanism of interlinkages among different indicators one has to develop representations of the functioning of society across different hierarchical levels of organization.

In this section we briefly illustrate how it is possible to establish a bridge between the process of ageing (which can be described using indicators referring to the whole society level) and the process of immigration (which can be described indicators referring to the whole society level) in relation to an analysis of the functioning of the society across different levels of organization. This bridge requires interfacing different views and representations defined at different scales.

Bridging the representation of human activity across levels

The demographic structure of a society is intricately linked to the resulting pattern of human activity, in term of the profile of hours invested into performing different tasks. An example is illustrated in Figure 11. The analysis in Fig. 11 refers to a hypothetical society of 100 persons. These 100 individuals can be represented as a fund of total human activity (THA) of 876,000 hours/year (100 persons x 8,760 hours in a year).

Figure 11: A grammar establishing a relation between demographic structure and profile of human activities



At the hierarchical level of individual beings we can define a set of *structural* types determining what the system *is*. Put another way, we characterize the population as being made-up of a set of structural types of individuals, each category having a determined size depending on the

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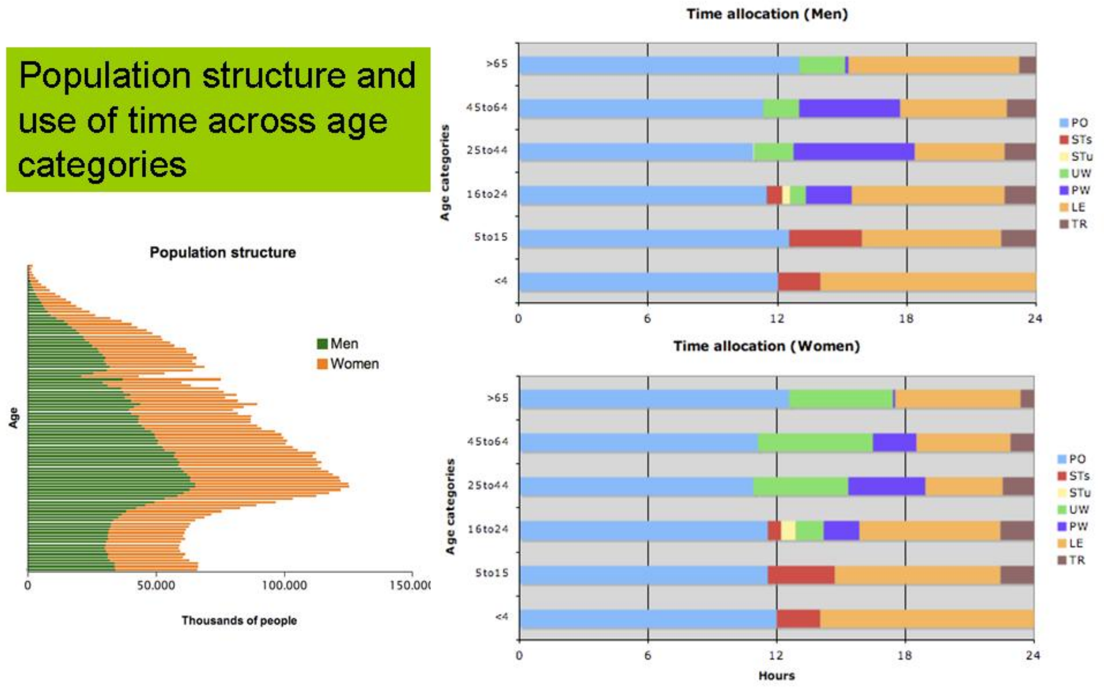
demographic structure. In Fig. 11 we distinguish six structural types based on: (A) age (3 groups: x_1 <16; 16< x_2 <65; x_3 > 65); and (B) gender (y_1 = males; y_2 = females); thus generating a 3x2 matrix. The population of 100 individuals (or 876,000 hours per year) is distributed over these six types according to the existing demographic structure.

At the same time, we have to define what the system *does* at the level of individual human beings. In other words, we have to define categories, or *functional* types of human activity. In Fig. 11, we distinguish three functional types of human activity (HA) to which time is dedicated (tasks): (i) physiological overhead (HA_{PO}), comprising activities essential to human survival such as sleeping, eating and personal care; (ii) paid work (HA_{PW}); and (iii) other activities such as household chores, leisure and education (HA_{HC+LE}) .

The simple grammar in which each structural type maps onto a known pattern of human activities (functional types) is shown in the middle of Fig. 11. In this way, it is possible to map the structural profile of the population (the given pattern of structural types on the left) onto an overall profile of distribution of human activities (a distribution of functional types at the level of the whole society on the right). An example of the application of this method to the analysis of Catalonia is given in Fig. 12. It clearly shows that different types of individuals (e.g. elderly, children, adults) do express different patterns of activities, and therefore they do have different preferences and requirements for goods and services. This confirms that socio-demographic variables do matter for studying the patterns of production and consumption of a society.

Figure 12: An application of the grammar presented in Fig. 11 linking the demographic structure and human time use in Catalonia (2007)



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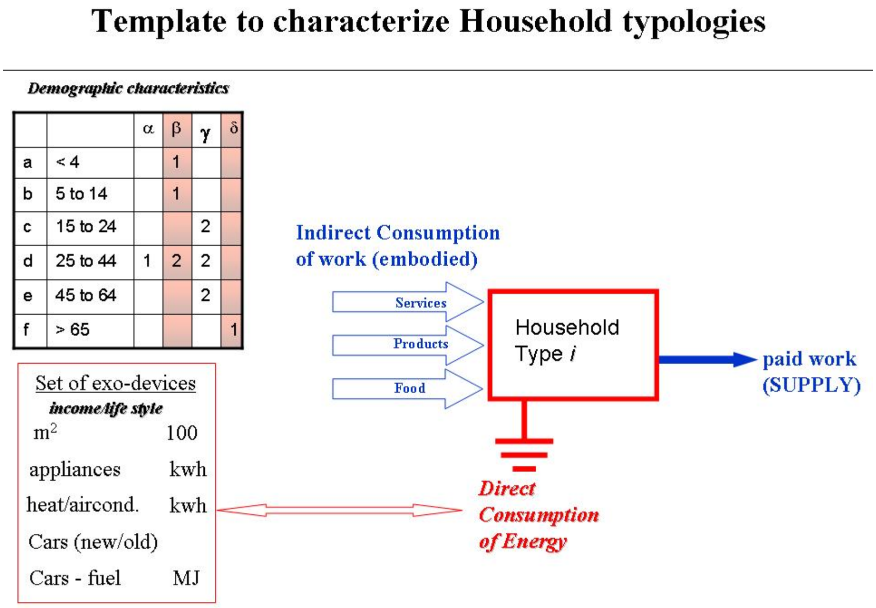
Including in the analysis of the profile of human time allocation, the analysis of the pattern of household metabolism

When considering a hierarchical level higher than that of individuals, we can link structural household types to pattern of household metabolism. For example, we can characterize household types in relation to their *direct* exosomatic energy consumption (energy that is directly consumed by the household) and *indirect* exosomatic energy consumption (energy that is consumed at the level of the economy to produce the goods and services consumed by the household). Having selected a set of relevant categories (a grammar) for such a representation, we can establish a relation between a relevant set of categories used for defining structure (typologies of individual human beings and exosomatic devices such as the house, appliances, cars) and functions, which can be associated to the definition of different typologies of households. This is illustrated in Figure 13. The definition of a household type makes it possible to associate a known levels of metabolic rate per hour of human activity spent in the Household compartment (this include also Leisure and Cultural activities outside the house!). Two cases study of the SMILE project present applications of the method – on in the metropolitan area of Barcelona, one in rural Laos – in which the analysis of changes in the pattern of human activities is related also to the relative changes in land use.

Figure 13: A grammar to map direct and indirect consumption of household typologies



		α	β	γ	δ
a	< 4		1		
b	5 to 14		1		
c	15 to 24			2	
d	25 to 44	1	2	2	
e	45 to 64			2	
f	> 65				1

A different profile of distribution of the population over defined typologies of households will change the overall characteristics of the household sector as a whole. An example of this relation is shown in Figure 14 for the metropolitan area of Barcelona (Catalonia), based on a simplified grammar based on only four household types relevant to that society.

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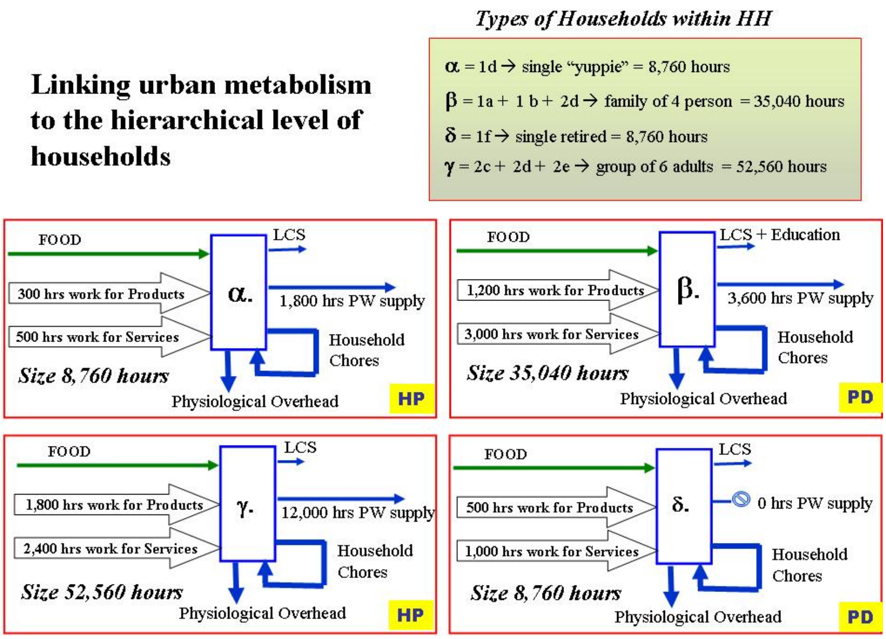
Indeed, also at the hierarchical level of the household, we can define a set of *structural* types determining what the system *is*: (A) the exosomatic devices associated with the household type (residential characteristics, use of personal car, house appliances); and (B) the profile of hours of human activity invested in different tasks. At this point we have a criterion to be used to characterize the final consumption compartment of a society, by expressing the population of a society in terms of a population of household types.

Figure 14: Characterizing Urban Metabolism of Household Types for the Metropolitan area of Barcelona (data from Gonzalo 2009)



The size of these different types can be expressed in terms of hours of human activity. In the example presented in Figure 14, we distinguish the following household types:

- Type α: single adult household, economically active: its size is 8,760 hours/year (1 x 8,760);
- Type β: classic family consisting of adult couple and two children: its size is 35,040 hours/year (4 x 8,760);
- Type γ: household consisting of 6 adults: its size is 52,560 hours/year (6 x 8,760);
- Type δ: single adult household, retired: its size is 8,760 hours/year (1 x 8,760).

Given the profile of distribution of a population of households over the chosen set of types, we obtain the overall profile of distribution of hours of human activity over the chosen household types. In turn this will map, through the information available over the metabolic rates per hour of human activity, into a metabolic rate for the household.

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In this way, we can define what the system *does* at the level of the entire household compartment (at the level n-1 of final consumption) in terms of the chosen set of categories of human activity defined in relation to flows of services, products, and added value. In other words, the chosen semantic categories are mapped onto quantitative assessments referring to the interactions that household sector (as a whole) has with the rest of society.

Within this framework we can see that households supply hours of paid work (PW) to the society. However, at the same time they require a certain amount of services and products, which entail for their production an investment of energy, material, and hours in the paid work sector. Therefore we can distinguish between household types: (i) the so-called *dissipative* household types, such as type δ in Figure 14 are net consumers of hours of paid work; they consume more hours of paid work (embodied in services and products) than they deliver to the paid work sector; (ii) the so-called *hypercyclic* household types, such as type α in Figure 14 are net providers of paid work hours to society, they deliver to the paid work sector more hours than they require.

Having established this relation, we can see that certain demographic changes such as population greying – a growing proportion of elderly in the population – will translate into a change in the profile of distribution of the population over the household types (e.g. a relative increase in type δ in Fig. 14). In this case, the demographic change will translate into a sharp increase in bio-economic pressure, that is, a reduced supply of work hours and a concomitant increase in demand for goods and services. These economic effects of greying of the population can in principle be counterbalanced by a relative increase in strongly *hypercyclic* household types, i.e., households supplying much more work hours than they demand – in the simplified example given in Fig. 14, these are households made up of several adults (type γ). As a matter of fact, in a preliminary analysis of the province of Barcelona the type of household composed of several adult immigrants stocked in small apartments has been the fastest growing household type over the past 10 years, together with the single elderly households.

This is an example in which a phenomenon of emergence – the system becoming something else by adding new typologies – can be predicted by examining the critical situation caused by actual demographic trends. The possibility of foreseeing the appearance of new categories required for describing typologies – something impossible for semantically closed systems of inference such as dynamical systems made of differential equations – is a major plus of our methodology.

Obviously, this analysis can be done with more accuracy using a larger set of household types than the one exemplified in Fig. 14. In fact, in the Case Study of Catalonia (SMILE) we have elaborated preliminary grammar based on a set of 9 household types (covering more than 80% of the total population). Some of the results have been already included in two papers: Ramos et al. (2009) and Gamboa (2009). In conclusion this approach makes it possible to study how the distribution of human activity and the relative requirement of products, services and metabolic rate, are affected by demographic changes and by the “movement” of hours of human activity across the various typologies of households (according to the type of analysis illustrated in Fig. 13). That is, a given number of people – say, 10,000 – will both “consume energy directly” and “require embodied work and energy for services, products” in a completely different way, if they are organized: (A) in

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1,667 households of type γ; (B) 2,500 households of type β; (C) 10,000 households of type α (single workers); or (D) 10,000 households of type δ (single elderly). The overall characteristics of the pattern of consumption will define the characteristics of the pattern of production (as illustrated next).

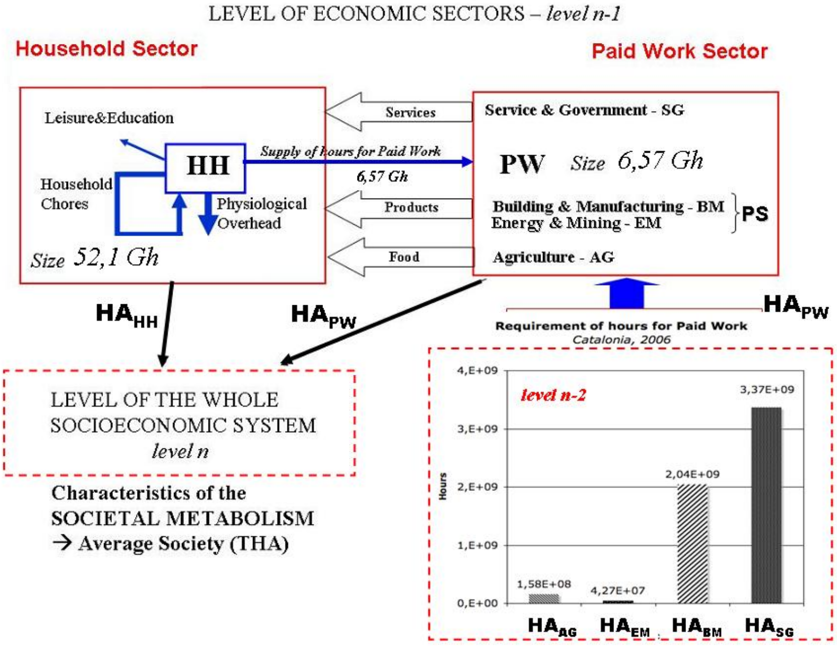
The dynamic budget between requirement of human activity and supply of human activity between the Household (HH) and the Paid Work (PW) sector

In this quick overview of our bridge across levels, we skip, in first approximation, the analysis dealing with the difference in the characteristics of the Urban versus Rural Household types, since in developed countries both the diversity and the relevance of Rural household types in determining the overall pattern of metabolism of the Household sector is negligible. The analysis of the difference between rural and urban households, however, would be crucial when dealing with China or India.

Depending on the characteristics of the chosen set of Urban household types and the given profile of distribution of the population of households over the chosen set of types (the information given in Fig. 13, Fig. 14 and Fig. 15), we can calculate the overall flow of products and services required by the HH sector (on the side of final consumption) – aggregate at the **level *n-1*** - and at the same time the supply of hours of work that the HH sector provides to the PW sector.

This analysis, applied to Catalonia, is given in **Fig. 15**.

Fig. 15 *The dynamic budget of hours of paid work (requirement vs supply) between the Household Sector and the Paid Work sector – Case Study of Catalonia - 2007*



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The overall amount of Total Human Activity (THA) per year in Catalonia is 58.8 Giga hours (6.7 million people x 8,760 hours/year). Recalling the relation - THA = HA_{HH} + HA_{PW} - we can say that this fund of human activity of 58.8 Ghours is divided between activities outside the Paid Work sector (HA_{HH} = 52.1 Gh) and activities within the Paid Work (HA_{PW} = 6.6 Gh). According to this analysis we can also say that the HH sector is supplying ***the amount of working hours required by the PW sector*** to perform its activities.

The multilevel analysis described in Fig. 15 can be used to understand the dynamic budget determining the viability of this pattern of metabolism. When representing the characteristics at the *level n* we obtain the standard indicators referring to the country as a whole, people, employment, GDP, flows of goods and services. But if we move across hierarchical levels, to the *level n-1* – addressing the distinction between the production side and the consumption side of the economy - then we can see that the division of THA (Total Human Activity) between consumption (HA_{HH}) and (HA_{PW}) determines a bridge between social indicators and economic performance determined by the ratio HA_{PW}/THA (see discussion in the previous point). If we move down another level – the red box on lower right corner of Fig. 15 – at the *level n-2*, the level of the economic subsectors, we address the existence of another relation of congruence over subsectors: in fact PW (Paid Work) is the sum of AG (AGriculture); EM (Energy and Mining); BM (Building and Manufacturing); and SG (Service and Government)

$HA_{PW} = HA_{AG} + HA_{EM} + HA_{BM} + HA_{SG}$

In semantic terms this means that the available work supply – the 6.57 Gh supplied by the household sector - must be divided among these 4 sectors competing for working hours. This new constraints can be calculated also using a bottom-up direction. That is, given: (i) the overall requirement of goods and services expressed by society; and (ii) the technical coefficients of the various activities carried out in the different subsectors, we can determine the requirement of jobs for each sector.

With the analytical scheme provided in Fig. 15 we can discuss of the implication of an increase in the **Bio-Economic Pressure** (**BEP**) associated with economic development. An increase in BEP is determined by an increase in the requirement of goods and services at the very moment in which the supply of work is decreasing, and a dramatic increase in the requirement of services is experienced in PW.

Looking at the relation of congruence illustrated in Fig. 15, there are very few options for a society facing a continuous increase in BEP. The options are:

(1) to externalize the requirement of work for products by importing, rather than producing, labour intensive goods (e.g. from China);

(2) to import workers from elsewhere (immigration) for those activities which cannot be externalized - e.g. low paid services such as cleaning, cooking, assistance of elderly;

(3) to use the financial leverage – i.e. spreading debts across different hierarchical levels to increase as much as possible the generation of virtual added value per hour of work.

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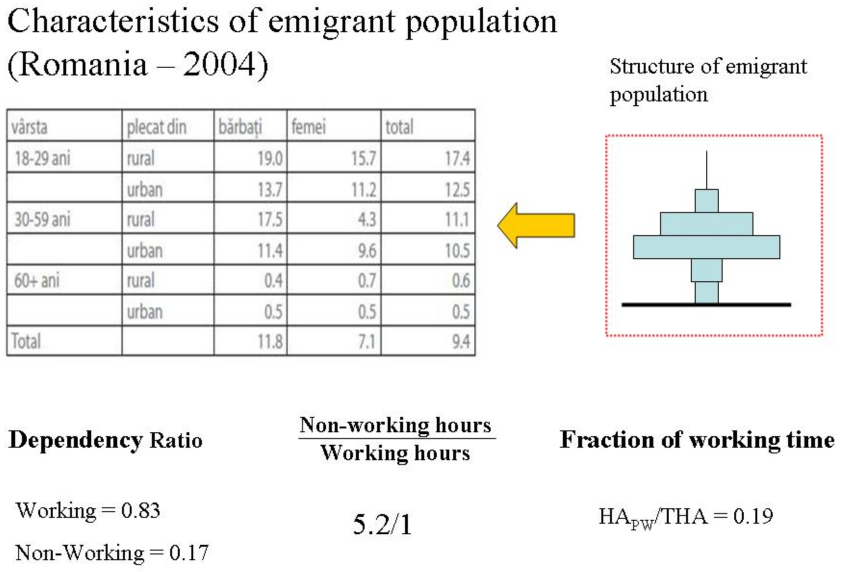
As a matter of fact, these three options represent the exact picture of the strategy of development followed by developed countries in the last decade.

The patch to the problem of shortage of work supply provided by the immigrants

As illustrated in Fig.16 (from the case study of Romania) below a flow of immigrants is effective in boosting the ratio HA_{PW}/THA of the society receiving them. In fact, immigrants have a much lower dependency ratio (83% of the individuals belong to the work force) and a much higher ratio of working hours/non-working hours (5/1) than the analogous values found in developed countries (less than 50% of the individuals belong to the work force, with a ratio of working hours/non-working hours higher than 12/1). The problem is that, as discussed below, the resulting improvement, associated with the change in population structure does not last for long . . .

Fig. 16 The demographic structure of the immigrants coming from Romania



Characteristics of emigrant population (Romania – 2004)

vârsta	plecat din	bărbați	femei	total
18-29 ani	rural	19.0	15.7	17.4
	urban	13.7	11.2	12.5
30-59 ani	rural	17.5	4.3	11.1
	urban	11.4	9.6	10.5
60+ ani	rural	0.4	0.7	0.6
	urban	0.5	0.5	0.5
Total		11.8	7.1	9.4

Dependency Ratio

Working = 0.83

Non-Working = 0.17

$$\frac{\textbf{Non-working hours}}{\textbf{Working hours}}$$

5.2/1

Fraction of working time

$HA_{PW}/THA = 0.19$

Implications (the trade-off short term vs long term)

The patch obtained with the inflow of immigrants works, but only: (A) in the short terms; and (B) if the economy is in a period of economic expansion or steady-state. On the contrary it can become a source of big troubles in a period of recession (as illustrated in the last years by the widespread problems in the suburbs of European cities where immigrants are the majority of residents).

The analysis illustrated in Fig. 12, Fig. 13 and Fig. 14 can easily explain this fact. At the beginning the immigrants live in big households made up mainly by adults. However, after a while, they become legitimate members of the new society and in this way they change the profile of distribution of households. By doing so, they increase the type of households purely dissipative (requiring more work than is supplied by the household). In the long term, the immigrants that

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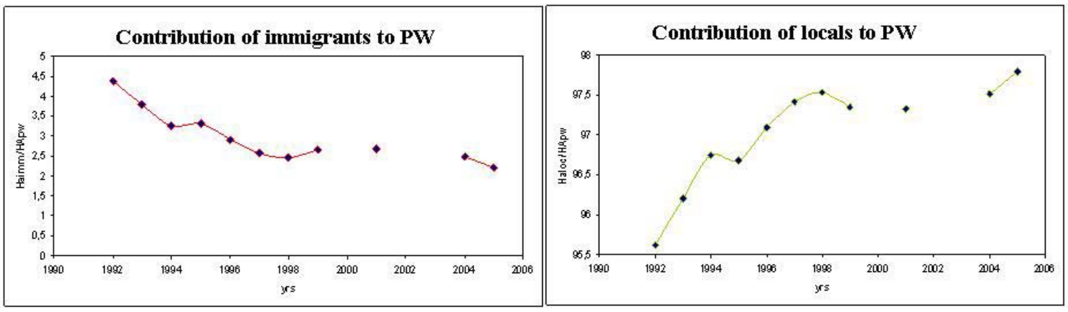
originally were only individuals belonging to the workforce, will start to retire. In this way they will increase even further the number of household types with a negative balance of working time.

Fig. 17 Turkish immigrant contribution of working hours to the economy of Germany



An example of this phenomenon is given in Fig. 17, based on data from Germany, a EU country in which it is possible to study the long term effect of the immigration of the 70s. From the comparison of the two graphs, it is evident that the supply of working time to the Paid Work sector of the Turkish immigrants has been significant in the 80s, but then in the 90s has been constantly less and less relevant.

We do not have an analysis of the structure of households in types (in terms of the balance of hours of paid work supplied and required) and the profile of distribution of household types in Germany. Therefore we are not be able to say whether, at the moment, the households of the first and second generation of Turkish immigrants are consuming more hours of work than they provide to the German economy. However, by extrapolating the data of Catalonia and by looking at the data of Fig. 17, this seems to be a very likely hypothesis.

3.2 Exploring external constraints to sustainability: the dark side of current strategy based on externalization and "bubbles-disease" *(the trade-off economic development vs the environment)*

3.2.1 Trade-off economic development vs the environment

<u>Key mechanism</u>

In this section we want to show that the change in the pattern of metabolism of European societies (associated with a decrease in energy intensity) in the last decade can be easily explained by a change in the profile of productive activities of the economy. This means that by using a favourable terms of trade and relying as much as possible on financial transactions, the EU has been able to externalize those economic activities more intensive in terms of: (i) consumption of natural resources (including energy); and (ii) environmental impact; to developing countries. In this way, it has been possible to move the shrinking EU work force on those activities in the service sectors and in the productive sector, which were providing more added value per unit of energy. This has required

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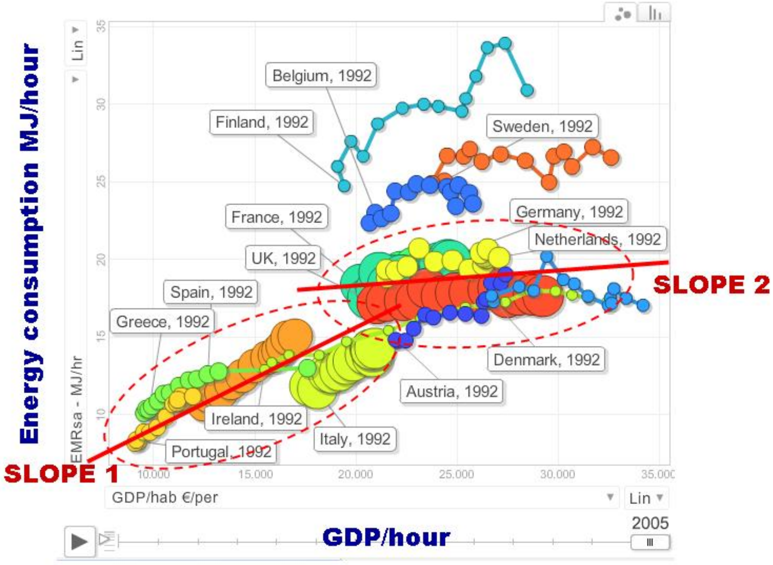
covering: (i) the internal demand of services on low paid jobs with immigrants; and (ii) the internal demand of labor for intensive and resource intensive products with imported goods, outsourcing work in the services whenever possible.

To illustrate this point, let's start by looking at the change in time of the profile of energy intensity of EU countries. To do so, we use a plane having on the two axes:
(i) energy consumption per capita (vertical axis); and (ii) GDP per capita (horizontal axis). This graph is shown in Fig. 18. It should be noted, that in order to be able, later on to study these changes across levels, we provide these two values in MJ/hours and €/hour. To obtain the equivalent value of MJ or € per person per year one has only to multiply the value found on the axes by 8,760 (hours per capita per year).
A few notes about this graph: (i) the original point indicating the starting position of each country in 1992 is indicated by a label identifying the various countries; (ii) the position of the country is represented year after year to visualize the change over the historic series (from 1992 to 2005); (iii) the relative size of the country (indicated by the size of the disk) is reflecting their population size.

Looking at the trajectories of European countries one can note two different slopes:
Slope #1 – refers to a simultaneous increase in time of the values on both axes – that is, over this period countries like Portugal, Greece, Spain, Italy did increased their GDP but they also consumed more energy;
Slope #2 - indicates an increase in time of the value of GDP faster than the increase in energy consumption – that is, over this period countries like Germany, France, the Netherlands (and other northern European countries not shown in this figure) have been increasing the rate of generation of GDP quicker than their increase in consumption of energy.

Fig. 18 Energy intensity of different countries in EU (1992-2005)



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As anticipated in Section 2.1.3, the analysis of this trend (a reduction of energy intensity of the countries with higher levels of GDP) led to the formulation of the Environmental Kuznet Curve hypothesis – that is energy intensity is reduced with economic growth, because of the adoption of better technology.

We claim here that the robustness of this hypothesis is very doubtful. In relation to this claim, it can be very instructive to analyze the trend expressed by the various countries (represented in Fig. 18) at the level of the whole society, after opening the black box, by looking at the internal changes of energy intensity at the hierarchical level of individual subsectors (level n-2) – this is done below. The differences found among countries in Fig. 18 can be explained by making hypotheses based on common sense and our general knowledge of the various countries. For example, we can hypothesize that the higher energy intensity of Belgium in relation to EU average is a legacy of its heavy industry based on coal in the 60s. In the same way, we can explain the higher energy intensity of northern countries – such as Finland and Sweden - with the higher consumption of energy associated with the expression of the same function expressed by the other European countries in a colder environment at a much lower density of population. However, by opening the black box and comparing the performance of each sector and subsector in terms of benchmarks, at lower hierarchical levels, we can actually check the validity of this type of hypotheses.

Let's start this exercise from the comparison of the evolution in time of the energy intensity of the three countries compared in Section 2.1.3 – Tab. 2 and Fig. 3 - Spain, Germany and UK.

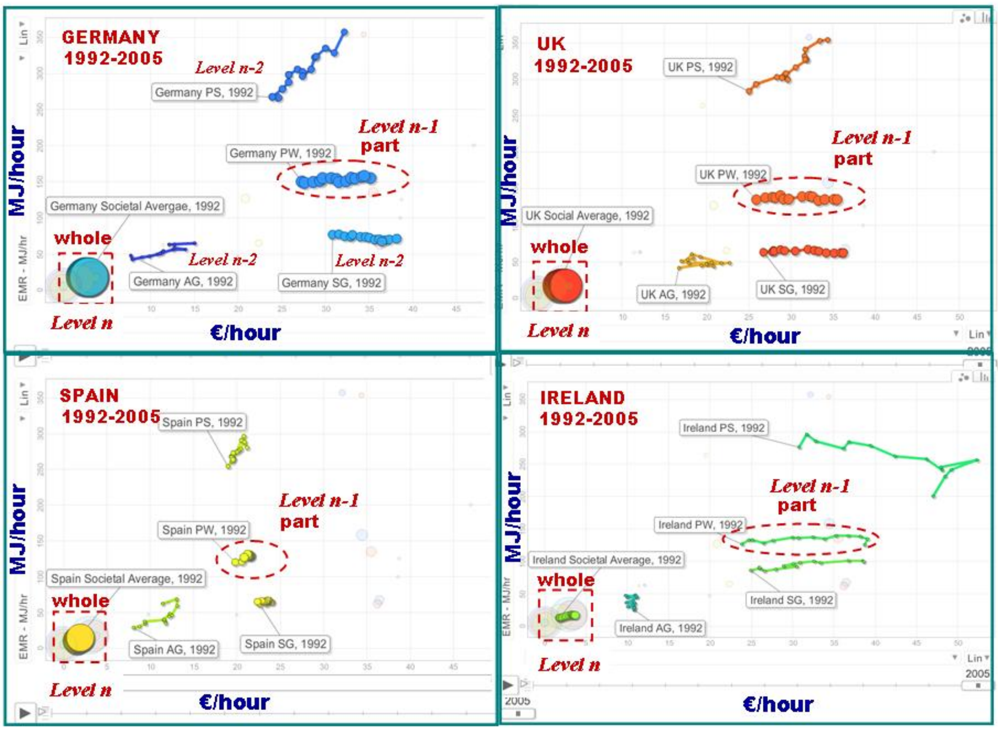

Fig. 19 Comparing the metabolic pattern of Spain, Germany and UK using simultaneously three hierarchical level

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The four graphs shown in Fig. 19 represent: (A) an integrated analysis – since it addresses both economic (€/hour) and biophysical (MJ/hour) variables and in indirect way demographic variables – the difference in size between the whole (average society) and the part PW (the ratio HA_{PW}/THA); and (B) a multi-scale analysis – since it provides a simultaneous representation at: (i) the *level n* is the value for the whole country; (ii) *level n-1* is the value for the productive side of the economy: the PW sector; and (iii) *level n-2* is the value for each one of the three sub-sectors of the productive sector (PS, SG, AG). That is, it is a multi-scale integrated analysis of the metabolic pattern of these countries.

The trajectory of change for each one of the representation across scale can be seen by looking at the "movement" of the disks in time (the shape of the "worms" made of the same type of disks). Let's now see more in detail the information given by this graph:

**** the characteristics of the whole*** – *level n* - are represented by:
(A) the size of the disk of the country, in terms of Total Human Activity – Population x 8,760 hours/year) – the average value for the whole country is in a red broken line box;
(B) the consumption of energy per hour (the value of the variable on the vertical axis);
(C) the GDP per hour (the value of the variable on the horizontal axis);

**** the characteristics of the Paid Work sector (a part)*** – *level n-1* - are represented by:
(A) the size of the disk of the PW sector, in terms of HA_{PW} – defined as the number of workers in the PW sector x average hours of work/year) – the average value for the paid work sector (the production side) is in a red broken line ellipsoid;
(B) the consumption of energy per hour (the value of the variable on the vertical axis);
(C) the added value per hour (the value of the variable on the horizontal axis);

**** the characteristics of the sub sectors*** – *level n-2* – in this example we consider three sectors: SG (Service and Government); PS (Productive Sectors); AG (Agricultural sector), which are represented by:
(A) the size of the disk of the sub-sector, in terms of HA_i – defined as the number of workers in the sector *i* times the average hours of work/year) - in the figure the average value for the various sub-sectors is represented by the disks moving in time;
(B) the consumption of energy per hour (the value of the variable on the vertical axis);
(C) the added value per hour (the value of the variable on the horizontal axis);

Moving from level n (societal average) to level n-1 (PW sector)
We can immediately see from this multi-level integrated analysis of the metabolism of a country, that the energy intensity of the country - the ratio (MJ/hour)/(GDP/hour) of the whole at the *level n* (the disk in the square box with broken line) is different from that of the productive part of the economy – PW at the *level n-1* (the disk in the ellipsoid with broken line). This difference depends on the relation between the characteristics of the Household Sector and the Paid Work Sector (HA_{PW}/THA and the energy consumption of the Household Sector – these two values reflect socio-economic variables describing the material standard of living in the compartment of final consumption – the whole set of relation is illustrated in Fig. 20, below). We can recall here the

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analysis in Fig. 10 referring only to the flow of $/hour – the difference between the pace of metabolism of the whole - GDP per hour of human activity – and the amount of GDP generated per hour of work in PW – ELP_{PW} - depends on the fraction HA_{PW}/THA.

Moving from level n-1 (PW sector) to level n-2 (subsectors of PW)

We can immediately see from this multi-level analysis of the metabolism of a country, that changes in the characteristics of the PW sector (the energy intensity of the productive part of the economy) cannot be related directly to changes in the technical coefficients of lower level compartments. Rather they reflect: (1) the differences in energy intensity ***which are typical of the different subsectors making up the PW sector***; (2) the relative size in percentage of sectoral GDP of the three subsectors in determining the overall value for PW. The combination of these two factors will determine the intensity of the PW sector.

An overview of the various pieces of the puzzle defining an overall value of energy intensity of a country is given in Fig. 20. The figure clearly shows that using a simple ratio TET (Total Energy Throughput – the energy consumption of a society) over GDP, a choice often done in econometric analysis, as an indicator of performance of economies, in reality has the effect of generating a number which does not carry any meaning. With this we mean that the ratio “Energy consumption”/“GDP” does not have an external referent. When using this indicator TET/GDP if we analyze the energy intensity of Finland and El Salvador we find the same value: 12.5 MJ/US$.

On the other hand, we claim that if we use rather than the direct ratio TET/GDP a ratio between the two paces of metabolism of a country: (i) expressed in GDP per hour (flow of added value generated in the GDP per person per year); and (ii) MJ per hour (aggregate amount of energy consumed per person per year at the level of the whole society), then we are dealing with benchmark values (external referents).

Since this distinction can result not clear to the reader we provide an explanatory example in Fig. 20. When calculating energy intensity of an economy using the ratio between two metabolic paces (GDP/THA and TET/THA) we deal with two benchmark values, which in turn can be related to other expected benchmark values. For example (i) a value of GDP of 2 $/hour (16,000 $/year p.c.) or an energy consumption of 20 MJ/hour are typical of a developed country (in blue on the left of Fig. 20); as well as (ii) a value of GDP of 0.4 $/hour (3,500 $/year p.c.) or an energy consumption of 4 MJ/hour are typical of a developing country (in red on the left of Fig. 20).

If we perform a multi-level analysis of the relations over the values of different benchmarks, we can find the existence of *an integrated set of benchmark values* (interlinkages!) referring to the intensity of flows per hour, when considering both ***Added Value*** and ***Total Energy Throughput*** across hierarchical levels:

(A) at the *level n* (whole countries) as indicated on the left of the figure - for developed (in blue) and developing countries (in red);

(B) at the *level n-1* for the average production of GDP per hour of human activity in PW – the value of ELP_{PW} - given in the middle of the picture for developed (in blue) and developing countries (in red);

(C) at the *level n-1* for the average ratio between hours of working activity/total hours of human activity (the ratio HA_{PW}/THA discussed above).

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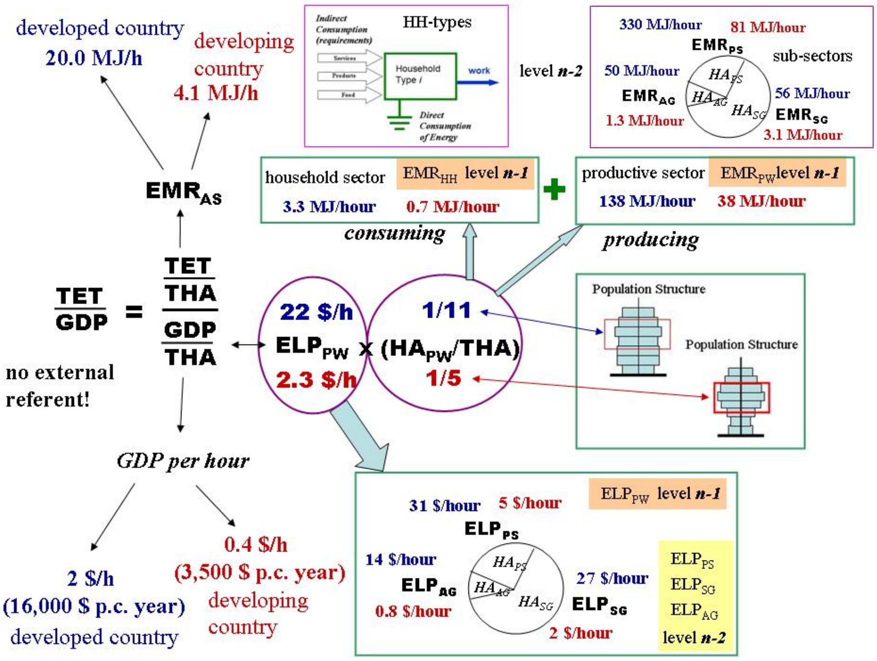
(D) at the *level n-2* for the average value of flows of both €/hour and MJ/hour typical of sub-sectors of the economy. In Fig. 20 the value of ELP_i are given in the pie in the box on the lower-right corner - for developed (in blue) and developing countries (in red);
(E) both at the *level n-1* in relation to the flow of energy consumption per hour - in the division in boxes on the upper-right corner – the expected relation between the fraction of TET going into the sectors of production and consumption;
(F) at the *level n-2* in relation to the flow of energy consumption per hour - in the boxes on the upper-right corner – within the productive sector for individual subsectors - for developed (in blue) and developing countries (in red).

Fig. 20 The overall structure of relations determining the overall energy intensity of an economy



The values of these benchmark values have to be changed ***in an integrated way*** to generate the overall value of GDP/THA or TET/THA. On the contrary, the two hypothetical countries represented in Fig. 20 as consistently different across the different benchmarks of their metabolic pattern across levels, have the same energy intensity - 10 MJ/$ - when using the ratio TET/GDP [***the choice of standard econometric analysis!***].

Looking at this complex set of relations it is easy to understand that changes in technical coefficients (= better technology) can only change the value of one of these benchmarks in just one of the lower level elements. But any change in lower level elements will only imply a re-adjustment over the various benchmarks across different levels. There is no guarantee that a change at the lower level will arrive to affect the emergent property of the whole in a predictable way. As a matter of fact, in order to be able to distinguish the effect generated by technological changes one should move down to another hierarchical level – moving at *level n-3* and even at *level n-4* – to individuate a

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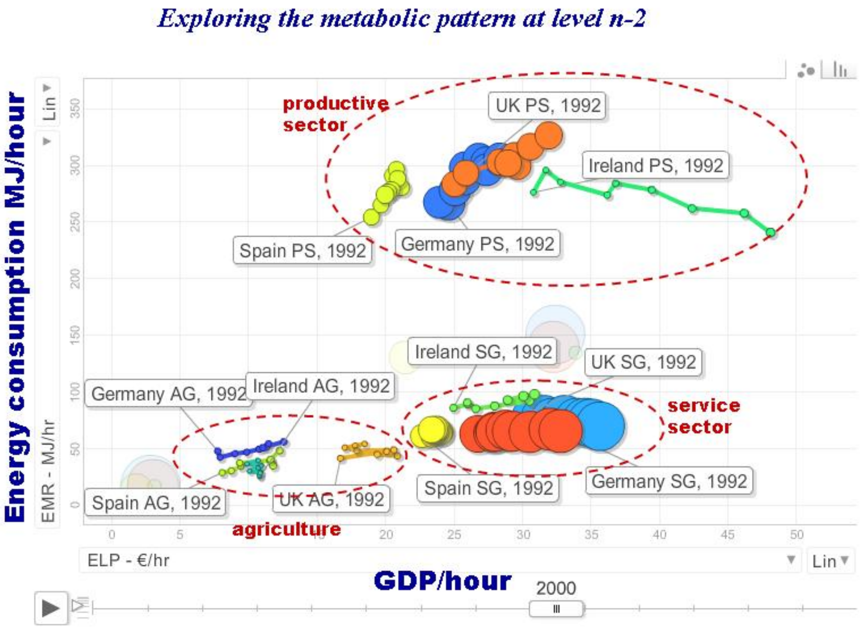
compartment expressing an homogeneous set of activities in which improvements in technical coefficients can make a difference in terms of generation of €/hour and MJ/hour.

Let’s now observe – in Fig. 21 - a comparison between the 4 countries considered in Fig 19. This comparison is made by focusing only on the characteristics of the subsectors at the *level n-2*.

Fig. 21 – Characteristics of the metabolic pattern of sub-compartments of the economy of Germany, UK, Spain and Ireland (level n-2)



In this figure the same type of graph is used to compare – over the 3 chosen subsectors – the differences between the 4 countries considered in Fig. 19. 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.

Therefore, we can observe two important points: (i) technical changes are not generating a reduction of energy intensity in 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.

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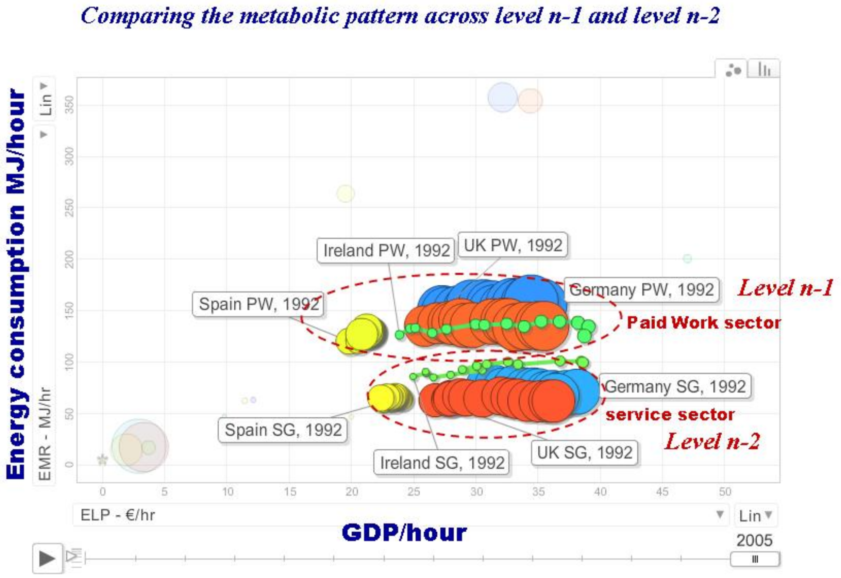
As a matter of fact, when comparing the trend of change in energy intensity - as observed at the *level n-1* (the characteristics of the PW sector, the side of production of the economy) and the characteristics of the SG sector at the *level n-2* – as illustrated in Fig. 22 - we can immediately observe 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. However, it should be noted that this post-industrialization of developed economies depends on the phenomenon of globalization (discussed below). That is, someone else must produce the energy and resource intensive products consumed but not produced by post-industrial countries.

Fig. 22 Comparing the trend across levels: PW versus Service sector



3.2.2 Can we study the evolutionary changes of developed countries more in detail?

An example of multi-scale integrated analysis of the metabolism of Catalonia can be used to discuss the possibility of performing a more detailed analysis of evolutionary changes of a society. But before analyzing a specific metabolic pattern more in detail (Catalonia) let's first make a couple of considerations referring to the analysis and graphs already illustrated. One refers to the effect of size (it is easier to change your characteristics if you are a small country . . .), and the second to the special status of the Agricultural sector, within the economies of EU countries.

(i) the effect of size in locking-in the structural and functional metabolic pattern of a society

When looking at the comparison of the 4 countries shown in Fig. 19 we can observe that when considering the whole country – the disk within the red broken line box – at the *level n*, Germany, Spain and UK moved very little during the period 1992-2005. On the contrary, the disk of Ireland over the same period moved quite a lot (it formed a sort of "worm"). This inertia against quick structural and functional changes (movements in this type of graph) can easily be explained by the natural inertia of socio-demographic variables: individuals move slowly across age classes, pattern

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of final consumption, associated to the cultural identity of a society tends to be conserved in time, institutional lock-in.

When moving to the level of a part - at the *level n-1* – on the production side, things change faster. Even large countries, such as Germany, Spain and UK generate “worms” when looking at the disk characterizing the metabolism of the PW sector. Let’s consider first Spain, which is moving slower than the other countries in this representation. In relation to this point, it should be noted that the impressive economic growth of Spain in this period is partially missed by this representation (and this fact, recalls the importance of having complementing views!). In fact, by using this representation we can say that the economic growth of Spain in this period has been obtained by doing “more of the same” (the disks just became bigger in their size).

Looking at the other countries we can see a visible movement of the overall characteristics of the PW sector. This movement of the PW sector is generated by combined effect of the movements of the lower level sub-compartments. In particular, we can notice that the sub-sector PS moves following the same pattern in Germany and UK and Spain (but at a slower pace there). On the contrary, Ireland shows something completely different. Looking at this difference one can hypothesize that small countries, being used to be open and fully dependent on imports for covering their internal consumption, do have a lower level of internal lock-in when deciding to change their internal mix of economic activities within both the PS and SG sector.

(ii) the bizarre evolutionary pattern of the Agricultural sector within EU countries

As soon as one increases the resolution of the graphs shown in Fig. 19 (an example is given below in Fig. 23) one can notice the bizarre evolutionary pattern of the agricultural sector all over EU countries. That is, over the period 1992-2005 the structure of the agricultural sector (the different production systems) has been adjusting continuously to different definitions of the function assigned to it by the regulations imposed by the EU. Looking at the resulting evolutionary pattern one can only wonder whether there is any logic in the continuous changes in the definition of the functions assigned to the farmers. The sector increases randomly with sudden changes in direction for energy consumption, added value generation rate, moving up and down back and forward. One possible explanation of this bizarre pattern is that in the third millennium the real economic function of farmers within EU (and more in general in developed countries) is to collect agricultural subsidies to be transferred, later on, to the transnational corporations producing industrial inputs. In relation to this function, it seems that the definition of the particular performance achieved by the agricultural sector in biophysical terms is not particularly relevant and therefore erratic. The only explanation which can be given to the continuous change of direction in the evolution of the performance of farming techniques is the necessity of farmers to continuously adjust to the changes in regulations decided at the EU level for giving subsidies. The criteria used for changing the rules must reflect political reasoning . . . When looking at the effects of these changes on a large scale, it is very difficult to see an emergent logic.

There is another important observation to be made here about the specificity of the agricultural sector. The values represented in this graph suggest that the Agricultural sector has a low economic performance, but also a low level of consumption of energy. Unfortunately this representation is misleading. What is shown in the energy statistics (used to prepare this graphs) are only the direct energy consumption at the level of the farm - fuels for tractors and machinery, electricity for the facilities. However, the real consumption of energy associated with agricultural

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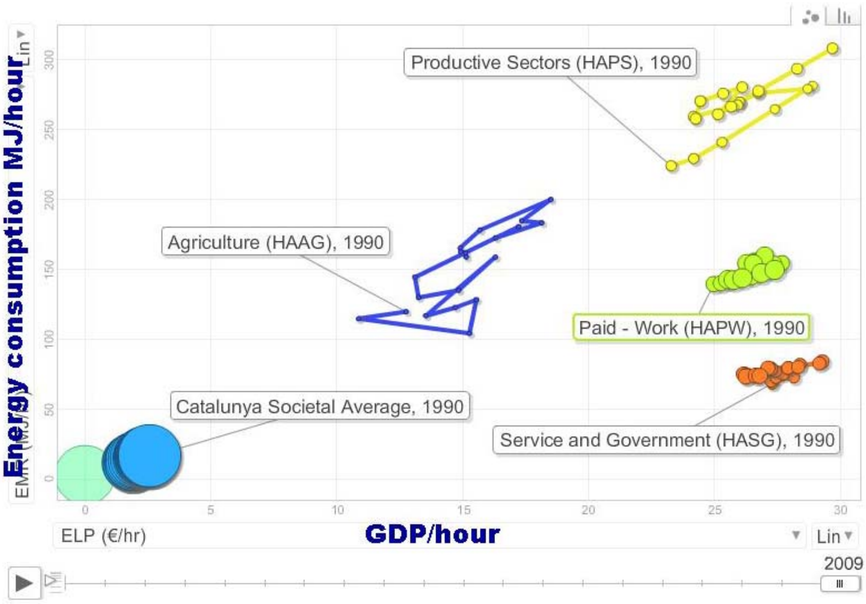
takes place in the process of production of fertilizers, pesticides, machinery and other technical inputs (accounted by energy statistics in the Manufacturing sector). When considering also these additional inputs, the agricultural sector becomes among the most energy intensive sectors of the economy (the one requiring the highest capital per worker, generating the lowest return on the investment, the largest environmental impact for either job of unit of added value). This is to say, that the wiser management of the agricultural sector would be of crucial importance for sustainability. In fact agriculture is the main driver of changes in land use, it generates important effects of biodiversity and on human health, it consumes 70% of water, beside being essential for the development of rural areas. When considering all these points, one is forced to note that the bizarre evolutionary trajectory of changes in the performance of this sector clearly indicates that there is something wrong in the way this sector is evolving in time.

Fig. 23 The evolution in time of the metabolic pattern of Catalonia – 1992-2005



Now we can move to the analysis of the evolution in time of the metabolic pattern of Catalonia shown in Fig. 23.

At this level of resolution, looking at changes in the metabolic pattern in the subsectors - at *level n-2* - it is possible to study the different evolutionary trajectories more in detail. Looking at Fig. 23 we can confirm the bizarre trajectory followed by the agricultural sector. More in general, it becomes also evident that the trajectory of Catalonia is similar to that of Spain. Even if Catalonia is using more energy and producing more added value per hour of work than Spain, like Spain, Catalonia does not show signs of a quick process of "becoming". As a matter of fact, the trajectory of Paid Work of Catalonia is illustrated by various disks (indicating the position in different years) making up a "worm", which are overlapping. Moreover, the "worm" is coiled on its own (the difference with Ireland is evident).

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In order to explain these different trajectories one should open again the black-box (this time the sub-sector defined at the *level n-2*!) in order to observe changes in the characteristics of lower level elements (at the *level n-3*). In fact, when dealing with PS (Productive Sector - *level n-2*), we still have a group of activities non homogeneous – Building, Manufacturing, Energy and Mining (sub-sub-sectors defined at the *level n-3*); the same heterogeneity can be found in the SG (Service and Government Sector - *level n-2*). In fact, within the compartment SG we find both the Private and Public sector, involved in pretty different activities – at the *level n-3* we can find: Transport Sector, Health Care sector, Public Administration, Financial Banking and Insurance, etc.

As a matter of fact, it is not difficult to find information disaggregated at this level of categorization of the economy (an example of the analysis of the SG sector on lower levels – *n-3* and *n-4* - is given in the case study of SMILE on Romania). But a serious problem we encountered was represented by the lack of a consistent and useful protocol adopted by those generating energy statistics, which makes it impossible, at the moment, to carry out this type of analysis at lower levels. In relation to this problem, as discussed in Section 4, we have to note that the energy accounting done by different office generating energy statistics (in the USA, in Europe, in the private sector, national governments) is based on different protocols. This implies that the available data are not comparable (not even the assessment of the total energy consumption of countries! Let alone the energy consumption in the SG or the HH sector). The problem is not due to the lack of data, but rather to different choices on how to handle the quantitative representation of the energetic metabolism of societies. It seems that so far, those generating energy statistics underestimated the deep epistemological implications of non-equilibrium thermodynamics. They seem to consider that the accounting of energy transformations referring to the process of autopoiesis of complex self-organizing systems (operating on impredicative loops and across different hierarchical levels) is a simple issue to be handled with arithmetic rules (as stated at pag 30 in the Energy Statistics Manual – OECD/IEA, 2004).

Since, in our view, this is a very important problem, we dedicate the entire Section 4 of this report (below) to the discussion of the quality of available energy statistics.

3.2.3 Interlinkages: short-term vs long-term sustainability of EU countries

<u>(A) what goes around comes around (the global view)</u>

It is obvious that if some countries of this planet – i.e. developed countries – manage to decrease the material and energy intensity of their economies through imports (meaning that they are consuming products without producing them) then we must find other countries of this planet – i.e. developing countries such as China and Brazil – which get the material and energy intensity of their economies increased by the terms of trade.

To make things worse for the global environment, we have to add: (i) the increase in material and energy intensity due to long distance transportation; and (ii) the increase in material and energy intensity due to the lower efficiency in production and the lower standards for environmental protection that the production of products in developing countries often implies. That is, the solution adopted at the moment by developed countries to improve their sustainability at the local scale, like the solution of immigration, translates into important negative effects, on a large scale.

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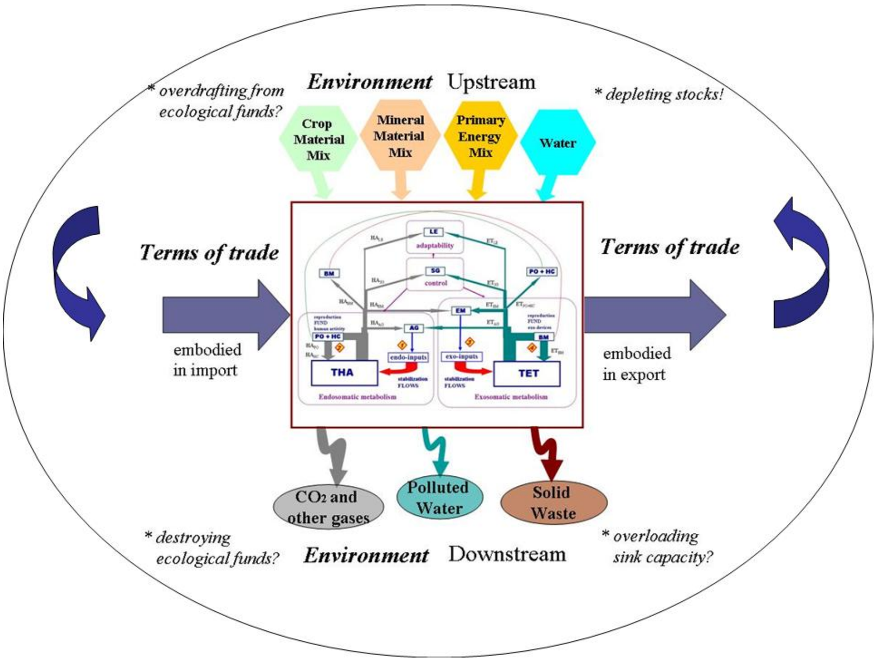
But the strategy of economic development based on externalization adopted by the developed countries has not only negative consequences on the global environment. It can also imply local problems on the socio-economic side in many countries of developing countries, which are forced to sell, to be competitive, cheap both their natural resources and their labor force. This can imply a high risk of abuse for marginal social and ethnic groups. In turn the continuous generation of high socio-economic stress in the most populated areas of this planet can translate into humanitarian crisis, riots, violence, international terrorism. All these elements should be considered as negative factors to be avoided as much as possible in the evaluation of sustainability strategies.

We have to repeat again that also in this way we arrive to the point made earlier. It is essential to include in the set of indicators of sustainability the two views: (i) the view referring to internal constraints - the pattern of metabolism as perceived as the dynamic interaction of the parts (compartments) of the society within the black-box; and (ii) the view referring to external constraints – the pattern of metabolism of the society, seen as a whole, with its context.

An overview of the possibility of obtaining this double view, by combining the MuSIASEM approach and the SUMMA approach within the DECOIN tool-kit is shown in Fig. 24.

Fig. 24 Overview of the double view: (i) parts/black-box and (ii) black-box/environment; which can be obtained using the DECOIN tool kit



In this overview we can see that it is possible to generate a biophysical representation of the metabolism taking place inside the society. This is the view from inside the black/box described in the previous sections (Fig. 9, 20, 21, 22, 23) addressing the viability of the relations between the various compartments of the society (internal constraints). However, this is only a part of the story. In fact, it is also essential to characterize the interaction of the society, the black-box, with its context (external constraints).

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In relation to this second point, it should be noted that there are two distinct forms of interaction with the context, which should be considered:
(A) a direct interaction - illustrated in Fig. 24 by the vertical flows – which refers to the local interference that the biophysical metabolism of a society entails on the biophysical metabolism of the ecosystem embedding it. This has to do with the flow of matter and energy used locally by a society, which will affect the health and integrity of local ecosystems;
(B) an indirect interaction - illustrated in Fig. 24 by the horizontal flows – which refers to the net effect of the terms of trade on the consumption of material and energy. This has to do with an assessment of the gains or losses in terms of intensity of the economy associated with "externalization".

When dealing with this indirect interaction it is important to have statistics about material flows within countries and associated with trade. But as discusses in section 4 below, one should be careful, when defining the protocols of accounting, to implement a system of accounting which would make possible to calculate both the material and energy intensity of the various compartments of the economy across levels (inside the elements of the black-box), avoiding the loss of valuable information. That is, when assessing the material intensity of the manufacturing sector, or of the electronic industry we must have ***data referring only*** to kg of specific typologies of materials used in those compartment - per hour of work or per € of added value. The accounting must remain separated over different categories. Mixing together millions of tons of construction material (with an error bar of 50%) with thousands of tons of shoes (with an error bar of 5%) with thousands of kg of special materials (with errors bars even more accurate) means only losing valuable information. A more detailed analysis of this point is provided in Section 4.

(B) the problem with "bubble-disease" in the economy - bubbles do not last forever and can easily blow-up

In his seminal book "Wealth, virtual wealth and debt" the Nobel Prize Frederick Soddy, in 1926, made the point that it is very dangerous to rely only on economic accounting to develop indicator of development of modern societies. In his book he explains that the very idea associated with money is that society will have to provide to the money holder either a product or a service of an equivalent price. Therefore, money "per se" should be associated with a debt that the society has with those holding money. Therefore, tracking flows of money means tracking flows of debt, and therefore those studying monetary flows are studying only a reflection (as in the Plato metaphor of the cave) of real wealth. Real wealth is the biophysical process of ***production and consumption*** of actual goods and services which is behind the flows of money. The generation of 'real wealth', therefore, is necessarily affected by the biophysical constraints associated with thermodynamic transformations.

In spite of these unavoidable biophysical constraints, debts, such as loans, make it possible to spend money now that refers to goods and products which have not yet been generated. The money that is spent now is based on the promise – e.g. made by someone that buys a house - that she/he will pay back the credit. However, the buyers can pay back the debt only if they will be able to earn money. To do that, they will have to be able to take part in economic activities which will be performed in the future earning either wages or profits. Here the discrepancy between real economy and virtual economy indicated by Soddy becomes relevant. If the pie keeps expanding, then these economic activities will keep increasing, also in biophysical terms. But when the wealth is

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generated by stock depletion (extracting and consuming oil and other non-renewable resources) we will end up in the paradox indicated by Soddy: the virtual economy based on the accounting of monetary flows will perceive as economic growth any massive increase of debt - which many will confuse with an increase of wealth - at the very moment in which the resources are depleted – the real economy is reducing its original endowment of wealth. The relevance of his analysis to the situation that is experienced in these years in Europe and in the world is clear. This analysis is directly related to the discussion done in Section 2 about a steady-state narrative about sustainability indicators (based on the actual perception of wealth, which includes also the effect of massive doses of debts injected in modern economies) and the narrative of the metabolic pattern of modern economies, which look at an integrated set of constraints affecting the feasibility of existing patterns of production and consumption of goods and services.

As soon as we start looking at the structural and functional organization required to be able to generate the processes of production and consumption of a given set of goods and services, then we can immediately see the existence of trade-offs in globalization and specialization. A high level of specialization (taking advantage of what is called in economics comparative advantages) implies a strong dependence on the possibility of importing and exporting. This is at the basis of the modern economic civilization based on market economy. However, this process of specialization reached in the last decade a scale and a degree of openness, which was never experienced before at the level of the whole planet. Some small countries can afford to take this risk (e.g. like Ireland, since they are protected by the size of EU), but how risky is a big reliance on imports for a big macro-economic entity – e.g. the EU? As a matter of fact both UK and Ireland that got the maximum advantage in terms of reduction of energy intensity from the process of externalization are now the most affected by the global crisis. We can recall here the famous sentence of Mahatma Gandhi about the possibility of having a major economic development in India following the example set by developed countries: "If it took Britain to use the resources of half the world to be where it is, how many worlds would India need?"

Looking at the EU context, an excessive reliance on imports and externalization could imply an increasing fragility in the case of a big world crisis (in the case nobody else is capable of exporting and importing) or a sudden contraction of trade due to various reasons - increasing costs of transportation or inability of guaranteeing safe transportation routes. Another problem may be represented by future bottlenecks in the production of critical imports due to shortage of natural resources. Finally, in the long term, all these risks will be further increased by the increasing internal demand within developing countries. That is, what if China in 20 years will be able to express and internal demand so high which will absorb the majority of its production, the production which is exported at the moment, and because of this fact, will stop exporting cheap to developed countries?

Obviously, when developing a set of indicators of sustainability we are not requested to generate scenarios about whatever can go wrong in the future. However, in this section we tried to illustrate with practical examples, that by complementing the actual representation of performance of EU economies with an integrated set of bio-economic analysis covering both the steady-state and the evolutionary view, it would become much easier to reach a more comprehensive understanding of the sustainability predicament faced by the EU in the next century.

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4. The need of a revolution in the field of sustainability indicators

4.1 The key role of statistics in relation to the sustainability issue

The name ***statistics*** reflects their crucial role in the functioning of modern societies. In fact the output of statistical offices is used to define "the state of the state", that is the representation of the perception that a society has about itself in its interaction with the external world. When explaining this role within a semiotic view of the process of autopoiesis we can see that in the iterative process of "making-itself" a human society moving in time (from t_i to t_{i+1}) has to go continuously go through the semiotic triad:

t_i → ACT → TRANSDUCE → REPRESENT → TRANSDUCE → ACT → t_{i+1}

In this iterative process the input given by statistics is crucial. It provides the agreed representation of the state of the state used: (i) by governments for deciding policies; (ii) by voters for deciding governments; (iii) by entrepreneurs for deciding their business strategies; (iv) by consumers for deciding their consumption strategies.

Put in another way, in a reflexive semiotic process the agreed representation of the state of the state is "the most important" step in the building of a shared perception of the reality. The special situation experienced in the last decades by humankind (we can recall the discussion related to Fig. 5a and 5c – the rice kernels doubled on the chessboard, the number of humans that grew in the last 35 years of 3 billions, more than in the last 35,000 year), living a situation of rapid transition, entails an extraordinary challenge to those working in generating statistics. We have been living an extraordinary phase of human expansion, at an exponential rate, and this implies that the number of relevant attributes to be considered when representing ourselves as a society grows as well exponentially. The number of relevant attributes to be considered not only expands because we are more people capable of doing more things, but also because we know much more than before. This entails that the representation to be covered by the office of statistics not only is continuously expanding ***in extent*** - from the state of national countries to the state of the European Union, from the state of the European Union to the state of the entire planet – but also ***in the resolution of the grain*** to be adopted in the representation required – more and more details are needed including the state of marginal groups, ecological species, natural resources, environmental equilibriums.

Facing this explosion in the complexity of what should be represented, the task of the statistical offices is becoming more and more a sort of "impossible mission". They are required to generate a very robust representation of a "reality" which is continuously changing and which is no longer perceived as the "same reality" by different social actors. The resulting challenge is double: it is not only what is observed that changes, but also the perceptions of the observers which are changing quickly in time. Modern societies, interacting at an increasing large scale with each other and with their natural context are getting more and more complex, and therefore more difficult to be perceived and represented in a useful way.

In our view this systemic problem associated with the individuation and development of useful indicators of sustainability justifies the methodological discussion provided in this section. The theoretical discussion is about how to handle datasets related to quantitative representations of complex systems, which are organized over different levels and which therefore require the simultaneous use of different dimensions and scales of analysis.

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4.2 Statistics and the concept of multi-purpose grammars

We recall again here the definition of a complex phenomenon given at the beginning of this report: a complex phenomenon is a phenomenon which can and should be perceived and represented using simultaneously several narratives, dimensions and scales of analysis (Ahl and Allen, 1996; Allen et al. 2001; Funtowicz et al., 1999; O' Connor et al., 1996; Rosen, 1977; 2000; Salthe, 1985; Simon 1962; 1976; Giampietro, 2003). The main point of this section is that when dealing with a quantitative representation of the energy metabolism of modern societies it is necessary to use the concept of grammar in order to organize in an effective way the relative data set.

To discuss this topic, we will use as case study the problems encountered when using EUROSTAT energy statistics. But in order to be able to analyze this problem in detail we have to introduce first, very briefly, a few theoretical concepts.

4.2.1 The concept of Grammar

The concept of *random grammars* as a key feature for the possibility of having autopoiesis in complex adaptive systems has been proposed within the field of complex systems theory by Kauffman (1993). In more general terms we can say that the concept of grammar is essential to explain the logical steps leading to the modelling relation (Rosen, 1986; 2000).

The definition of a grammar can be associated to a pre-analytical declaration of a set of expected relations between:

(a) a set of semantic categories (the meaning attached to the value of the variables by those that will use the numbers). Addressing the semantic part of quantitative analysis is essential. In fact, in order to have an effective semiotic process, it is essential that all those that will be using the resulting database share the same meaning about the semantic categories used in the grammar; and

(b) a corresponding set of formal categories – the proxy variables used in the formal representation, to which we can assign quantitative values – the numbers of the dataset.

Using the language of software development we can say that a grammar requires the definition of:

(i) a lexicon – the finite set of categories that will be used to represent the possible transformations. These categories can be divided into two classes: ***tokens*** and ***names***. Tokens are numbers obtained directly from measurement (data input), whereas names will depend on both the values of the tokens and the set of production rules established in the grammar;

(ii) the set of production rules determining the value assigned to names when data are entered in the category of tokens;

(iii) someone, beside the machine operating the computations, capable of assigning meaning to the operation of the grammar (what handling the data input, and when handling the data output).

4.2.2 The concept of Mono-Purpose Grammar

To save time, let's consider a quantitative protocol used for the representations of a given situation, which can be considered as a mono-purpose grammar. The example considered here is the assessments of primary energy consumption (the overall consumption of countries) found in international energy statistics given by BP. This database is an example of a quantitative assessment generated by a simple, mono-purpose grammar, characterized by use of a limited lexicon and limited set of production rules in the pre-analytical step.

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As concerns the lexicon, the system of accounting used in BP international statistics (http://www.bp.com/productlanding.do?categoryId=6929&contentId=7044622) has:

#1 a very reduced lexicon

It does not deal with the entire set of energy forms and energy transformations which can be found when looking at the functioning of an economy. For example, solar energy, gravitational energy, the kinetic energy of rain drops, food energy are not accounted for in these statistics. The grammar behind the development of the BP database focuses only on a finite set of relevant categories of energy forms:

(a) **Primary Energy Sources** (PES) - oil, coal, natural gas, nuclear, renewables, etc.;
(b) **Energy Carriers** (EC) - electricity, fuels, heat; and
(c) **End Uses**/energy services (EU) - power generation, transport, residential, etc.

Because of these choices this grammar deals only with commercial energy. In particular it has 3 semantic categories (PES, EC, EU) to which several formal categories are assigned: (i) assessments of oil, coal, natural gas to PES; (ii) assessments of electricity, fuels and heat to EC;

#2 an extremely simple production rule

As concerns the set of production rules, this simple grammar deals only with the correction of the accounting of energy in relation to the generation of electricity. That is, this very simple grammar has only a production rule consisting in a fixed conversion factor. The rule says: each Joule of electricity which is generated not using fossil energy has to be converted into a *reference* value of primary energy source – e.g. Tons of Oil Equivalent. That is, this production rule “imposes” a standard value for the conversion losses associated with the generation of electricity. In the particular example shown in Fig. 25, the generation of 1 J of electricity has a “virtual cost” of 3 J of oil equivalent (it is based on a conversion efficiency fossil energy → electricity of 33%). This implies that all the electricity produced non using fossil energy - by nuclear, hydroelectric, photovoltaic or wind - is accounted as 3 J belonging to the formal category Tons of Oil Equivalent (1 TOE = 41.868 GJ) belonging to the semantic category Primary Energy Source. The conversion efficiency used in the production rule refers to the average technical performance of the conversion. For example in the year 2007 the statistics of BP used a conversion efficiency of 38% - a ratio 2.63 MJ of oil equivalent per MJ of electricity – a value based on an estimate of the average efficiency of oil/electricity production in OECD countries.

This mono-purpose grammar, therefore, is useful only in relation to a given purpose: ***the calculation of a standardized quantification of total energy consumption (a semantic concept), which is expressed: (A) in a given semantic category of energy form - primary energy source; which (B) must refer to a specific formal category of Primary Energy Source of reference – Tons of Oil Equivalent***. As a matter of fact, one can use the same mono-purpose grammar and express the same semantic concept – total energy consumption - expressed in the same semantic category - primary energy sources – using a different formal category: Tons of Coal Equivalent rather than Tons of Oil Equivalent. But this different choice of standard would not represent a problem, since the structure or relation within the semantic side remains the same (semantic concept associated to semantic category). It is only the different formalization of the final step (the formal category to be

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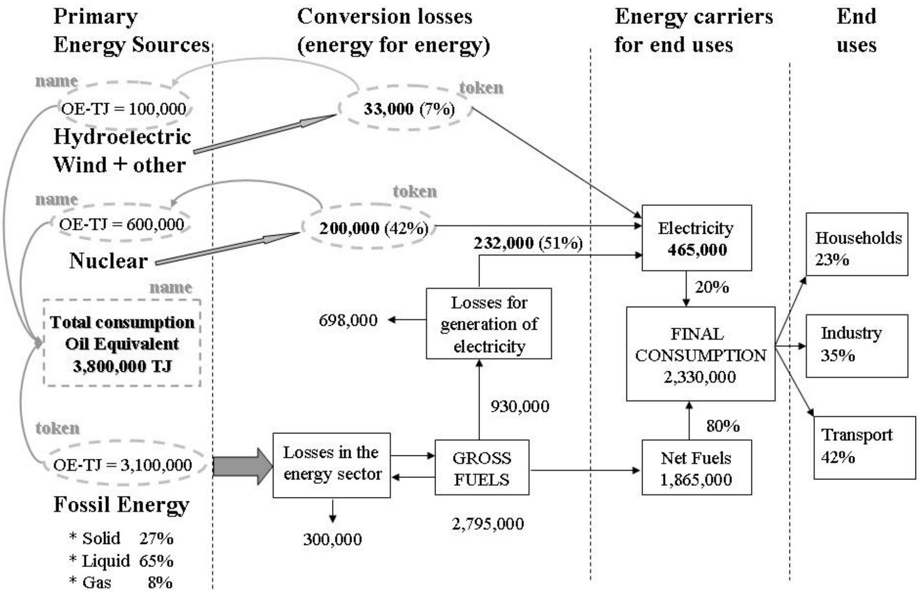
assigned to the semantic category) - expressing the MJ of Primary Energy Sources of fossil energy either TOE or TCE – which changes.

It should be noted that this standardized quantification – based on a particular choice of semantic and formal categories - has a limited and specific application: it is useful ***for making international comparisons and only in relation to total energy consumption***. In order to obtain this result each J of electricity generated by energy sources alternative to fossil energy has to be accounted as equivalent to a *virtual* amount of energy consumption of oil. This represents a bifurcation from the representation of the "reality", since this virtual consumption of oil, included in the assessment of final consumption, has not been used in the generation of that 1 J of electricity. However, the accounting of this virtual consumption has the only goal of making it possible to compare the "primary energy consumption" of countries at different level of electricity generation from non-fossil energy, using a common standard. In this case, when applying this production rule, the amount of electricity generated is a *token* in the grammar (a data input) which determines the value to be assigned to the *name* - the assessment of 'primary energy consumption *equivalent*'.

Fig. 25 Simple, mono-purpose grammar used to generate energy statistics: Assessment of primary energy consumption in TOE of Spain in 1991



In conclusion in this example, the overall assessment of energy consumption of a country (semantic concept), useful for comparing different countries, is obtained by using a semantic category (Primary Energy Sources) and it is quantified by using a formal category- Tons of Oil Equivalent (TOE) or Tons of Carbon Equivalent (TCE).

Because of this rationale, the international database of BP energy statistics, applies the same standard conversion –2.63/1 in 2007 - to all countries included in the statistics. This implies that this grammar decides to ignore country-specific variations. That is, there are countries that produce

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electricity with inefficient coal power plants which may use 3 or even 4 MJ to produce a 1MJ of electricity. Ironically, the use of a flat conversion factor (one size fits all . . .) should not be considered as an error within this grammar. On the contrary, systemic and easy comparison can only be obtained by *normalizing* apples and oranges in relation to a chosen criterion of equivalence – a "virtual" standard consumption of primary energy sources per kwh of electricity supplied. As a matter of fact, in recent years, the attempt to refine the definition of this simple grammar has generated differences among datasets found in different statistics – e.g. EIA statistics and Eurostat (more discussions on this point below).

The adoption of this "single (mono) purpose grammar" implies a few shortcomings in the resulting quantitative analysis:

(1) the assessment "of primary energy consumption equivalent" (the total amount of virtual TOE that are consumed by an economy per year) **does not map** onto the amount of goods and services obtained by that economy (*final energy services*). That is, when using this statistical database we cannot compare neither the amount of "energy carriers" delivered to the society, nor the amount of "final energy services" enjoyed by the citizens of different countries. These two values do not map onto the total amount of PES expressed in TOE;

(2) the assessment of "primary energy consumption equivalent", expressed in TOE, does not map onto *CO_2 emission*. In fact, the final numerical assessment of consumption of TOE, includes "virtual" TOE (assigned to nuclear, hydroelectric generation, wind) which in reality do not translate into real CO_2 emission;

(3) the overall assessment of TOE equivalent found in Energy Statistics cannot be related to the *amount of land required* to obtain this energy supply. It is completely useless for a comparison among countries, where the purpose is to analyze the *pressure that the energy sector implies on land cover*;

(4) the overall assessment of TOE does not make a *distinction between renewable and non-renewable* primary energy sources.

(5) the overall assessment of TOE equivalent found in Energy Statistics is completely useless for a comparison among countries, where the purpose is to analyze the *total requirement of hours of work, water or capital or aluminum or* ***any other critical inputs*** *that the energy sector implies.*

In spite of all these shortcomings this old-fashion characterization of the energy consumption of developed countries is still very popular. An example of the typical result of the application of this mono-purpose grammar to the characterization of the metabolic flow of a developed country is given in Fig. 26.

This is the standard map-flow of the energy consumption of a developed country. In this example, the map-flow is provided by Energy Information Agency of the USA, and it is based on the same grammar illustrated in Fig. 25. It refers to the energy balance of USA in 2003.

What is important to observer in this figure is the choice of adopting ***a linear representation*** of the various flows. This implies that the representation is based on the idea that you have energy forms entering the system from the left side, then these energy forms are transformed (in the middle) and they are finally used on the right side of the graph. This implies that during this trajectory the energy flows considered in the analysis **must change** both **their values and their identity**, across the linear trajectory, which starts form left and end to right. Assuming that it is possible to perform this quantification, therefore, means assuming that it is possible to define in a substantive way the

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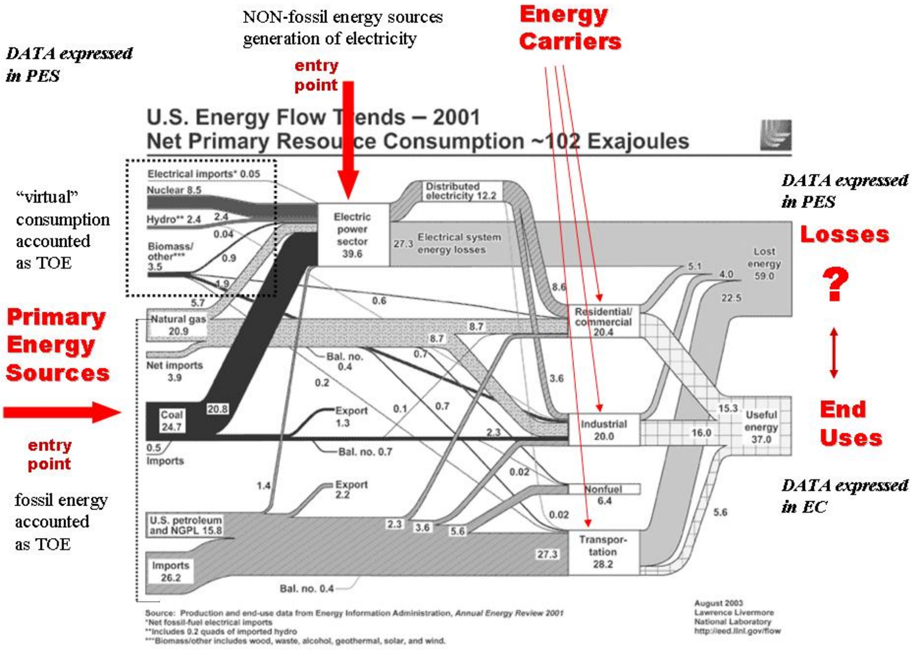
series of two conversions: (A) Primary Energy Sources → Energy Carriers (when moving from the left to the center of the figure); and (B) Energy Carriers → End Uses (when moving from the center of the figure to the right). As a matter of fact, as it is discussed below this assumption is not valid. The conversion (A) PES → EC can be quantified in two non-equivalent ways (depending on the energy form we decide to use are reference); and the conversion (B) EC → EU cannot be quantified at all, since the proxy variables needed to quantify End Uses are not commensurable with the proxy variables needed to quantify Energy Carriers.

Fig. 26 Linear map-flow of energy consumption in the USA 2007



Looking at Fig. 26 in details, we can see on the left of the graph a quantity of primary energy sources (semantic category - PES) which then becomes a flow of energy carriers (semantic category - EC), in the middle. The logical difference between the semantic categories PES and EC entails an unavoidable amount of energy losses (second law of thermodynamics) due to the transformation PES → EC. Finally, the linear flow ends (on the right of the graph) with the definition of yet another semantic category End Uses. It should be noted though, that in this representation, the formal representation of "energy losses" (the quantitative representation) is located on the right of the graph, for balancing the accounting, as if it were playing the same role of end uses. In fact, the balancing of the accounting (done using numbers referring to formal categories) over the chosen set of semantic categories is everything but easy . . .

Within this representation, the production rule (correction factor) adopted to account for the difference between primary energy sources and energy carriers (electricity) is used only to define the values written on the left of the graph. That is, the accounting of electricity (a token) which enters in the graph in the middle (belonging to the category Energy Carrier) is done using Tons of Oil Equivalent (on the left of the graph) as reference, within the semantic category PES. This is done in

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order to generate a comparable assessment of primary energy sources equivalent between different countries. Here we have a first hint at the epistemological problem with this representation: some energy flows (fossil energy) enter into this graph from the left side, whereas other (electricity generated by Nuclear Power or Hydropower) enter in the middle of the graph. This generates a semantic problem of categorization. Electricity is an energy carriers (according to a logical system of categorization), but when entering in the form of Nuclear Power or Hydroelectric energy, may be considered as a Primary Energy Source (according to another logical system of categorization). This generates an unavoidable bifurcation in the quantitative representation of energy flows, which is discussed in the next section.

In conclusion, this system of accounting is implemented ***in order to be able to take in account the fact,*** that when looking at the overall consumption of Primary Energy Equivalent, ***there are countries with a very large production of Nuclear and/or Hydroelectric Power, which would result as consuming much less Primary Energy Sources than other, even though they are consuming much more Energy Carriers (electricity)***.

Let's get back to the problem found with the representation used by BP and USA. The choice of accounting for Joules of "virtual tons of oil equivalent" (on the left of the graph), which later on will end up in the category of energy losses (on the right of the graph) - as indicated in Fig. 26 - entails an additional problem. Not only, there are virtual losses which enter in the accounting, but also there is a problem of how to deal with these losses. The total losses reported on the right, either real or virtual, cannot be allocated directly to the flows of energy carriers represented in the middle.

In fact, the numerical assessments indicating the relative percentage of energy consumption of: (i) Residential and Commercial; (ii) Industry; and (iii) Transportation (in the middle of the graph) refer to energetic measurements belonging to the semantic category Energy Carriers. The relative values of these numbers (generated by summing together distinct formal categories – electricity, fuels and heat - belonging to the semantic category EC) no longer maps onto the relative consumption of J of TOE given on the left of the graph (which is expressed using a chosen formal standard category of reference – Tons of Oil Equivalent – belonging to the semantic category PES).

In fact, let's assume that two sectors – A and B – are consuming the same amount of GJ - a number referring to the semantic category of energy carriers (a number obtained by summing together MJ of electricity, fuel and heat without using any quality corrections). Then if A is consuming 90% of its energy in the form of electricity, whereas B is consuming only 10% of electricity, we can conclude that A is responsible for a much larger fraction of primary energy consumption, since A entails much more energy losses than B. However, when using the method of accounting shown in Fig. 25 and Fig. 26: (i) all the losses are counted together (on the right of the graph) as if they were another form of end use; (ii) the numbers referring to the total of energy consumption getting into End Uses do not carry any meaning (are not useful for defining any useful category of energy consumption). Getting back to the examples of the two sectors with a total different fraction of consumption of electricity, when using at the data reported on energy statistics in the middle of the graph, we would find that the two sectors A and B have the same consumption of energy - whereas they have: (i) a different requirement in terms of PES; and (ii) a different efficacy in relation to EU. Since this is an essential point, if not ***the essential point*** of this discussion, this problem is discussed in details, using as example from a case study of SMILE in section 4.3.

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So far we discussed only one example of mono-purpose grammar used to generate the representation of the energy consumption of a country (semantic concept) in terms of Tons of Oil Equivalent (formal category used as standard) mapping onto a semantic category of energy forms (PES).

However, it is possible to find alternative quantitative representations, similar to the one illustrated in Fig. 26, which have been developed using other types of mono-purpose grammar. For example, there are analyses of the energy consumption of a society which focus only on the production of CO_2. In this case, nuclear Power and Hydroelectric power becomes almost invisible (but for the production and handling of uranium and the making of the plants). Examples of this alternative application of mono-purpose grammar can be found at http://www.eia.doe.gov/.

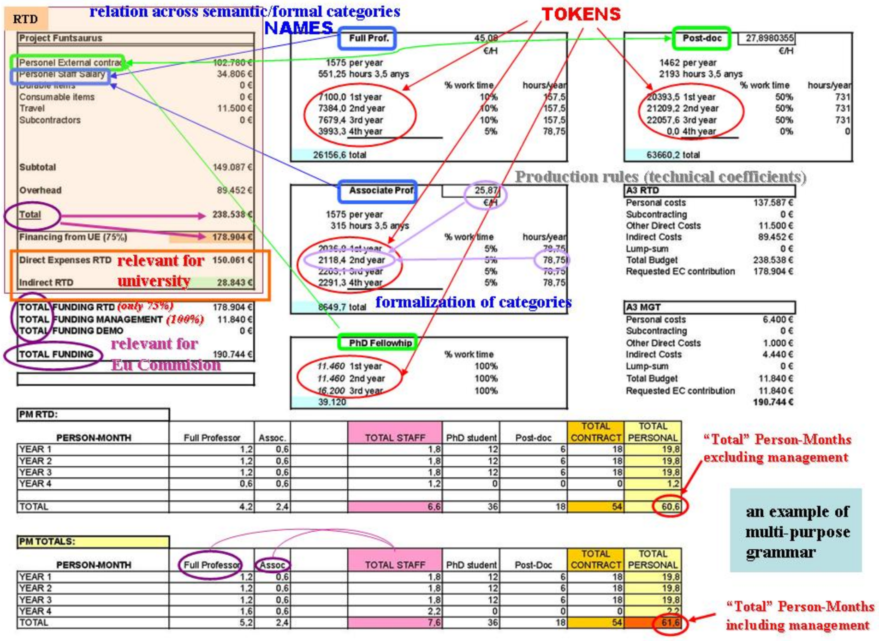
4.2.3 The concept of Multi-purpose grammar

The concept of "*multi-purpose grammar*" can be associated with a meta-system of accounting based on a flexible network of expected relations between semantic categories (e.g. relevant attributes of sustainability) and formal categories (names – indicators) generated by production rules which are applied in a flexible way, depending on the purpose of the analysis, to a given database (tokens).

In epistemological jargon we can say that a grammar helps to identify the right set of external referents (what has to be known and measured) for performing a given quantitative assessment, judged useful in relation to a given purpose.

To illustrate this concept we will use a very familiar example for those working with European funds of research. The example is illustrated in Fig. 27 and it is the excel spread sheet used to provide an integrated assessment of the budget of a research project carried out using European funds.

Fig.27 A multi-purpose grammar in action: the budget of a RTD project



RTD

Project Funtsaurus	
Personel External contrac	102.780 €
Personel Staff Salary	34.806 €
Durable items	0 €
Consumable items	0 €
Travel	11.500 €
Subcontractors	0 €
Subtotal	149.087 €
Overhead	89.452 €
Total	238.538 €
Financing from UE (75%)	178.904 €
Direct Expenses RTD	150.061 €
Indirect RTD	28.843 €
TOTAL FUNDING RTD (only 75%)	178.904 €
TOTAL FUNDING MANAGEMENT (100%)	11.840 €
TOTAL FUNDING DEMO	0 €
TOTAL FUNDING	190.744 €

Full Prof. 45,08 €/H
1575 per year
551,25 hours 3,5 anys

	% work time	hours/year
7100,0 1st year	10%	157,5
7384,0 2nd year	10%	157,5
7679,4 3rd year	10%	157,5
3993,3 4th year	5%	78,75
26156,6 total		

Post-doc 27,8980355 €/H
1462 per year
2193 hours 3,5 anys

	% work time	hours/year
20393,5 1st year	50%	731
21209,2 2nd year	50%	731
22057,6 3rd year	50%	731
0,0 4th year	0%	0
63660,2 total		

Associate Prof 25,87 €/H
1575 per year
315 hours 3,5 anys

	% work time	hours/year
2036,0 1st year	5%	78,75
2118,4 2nd year	5%	78,75
2203,1 3rd year	5%	78,75
2291,3 4th year	5%	78,75
8649,7 total		

PhD Fellowhip

	% work time
11.460 1st year	100%
11.460 2nd year	100%
16.200 3rd year	100%
39.120	

A3 RTD	
Personal costs	137.587 €
Subcontracting	0 €
Other Direct Costs	11.500 €
Indirect Costs	89.452 €
Lump-sum	0 €
Total Budget	238.538 €
Requested EC contribution	178.904 €

A3 MGT	
Personal costs	6.400 €
Subcontracting	0 €
Other Direct Costs	1.000 €
Indirect Costs	4.440 €
Lump-sum	0 €
Total Budget	11.840 €
Requested EC contribution	11.840 €
	190.744 €

PM RTD:

PERSON-MONTH	Full Professor	Assoc.		TOTAL STAFF	PhD student	Post-doc	TOTAL CONTRACT	TOTAL PERSONAL
YEAR 1	1,2	0,6		1,8	12	6	18	19,8
YEAR 2	1,2	0,6		1,8	12	6	18	19,8
YEAR 3	1,2	0,6		1,8	12	6	18	19,8
YEAR 4	0,6	0,6		1,2	0	0	0	1,2
TOTAL	4,2	2,4		6,6	36	18	54	60,6

PM TOTALS:

PERSON-MONTH	Full Professor	Assoc.		TOTAL STAFF	PhD student	Post-Doc	TOTAL CONTRACT	TOTAL PERSONAL
YEAR 1	1,2	0,6		1,8	12	6	18	19,8
YEAR 2	1,2	0,6		1,8	12	6	18	19,8
YEAR 3	1,2	0,6		1,8	12	6	18	19,8
YEAR 4	1,6	0,6		2,2	0	0	0	2,2
TOTAL	5,2	2,4		7,6	36	18	54	61,6

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This particular application of a grammar has the purpose to establish a useful relation between: (i) the system of accounting of the University getting the money for the project; and (ii) the system of accounting required by the European Commission, when providing financial support for the RTD project.

In particular this example focuses mainly on the person-months allocated in the project in order to handle the accounting of the relative costs. In relation to the grammar shown in Fig. 27, we can individuate in this excel spreadsheet two different sets of categories:

#1 a set of semantic categories - such as: "personnel external contracts"; and "personnel staff salary", which are related to the analogous definition of formal categories (names). In this example, the semantic category "personnel: external contracts" is associated to two formal categories (names): "cost of post-doc" and "cost of PhD student"; whereas the semantic category "personnel: staff salary" is associated to the two formal categories (names): "cost of full professor" and "cost of associate professor". Other semantic categories would be:
* "direct expenses" versus "indirect expenses", which are "relevant information" since they are used by the University to handle the accounting of the money received from the EU commission; and
* "total funding RTD" and "total funding management" used by the EU Commission to handle the money to be given to the University.

#2 a set of formal categories, which can be divided into **"names"** and **"tokens"**.
For example, the value to be assigned to the "name" → "cost of associate professor" – is determined by an expected relation (production rule) combining the values associated with the "token" categories: "cost per hour", "hours in a year", "profile of distribution of hours over the 4 years".

When looking at the overall analysis of costs for RTD activities (the box in the upper corner on the left), we can see the presence in that box of several "totals" – "names-categories" - mapping onto semantic categories. These different totals represent different formal outputs – numerical assessments – which are useful for different purposes.

For example, there is an assessment of the total costs - 238.538 € "no matter who pays for them" - which indicates the overall economic cost of this budget for EU tax payers. There is a total referring to the financing from EU - 178.904 € - but only in relation to RTD expenses. There is another total referring to the overall financing from EU - 190.744 € - which includes also the management costs. These are semantic categories relevant for the administrative office within the EU Commission. In a smaller box, located among the various totals, there is a "logically distinct" division in categories. These categories are not relevant for the EU Commission, but they are relevant for the University receiving the money. These two categories will be used by the administration of the University for the handling of the money received from the Commission. For this reason, the distinction based on the semantic categories "Direct Expenses" and "Indirect Expenses" - although meaningless for the EU Commission giving the money, is required to provide a useful output for the administrative offices of the University receiving the money.

In conclusion, in Fig. 27 we see an example of use of this grammar for generating an useful dataset - i.e. an integrated set of useful indicators - useful for different people having different purposes. As noted, the purpose of this particular application is:

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(#1) to establish a useful relation between the system of accounting of the University getting the money for the RTD project, and the system of accounting of the European Commission providing financial support for RTD.
By applying this grammar it becomes possible to "share meaning" about the quantification (the numbers), according to the rules adopted both by the European Commission and by the University receiving the money. This shared meaning makes it possible to agree on the amount of money to be transferred from the EU commission to a given university, the amount of money that a given research group can use for travels, the money that a PhD student will receive during this project, etc.

However, it is important to observe that ***the same grammar*** can also be used for ***different purposes*** if needed:

(#2) to check the desirability and viability of a given project against an external definition of budget constraint.
For example, let's imagine that the given group of research has been invited to become part of a consortium within an assigned budget as partner (the coordinator says to the group, I see you as a potential partner, and within the consortium this is the amount of money that more or less can be assigned to you). Then in this situation, when running an analysis of viability and desirability, the number included in the category "total financed by the EU Commission" should be considered as a "token-category" and no longer as a "name-category". The research group invited, in order to be able to decide whether or not it is desirable and feasible to join the consortium under the given budget constraint, can use this very same grammar to visualize the "option space" when allocating person-months over the given set of categories. Now the person-months of full professors, associated professors, post-doc, PhD students become "names" categories (variables). Then, by using this grammar (after shifting a few definitions of names and tokens) one can study what combination of person-months across the categories included in the lexicon is feasible given the limited budget. In this way, the group can check whether the participation to the consortium, under any one of the feasible options is also desirable;

(#3) to compare differences among universities operating in different countries in relation to economic costs of research.
For this purpose what is relevant is the input data entered in the grammar before the application of the production rules. That is, this analysis will be based on a comparison of the values used for the "token-categories" – cost per hour of labour in the different categories of personnel. Yet the set of expected relations provided by the grammar is still needed, since when dealing with a comparison among personnel costs, such a comparison among different countries has to be performed by looking at the cost "per hour of working time" ***across homogeneous semantic and formal categories*** - i.e. full professors with full professors and PhD students with PhD students. In order to compare the same typology of token categories we need to organize the relative data sets using the same grammars. The reader can recall here the example of the comparison given in Fig. 21 between UK, Spain, Germany and Ireland. A meaningful comparison requires looking at benchmarks referring to the same category of compartments in the economy.

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(#4) to compare differences among research groups in relation to the adoption of different strategies for use of financial resources.
For this purpose, it is the overall profile of investments over different semantic categories of cost that can be used to look for benchmark values and peculiar situations. For example, when comparing a large number of budgets, all represented and characterized using the same grammar illustrated in Fig. 27, we can look for outliers.

(#5) to look for typical patterns of typologies of research (expected relations over the values taken by different benchmarks).
For example, is the difference in percentage between the "cost per hour" of a full professor versus the "cost per hour" of an assistant professor homogeneous over the sample? Can we find typologies of universities with very high cost per hours and those with very low cost per hours – e.g. there are cluster of values for different "token-categories" over the sample? Can we look for ***typologies of RTD projects*** in relation to the profile of allocation of the cost over the given lexicon – e.g. when we deal with budgets in which "cost equipment" >> "cost of personnel" we can conclude that the project is aimed at *technological development (engineering)* – whereas when we deal with budgets in which "cost of equipment" << "cost of personnel" we can conclude that the project is in *social sciences and humanities*.

4.2.4 Wrap-up of the discussion on the use of grammars and databases

This brief theoretical discussion about the conceptual tool of multi-purpose grammar had the goal to clarify why is it so important to handle the quantitative characterization of complex systems in this way. We will make the point, in the next section, that this concept is a must when dealing with the quantitative representation of complex networks of energy transformations (energy analysis). In fact, the functioning of complex systems requires the simultaneous use of non-equivalent quantitative models in order to be able to handle logical bifurcations in the system of accounting. Each of these non-equivalent models allows us to focus on some of the characteristics of the investigated system, at the cost of ignoring others. For this reason it is of the uttermost importance to adopt an integrated system of accounting capable of keeping coherence and meaning across these non-equivalent characterizations.

We believe that when dealing with the analysis and the quantitative representation of the energy metabolism of societies, what is needed is a better articulated or multi-purpose grammar; a grammar that, starting from a given dataset, would allow us: (i) to compare the patterns of energy metabolism of different countries in relation to different benchmarks; (ii) to develop different indicators of performance referring to different purposes. These integrated set of indicators can be generated by assigning different production rules to the same original set of tokens. Depending on the purpose of the different indicators the same set of tokens will generate a different set of names; and (iii) to analyze different scenarios, by switching 'names' with 'tokens' and/or imposing different production rules (e.g. assuming technological changes).

In particular, this would make it possible to add new information, meaning and understanding to the representation, when needed, by adding new categories to the lexicon (tokens and names) of the grammar. Indeed, the conceptual tool of grammar is semantically open. The

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same semantic can take in different points in space or in time different formalization. The meaning of the same names can be expressed using an evolving family of names, using an evolving set of tokens or different production rules. This implies that additional categories and production rules can be added to the original data set, making it possible to enlarge the set of relevant indicators. As it is discussed later on, this ability to change the structure of accounting based on previous structural and functional pattern is essential when discussing of future scenarios no longer based on fossil energy. The energy statistics we know are "fossil-energy" statistics. The very marginal contribution provided by non-fossil energy sources is manipulated in the statistics in order to look like fossil energy (everything is expressed in Tons of Oil Equivalent). Needless to say, that this system of accounting is not particular useful to discuss of scenarios of societal metabolisms no longer based on fossil energy.

Before closing this theoretical section, we would like to observe, that the very same systemic problems found with the accounting of energy flows are found with the accounting of material flows.

Also when producing statistics referring to material flows, there is the serious risk to start with valuable information (the original dataset of the flows of matter and energy consumed in the various sub-sub-sectors) – the token to be used in the grammar – which is then destroyed by the process of aggregation adopted by the statistical office – when providing the statistics in terms of a list of names. This issue is dealt with, in the next section in relation to energy data.

4.3 The lesson from cases study: how useful are EUROSTAT energy statistics?

4.3.1 Basic epistemological problems with accounting of energy

<u>(A) The huge misunderstanding about the concept of energy</u>

Even though energy is handled by the "queen of hard science" – physics – energy is a semantic concept, which is quite tricky to formalize. Unfortunately, many, including those working in the business of energy accounting, seem to have a very naïf view of energy and its quantification. Many seem to believe that energy is the ultimate example of an exact and deterministic variable. Since physicists have shown that it is possible to measure specific energy transformations, at a given point in space and time, many people believe that then the resulting numbers are very robust. Therefore they believe that after incorporating these numbers in a dataset, later on these numbers can be summed and aggregated just by using arithmetic operations. As matter of fact, the Energy Statistics Manual literally says in the section entitled "how to calculate energy balances": *The balance is calculated according to the arithmetic rules shown in Figure 1.3* – Pag. 30 OECD/IEA, 2004.

This belief is supported by the fact that different energy forms can all be expressed in the same unit Joules or in units which can be reduced to each other (kWh, kcal, BTU). But not necessarily all the items which can be measured using the same units should be summed. Let's imagine that we sum kg of grain to kg of rocks. The resulting sum would be useful for a truck driver checking the overall load of his truck. However, this very same sum would result not only useless but misleading to someone trying to calculate the supply of food, provided by that truck, to a refugee

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camp. As a matter of fact, energy accounting can be called as the art of choosing how to aggregate "apples and oranges" (Giampietro and Mayumi, 2009).

In general terms, we can say that this erroneous view about the possibility of getting a substantive quantification of "energy" has been generated by the huge misunderstanding that took place at the end of the XIX century in the scientific community. This misunderstanding was generated when the scientific establishment remained astonished by the enunciation of the first and second law of thermodynamics. These two laws implied a major revolution in the scientific thinking, which led to a major restructuring of old scientific paradigms. In the confusion that followed this revolution, the scientific establishment assumed by default that these two laws could be applied, ***in formal terms***, across any scale, to everything, including the whole universe! (Mayumi and Giampietro, 2004).

At that time, the scientific establishment missed the distinction between the semantic message of these "laws", and the actual possibility of implementing these laws in substantive quantitative terms. The wrong hidden assumption was that it is possible to formalize these concepts using protocols that can remain invariant across non-equivalent observers and descriptive domains.

This unchallenged acceptance of the idea that formal analyses of entropy and exergy could be applied to any complex system across different scales - over different space-time domains and simultaneously across different hierarchical levels of organization - is at the basis of the widespread erroneous belief, that energy accounting can be done in a substantive and deterministic way.

But nothing is more far from the truth that this belief. As the Nobel Prize winner in physics Richard Feynman pointed out: "*it is important to realize that in physics today, we have no knowledge of what energy* **is**… *it is an abstract thing in that it does not tell us the mechanism or the* ***reasons*** *for the various formulas*." (Feynman et al. 1963, Chapter 4, p. 2). In practice, energy can be perceived and described in a large number of *different forms*: gravitational energy, kinetic energy, heat energy, elastic energy, electrical energy, chemical energy, radiant energy, nuclear energy, mass energy, etc. These are semantic categories, which can be translated into formal categories, by choosing an adequate proxy variable. However, a general definition of energy, without getting into specific context and space-time scale dependent settings, is necessarily limited to a vague expression, such as "*the potential to induce physical transformations*". This implies that it is not possible to reduce all these energy forms to each other ***in a substantive way***. Any reduction and aggregation requires, first of all, deciding a set of criteria of equivalence (what is the equivalent of 1 MJ of the energy form A, when expressed in 1 MJ of energy form B?). The problem with the adoption of a criterion of equivalence is that it requires ***choosing a point of view***, it is about a given perception of relevance about which point of view should be considered as more important than another. That is, when dealing with the analysis of different energy forms, it is impossible to define an uncontested criterion of equivalence. Using technical jargon, we can say that when energy is represented over non-equivalent descriptive domains (e.g. a different definition of scale – the hidden perception of space and time associated with the relative change) the different definitions and

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measurement of energy quantities are incoherent (Giampietro and Mayumi, 2004). They cannot be reduced to each other in a substantive way (Rosen, 2000).

A sentence, taken again from the explanations given in the Energy Statistics Manual on the chosen system of accounting is quite illuminating: "*For example, the gross electricity production from hydro plants is used as the primary energy form rather than the kinetic energy of the falling water* ***because there is no statistical benefit from pursuing the adoption of the kinetic energy as the primary energy form*** (?!). *It does not, however, say how the amount of energy to be attributed to the primary energy form is calculated but in this case* ***it is natural to adopt the amount of electricity generated as the measure****"* (?!) [question and exclamation marks are ours] - OECD/IEA, 2004 pag. 136. In this example, it is clear that without a pre-analytical structuring of the formal analysis based on the pre-analytical definition of the logic associated with the choice of the grammar: "semantic concepts → semantic categories → formal categories, and expected relations over them", then *everything goes*. The accounting becomes a series of arbitrary decisions taken by the accountant to patch here and there the accounting into a protocol of accounting that balance inputs and outputs. But unfortunately, this arbitrary patching entails that later on it can become difficult to share meaning with other people willing to use the resulting set of numbers.

It should be noted that the classic definition of energy found in conventional physics textbooks, often used by many non-expert of this field, is "*the potential to do work*". However, this definition refers to the concept of "free energy" or "exergy" (which is another potential source of confusion). In fact, both the concept of "free energy" or "exergy" can be quantified. But again this quantification can only be done after defining a formal definition of work. In turn, a formal definition of work requires a clear definition of operational settings which must be necessarily referring to a given descriptive domain – scale, boundary, duration of the process to be quantified, end state, power levels (Giampietro and Mayumi, 2004; Mayumi and Giampietro, 2004). There is no formal definition of work which could be applied to "the activities performed in the Industrial sectors" or the "activities performed in the Household sector", let alone if we want to consider the efficiency of the whole economy.

In conclusion we can say that when studying the energetics of complex adaptive systems the quantifications of different forms of energy are never substantive (Giampietro, 2006; Giampietro and Mayumi, 2009 – Chapter 5). As a result of this epistemological challenge, any comparison of two different energy forms, when referring to the process of autopoiesis of a complex adaptive system, ***will depend on the reasoning chosen by the analyst*** when ***defining the criterion determining an equivalence class for the accounted Joules***. It is simply not true that 1 MJ referring to a given formal category (coal) is equal to 1 MJ referring to another formal category (natural gas). Let alone if the Joules to be aggregated refers to different semantic category: Primary Energy Source (1 MJ of coal) vs Energy Carriers (1 MJ of electricity). Finally, it is impossible to quantify, in substantive terms, the conversion of MJ of energy carriers into "MJ" of useful work (End Uses) if we adopt a linear representation – left to right flow of energy transformations (for a theoretical discussion of this

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point Giampietro and Mayumi, 2004; 2009). This means that any number found in energy analysis of socio-economic systems must always reflect the choices made by the accountant (the choice of the identity of the grammar). In turn, this means that the identity of the grammar (the set of expected relations between semantic and formal categories) should receive top priority in terms of attention and discussion. If possible a discussion of the logic behind the grammar should receive even more attention than the discussion over the protocols used to gather data. Unfortunately, this is not the case.

That is, the chosen quantification of energy requires a choice of accounting which must be able to reflect the semantic perception of relevance of the chosen set of energy transformations. In simpler terms, we can say that we need to adopt non-equivalent methods of accounting depending on the type of energy transformations we want to describe and depending on the semantic categories we want to assess.

For example, the quantitative method useful to assess the energy input for a virus (based on the lexicon of biochemistry in which fuel is represented by energy-rich molecules) even if measurable in Joules, is not reducible to the quantitative method useful to assess the energy input for the industrial sector of Germany (based on the lexicon of technical energy conversions). Therefore, any time we decide to use qualitative indices referring to comparable energy forms – for example when calculating the overall output/input energy ratio of an economic process - we are analyzing the overall effect of the interaction of different (non-equivalent) energy forms. For example, in order to assess the energetics of agricultural production, we have to include in the assessment primary energy sources such as solar energy and rain, which are transformed into energy carriers for human metabolism such as crops, via the consumption of fossil energy carriers used for making the fertilizers. Then we have to include other energetic inputs very difficult to quantify, such as the input of human labor. Because of this heterogeneity of energy forms interacting in the process, the final number generated by the aggregation of all these non-equivalent energy forms in just an output/input ratio, will never be substantive. It will always depend on the series of pre-analytical choices made by the analyst when defining the underlying grammar.

(B) The solution used by ecologists to overcome the problem of accounting energy forms of different quality

The new paradigm associated to complexity, which is rocking the reductionist building, is the son of a big epistemological revolution started in the first half of 19th century by classic thermodynamics (e.g. by the work of Carnot and Clausius) and continued in the second half of the 20th century by non-equilibrium thermodynamics (e.g. by the work of Schroedinger and Prigogine). Both revolutions used the concept of “entropy” as banner. The equilibrium thermodynamics represented a first bifurcation from mechanistic epistemology by introducing new concepts such as irreversibility and symmetry breaking when describing real world processes (e.g. unilateral directionality of real time). Nothing can be the same (e.g. the same state) when it happens for the second time. However,

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it is with the introduction of the paradigm of non-equilibrium thermodynamics that science experienced a final departure from the reductionist epistemology.

In fact, acknowledging the non-equilibrium thermodynamic paradigm implies the uncomfortable acknowledgment that scientists can only work with system-dependent and context-dependent definitions of entities (when adopting formal models). Obviously, this applies also to the concept of energy and its formalizations.

For example, the concept of “negative entropy” is not a substantive concept. Rather the concept of “negative entropy” coincides with the definition of “the needed point of view” associated with the given identity of a dissipative system which is perceived and represented as operating at a given point in space and time. Starting from the “dissipative pattern” (the identity of the metabolic system) considered as relevant in the analysis we can then define “favorable boundary conditions” – negative entropy. This concept cannot be defined “a priori” without knowing the identity of the dissipative pattern which has to be maintained. We can only define/represent negative entropy in relation to a dissipative pattern to be maintained.

This epistemological revolution introduced with the study of the class of dissipative systems (by the school of Prigogine), is a must for those willing to study metabolic systems. The class of metabolic systems includes both ecosystems and social systems. Members of this class can survive and reproduce only if they manage to gather what *they* define as energy input (negative entropy or *exergy* within a given well-defined system of accounting) and to discard what *they* consider waste (positive entropy or degraded energy). However, in this “contextualized” definition, what is waste or positive entropy for one system (e.g., manure for a cow) may be seen as an energy input or negative entropy by another (e.g., soil insects) (Giampietro, 2006). What was an excellent energy input for Europe in the year 1850 – coal – is no longer considered an excellent energy input for Europe in the year 2009 – now Europe goes for natural gas. What is an excellent energy input for a car (gasoline) is not an energy input for humans.

The assessment of energy flows both in terms of semantic and formal categories, depends on the pre-analytical definition of a grammar, in turn, the usefulness of the grammar depends on the purpose of the analysis.

But what are the implications of this revolution on the mechanism of energy accounting? Below we provide the answer given to this question by one of the pioneers of theoretical ecology Bob Ulanowicz: “*Energy begins to seem less a concrete reality than an artifact of constructivist book-keeping system necessary for estimating quantities whose role seems far more palpable and physically relevant (Reynolds and Perkins, 1977). It has always seemed to me passing strange that the law of conservation of energy should be the only law in all science to hold without exception, everywhere, all the time. I have often speculated that perhaps things were merely defined in exactly such a way that they would always balance. . . . Newton had declared the world to be a closed system, so why not simply* ***define*** *energy to be conserved?*” Ulanowicz, 1997 (pag. 23).

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In simpler terms, this implies that self-organizing systems, which are expanding continuously their definition of what is energy, useful energy and waste, entail/need an "ad hoc" definition of criteria to be used before starting their energy accounting.

Since they become something else in time, changing the original definition of what should be considered as useful energy, the system of accounting not only has to be tailored on the specificity of the system to be characterized, but also has to learn how to cope with these changes. The idea of using a protocol of accounting which is supposed to remain valid forever is unpractical.

In relation to this challenge theoretical ecology, when developing its peculiar network analysis in the 60s, came-up with a solution to this problem. The solution found by the pioneers of theoretical ecology - H.T. Odum and his brother E.P. Odum - was that of using "transformity factors" referring to a given grammar based on the network of energy transformations, specific for ecological systems (for a discussion of this point see Giampietro and Mayumi, 2009 – Appendix 1). That is, an ecosystem can be seen as a network of energy flows in which a Primary Energy Source (solar energy) is used to generate Energy Carriers (chemical bonds making up the biomass of the various elements of the ecosystems). In this way, after describing the set of internal and external relations of the network (after drawing a grammar reflecting the network of transformations similar to the grammar represented in Fig. 9) one can define a criterion of equivalence for the accounting of the various energy forms of different quality found in the ecosystem.

Different energy forms can be aggregated, only after: (i) defining their relations over the network; and (ii) calculating the resulting quality factors. For example, considering only the transformation of chemical bonds (remaining within the semantic category: energy carriers!) – that is, the biomass found in the various compartments making up the ecosystem - we can establish factors of conversions between the formal categories belonging to this semantic category. That is: IF it takes 10 MJ of plant biomass to make 1 MJ of herbivore biomass, and IF it takes 10 MJ of herbivores biomass to make 1 MJ of carnivore biomass, THEN in the internal accounting of energy transformations required for the stabilization of this particular structural and functional organization, 1 MJ of carnivores ***has embodied in itself*** the equivalent of 100 MJ of plant biomass. That is there is a "transformity factor" of 100/1 (100 MJ belonging to the formal category plants are required to have 1 MJ belonging to the formal category of carnivores).

This very same rationale has been adopted for developing energy analysis of modern societies. The calculations performed to assess the embodied energy can be performed using input-output tables (Herendeen and Bullard, 1976; Herendeen, 1981; Hannon, 1973; 1981; 1982; Slesser, 1978) made it possible to calculate the concept of embodied energy for different energy forms.

The concept of embodied energy can be used to define a quality factor for different energy forms. The rationale is the following one. IF in a given set of energy transformations associated with the metabolism of a society, there are some energy carriers – MJ of electricity – which have embodied a certain quantity of MJ of Primary Energy Source, which are consumed for their production; THEN, ***if the society is willing to waste 3 MJ of fossil energy in order to obtain 1 MJ***

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of electricity, this indicates that electricity is "more valuable" to that society than 1 MJ of fossil energy. As a matter of fact, it is possible to find in network theory the concept that the transformities of flows, defined over a given network of transformations, can be considered as network prices...

In conclusion, this is the rationale behind the adoption of the conversion factor by old international energy statistics, which is still used by the BP statistics and in the USA. In these statistics 1 MJ of electricity (referring to the energy form "Energy Carrier") is equivalent to a certain amount of MJ referring to a standard reference value of Primary Energy Source (e.g. Tons of Oil Equivalent; or Tons of Coal Equivalent). May be this rationale is what has been called Partial Substitution Method in the Energy Statistics Manual provided by International Energy Agency and Eurostat - even though by reading their explanations on Pag. 136 (OECD/IEA, 2004), it is not sure that they interpret this protocol of accounting in the way it has been explained here so far . . .

4.3.2 The unavoidable bifurcations in energy data found on existing energy statistics

(A) The main problem with the actual system of accounting in energy statistics

In this section we want to use a practical example (taken from a SMILE case study) to show the unavoidable emergence of bifurcations in the quantitative accounting of energy transformations, when representing the pattern of energy metabolism of a country.

The main point to be made is that a quantification using a criterion of aggregation can be obtained over different formal categories referring to the same semantic category. That is it is impossible to aggregate in a substantive way different formal categories of energy carriers (electricity, fuel and heat) belonging to the semantic category of energy carriers and different formal categories of primary energy sources (nuclear, coal, natural gas, wind, hydroelectric) belonging to the semantic category of primary energy sources. In Fig. 28 we use an overall representation of the network of energy consumption of Spain (in 2005) to illustrate this point. The quantitative analysis described in Fig. 28 still uses the linear representation found in energy statistics (the same used in Fig. 26), with the difference that here the linear series of conversions is vertical (bottom-up), rather than horizontal (left-right) as done when representing the energy flows in the USA.

Let's now go through the information given in Fig. 28 starting from the bottom.

On the bottom of the figure we find the given MIX of different types of Primary Energy Sources (Semantic Category) which are required to power the energy sector. Starting from the left we have 7 different formal categories of PES [which can be divided into 3 sub-semantic categories: (A) Fossil Energy Sources (non-renewable) represented by: 3 formal categories - coal, oil and natural gas. In the middle we have: (B) Nuclear Energy (difficult to define in relation to its degree of renewability).

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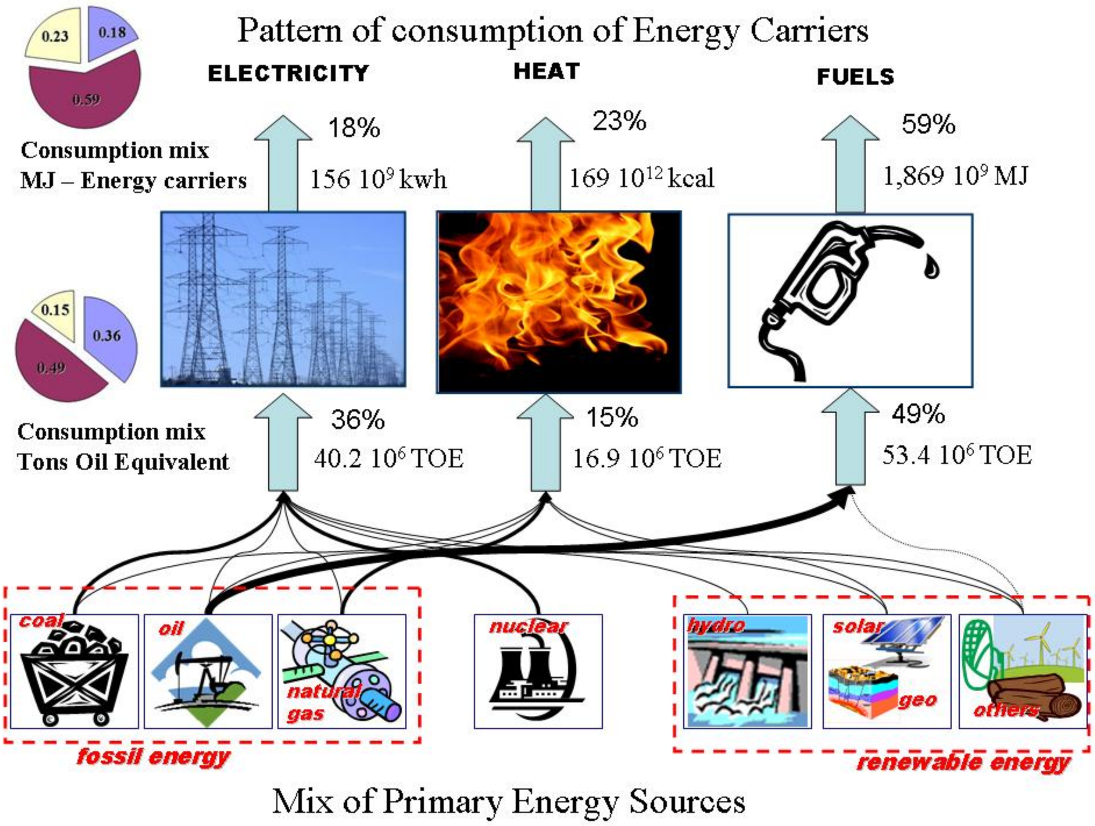
On the right we have: (C) Renewable Energy Sources represented by 3 formal categories : hydro, solar and geo, wind and biofuels.

Fig. 28 The flows of energy consumed in Spain quantified by keeping the distinction between: 2 semantic categories – (1) Primary Energy Sources (PES) and (2) Energy Carriers (EC) - and 3 formal categories [electricity, heat and fuel] in EC; and 7 formal categories [coal, oil, natural gas, nuclear, hydro, solar&geo, other renewables] in PES.



As observed earlier, since these 7 formal categories refer to the same semantic category (PES) it is possible to aggregate their value, by adopting a protocol of accounting (production rules). The quantitative assessment of the total amounts of energy from different PES, which is used in the energy sector to produce energy carriers, can be expressed in a common unit of measurement – but it requires the selection of a standard formal category used as reference – i.e. Tons of Oil Equivalent. The overall total must be expressed in MJ of a given formal category of reference and therefore it must be in the form of → MJ of "formal category x" equivalent.

In the middle of the figure we find the quantitative representation of the MIX of different Energy Carriers produced by the Energy Sector and consumed by society. This is another semantic

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category referring to the particular attributes that these energy forms must have in order to guarantee the end uses required by society. The three formal categories of energy carriers are: (i) Electricity; (ii) Fuels; and (iii) Heat.

To underline the difference ***in quality*** between these the numerical assessments of the amount of energy calculated using the three different formal categories of energy carriers we decided to express the *different amounts of energy* referring to each one of these *different energy carriers*, using *different units of measurement*. In particular, the three units are: (i) kWh for measuring electricity; (ii) kcal for measuring heat; and (iii) MJ for measuring fuels.

These different units of measurement reduced to each other using standard conversion factors [which are well known - 1 kWh = 3.6 MJ; (ii) 1 kcal = 4.186 kJ].

Then, it becomes possible to use a common unit (Joules) to calculate two important pieces of information: (A) the total amount of energy consumed by society in the form of energy carriers; and (B) the profile of the relative percentage of the three energy carriers in this total.

However, if we do so, we get the bifurcation in the possible quantifications of the energy consumption of Spain, illustrated in Fig. 28. That is, when we generate a quantitative assessment of energy consumption using the semantic category – energy carriers – then the resulting numerical value is not equivalent to the one discussed in the previous paragraph. The total consumption of energy of Spain (expressed in MJ of Energy Carriers) ***refer to an energy form of reference*** (the semantic category EC) which is non-equivalent to the energy form of reference (the semantic category of PES) used for the assessment of Tons of Oil Equivalent!

As easily observed when looking at Fig. 28 there are two non-equivalent quantifications of the mix of energy carriers used by Spain. More specifically, in the figure there are two pies of different size, providing a different profile of percentages characterizing the relative use of the three energy carriers. Looking at the two pies on the left-upper part of the figure we can see that is we use:

(A) Tons of Oil Equivalent (based on the consumption of Primary Energy Sources) then we get a quantitative assessment of: 4.6 ExaJoules of PES are consumed and that 36% of this energy goes in the making of electricity. When calculating the same pie using: (B) MJ of energy carriers (after eliminating from the accounting the conversion losses) then we get 3.1 ExaJoules of EC are consumed and that only 18% of the energy spent in Spain is in the form of electricity (this when converting the three different units in MJ and without applying any quality/conversion factor).

Needless to say, that this bifurcation in the quantitative assessments of the same semantic concept (a representation of how energy is used in Spain) is a natural phenomenon. There is nothing wrong with it, but it fact has to be acknowledged. As discussed below, the dataset of Eurostat presents just a single set of numbers, which is perfectly balanced, and which is based on the accounting and summing together of items belonging to the two semantic categories of Primary Energy Sources and Energy Carriers. As discussed more in detail below this is certainly a reason for concern.

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The second observation to be made about Fig. 28, refers to the implications of the structure of the network of energy transformations. In fact, not all the MJ of fossil energy (formal categories within the semantic category PES) are the same. It is well known that 1 MJ of natural gas is more effective than 1 MJ of oil, and 1 MJ of oil is more effective than 1 MJ of coal. Therefore, the same amount of Total Energy Throughput (expressed in Joules of PES) can have different effects on the economy depending on the profile of distribution of the total amount of Tons of Oil Equivalent over the set of 7 formal categories. In this regard, it is well known that in the last decades for developed countries, an important factor determining the increase in performance of the economy has been a continuous adjustment in the mix of Primary Energy Sources (Hall et al. 1986!; Ayres et al. 2003) - oil replaced coal and now natural gas is replacing oil. The same phenomenon took place in relation to the mix of energy carriers (the upper pies on the left). The post-industrialization coincides with a continuous adjustment in the mix (relative importance of the 3 formal categories) of Energy Carriers (Ayres and Warr, 2005). The fraction of electricity has been continuously expanding now for decades within the pie of energy carriers.

So if we want to study the changes in the efficiency of the economic process in terms of energy analysis, it is essential to be able to study changes in both pies, addressing the implications of both: (i) changes in PES (on external constraints); and (ii) changes in EC (on internal constraints).

To makes things more difficult, the amount of energy accounted over the various formal categories (7) included in the category PES are not all equally useful for generating the required mix of energy carriers by society. For example, nuclear, hydroelectric and wind power, at the moment, can only generate electricity. Depending on the particular mix of energy carriers required for a given task, this can represent a problem. In fact, even if electricity is the most valuable among the energy carriers, there are some tasks (e.g. powering a jumbo jet or a harvester), which cannot be performed using electricity. Therefore, it is important to be aware of the importance of considering the various connections over the network of energy transformations shown in Fig. 28: who is producing what on the supply side and who is consuming what on the consumption side.

This entails two distinct feasibility/viability checks:

(1) a check on the feasibility of the energy sector (supply side) - the mix of 7 formal categories, included in the semantic category ***Primary Energy Sources*** has to be able to match the mix of 3 formal categories, included in the semantic category ***Energy Carriers***; which is required by society (EXTERNAL CONSTRAINTS);
(2) a check on the viability of the metabolic patterns of society (consumption side) - the mix of 3 formal categories, included in the semantic category ***Energy Carriers***, has to be able to match the mix of formal categories of functions, included in the semantic categories ***End Uses*** (INTERNAL CONSTRAINTS).

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This observation is very important either if we want to study the performance of the metabolic pattern or if we want to use energy data to discuss of possible alternative future energy scenarios, no longer based on fossil energy.

In fact, with the combined predicament of Peak-oil, climate change and environmental stress it is becoming more and more evident that it is not possible to keep alive the existing pattern of development just by developing alternative energy sources capable of substituting fossil energy (e.g. the search for the "silver bullet" of biofuels). Rather we have to develop an alternative pattern of development in order to be able to use alternative energy sources (the whole pattern represented in Fig. 9 will have to be readjusted).

But accepting this idea, means accepting that in the future, the metabolic pattern of developed societies will have to be based on a patchwork of energy transformations – a differentiated mix of different primary energy sources will have to be integrated into a network of flows of energy carriers required by an integrated set of end uses. When establishing this new "patchwork", we will have to be able to match the different mixes of requirement of energy carriers in space and time, using a variety of different types of Primary Energy Sources. The final look of this network of energy transformations will look much more like a spider-web rather than the linear map-flow – shown in Fig. 26. This linear energetic representation is a representation developed (and therefore useful) only to represent the metabolic pattern of the fossil energy era - from below the ground, through the society and then up into the sky.

But let's explore more now in details the explanations and implications of the co-existence of two non-equivalent quantitative characterizations of the pies of energy carriers in Spain shown in Fig. 28. A more detailed analysis of this co-existence is given in Fig. 29, which focuses on the transformations performed by the energy sector.

Moving from PES to EC (focusing on the performance of the energy sector)

Let's first of all measure the amount of losses associated with the overall conversion of the mix of PES (a total amount of 4,641 10^9 MJ → 4.6 EJ → 4.6 10^{18} J) into the mix of EC (a total amount of 3,142 10^9 MJ → 3.1 EJ → 3.1 10^{18} J).

This overall loss is detected when moving from the energy accounted in the semantic category PES and the energy accounted in the semantic category EC. The difference in the case illustrated in Fig. 29 is equal to 32% of the original amount of energy accounted as PES. This quantitative assessment is obtained as follows.

#1 – when the semantic concept of ***total energy consumption*** is defined in relation to the semantic category PES, then the ***name*** total consumption is expressed in TOE (a formal category of reference) and it is calculated by aggregating the tokens coming from the 7 formal categories (all belonging to the semantic category PES) according to a specified set of production rules.

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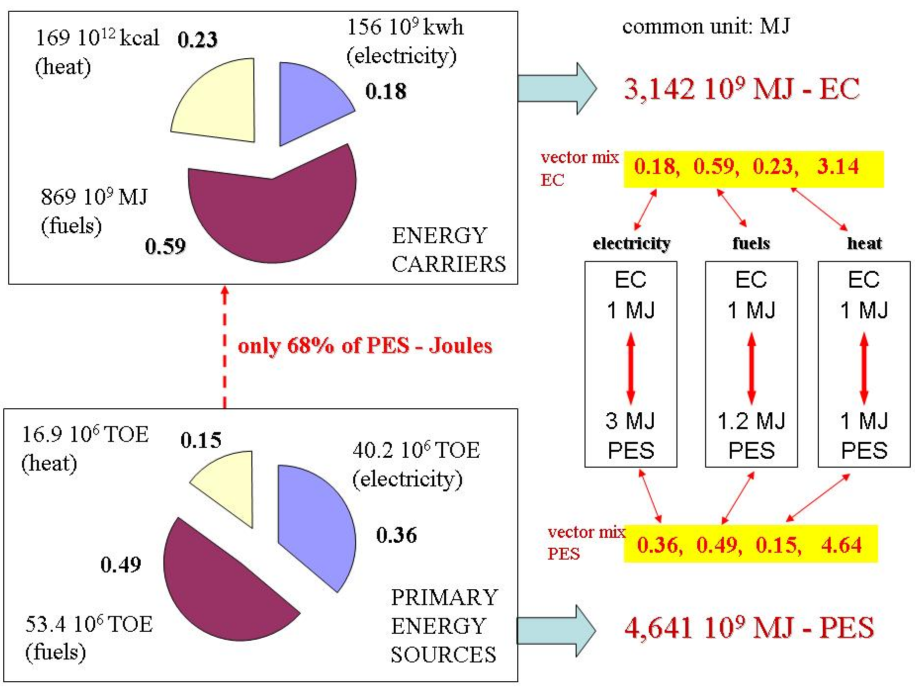
#2 – when the semantic concept of ***total energy consumption*** is defined in relation to the semantic category EC, the ***name*** total consumption is expressed in MJ (without the definition of a formal category of reference). The sum is just a numerical sum made without using any aggregation protocol.

Fig. 29 The factors determining the non-equivalent quantifications of energy consumption of energy carriers



The protocol used to move from PES to EC

The production rule can be defined in the following way: we can write the information given by the two pies in the form of a vector made of 4 elements: (i) the fraction of electricity; (ii) the fraction of fuel; (iii) the fraction of heat; (iv) total energy consumption (expressed in EJ). When adopting this convention we can characterize the two quantitative assessments using the following vectors:

Pie expressed in terms of PES energy form → 0.36; 0.49; 0.15; 4.64
Pie expressed in terms of EC energy form → 0.18; 0.59; 0.23; 3.14

Then a simple protocol can be used to establish a systemic relation between the two characterizations by addressing: (i) the set of specific losses of conversion (PES → EC) for each one of the energy carriers generated by the various PES; (ii) the given mix of energy carriers; (iii) the amount of each one of the energy carriers used.

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As shown on the right side of Fig. 29 we can assign "quality factors" based on the loss associated with the transformation PES → EC_i for each one of the energy carriers. In this simplified example, we used: (i) 3 MJ of PES/1 MJ of EC for electricity; (ii) 1.2 MJ of PES/1 MJ of EC for fuels; (iii) 1 MJ of PES/1 MJ of EC for heat, but a discussion of the chosen set of conversion factors is not relevant here.

What can we say about the move from Energy Carriers to End uses? Can we quantify, using numbers referring to energy carriers, the efficiency of a society?
The second transformation EC → EU would require quantifying how effective is the use of this mix of energy carriers in delivering to society the required set of end uses. However, in relation to this task, none of the figures considered so far (Fig. 25, Fig. 26, Fig. 28, Fig. 29) provides sufficient information to make any quantitative assessment of this types. In fact, the selection of end uses: (i) residential & commercial; (ii) industry; and (iii) transportation; does not reflect a logical definition of semantic categories (it does not map onto homogeneous functions to be expressed within the society). As a matter of fact two of these end uses: *residential and commercial*; and *transportation* are very heterogeneous entities. They include different sectors of activities (Agriculture, Residential and Service and Government together!) and they refer to both commercial (PW sector producing added value) and private activities (HH sector consuming added value). For this reason, it is impossible to define a quantitative criterion to be used to check how effective has been, a given amount of energy invested in these end uses (more on this point in section 4.3.3). For this purpose we cannot use either "added value generated per MJ", or "goods and services provided per MJ" to assess how effectively this flow of energy carriers has been used.

Three important observations about the grammar illustrated in Fig. 29:

#1 ***It confirms that it is necessary to use simultaneously non-equivalent quantifications when dealing with the analysis of the metabolic pattern of a society***.
In fact, when dealing with the analysis of:
(A) EXTERNAL CONSTRAINTS on the viability of the energy sector - we have to use a semantic definition of energy consumption which can be related to the interaction of the whole society (seen as a black-box) with its context. In this case, it is necessary to discuss of the type of constraints that – given a required mix of energy carriers – will be faced when forced to generate them using Primary Energy Sources;
(B) INTERNAL CONSTRAINTS on the viability of the metabolic patterns of society - we have to use a semantic definition of energy consumption which can be related to a viable and desirable interaction of the various sub-parts and parts, inside the black-box. In this case, it is necessary to focus on the technology and hours of human work required to be able to handle this flow of EC in order to deliver the required EU.

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These two checks refer to two different views of the network of energy transformations (from outside the black-box and from within the black-box), and therefore, it is unavoidable to expect the insurgence of bifurcations in the quantification of energy flows. The need of using simultaneously non-equivalent representations is an expected feature to be found in the quantitative analysis of complex systems. What is a reason of concern is that official statistics pretend this problem does not exist, and continue to generate quantitative representation based on just on "the right set of numbers" balancing each other over an input/output scheme.

#2 there are two typologies of *tokens* – measured data – which are required for the assessment of energy consumptions referring to PES and EC:
(a) when dealing with the mix of PES ***we need a mix of energy data and non-energy data*!** Primary energy sources ***should be assessed using a combination (a mapping) between two sets of data***: ***(i) natural units*** – e.g tons of carbon, tons of oil, cubic meters of natural gas, liters of ethanol, kg of uranium used in Nuclear Plants, cubic meter of water falling into hydrohelectric plants, hectares of crops or forest used for generating biofuels, the strength of the wind and the number of hours of wind/year for eolic parks, etc.; ***(ii) energy units*** – e.g. kWh, kcal, MJ - the type and quantity of energy carriers coming out from the exploitation of the PES;
(b) when dealing with the mix of EC – ***we have data which can only be expressed in energy units!*** (the reading of the amount of energy generated in power plants, the consumption of energy of industries or households). As noted earlier these data refer to different types of energy carriers, having different qualities, and performing different tasks – they are kWh of electricity, MJ of fuels, kcal of heat.

#3 there are consumptions calculated in PES (e.g. the value of 4.6 EJ for Spain found in Fig. 28 or the value of 102 EJ for USA found in Fig. 26) which refer to a semantic concept (total consumption of primary energy) and that can only be expressed using a standard energy form – a formal category of reference, associated with the chosen semantic category - ***Tons of Oil Equivalent***. **This overall assessment of total consumption of primary energy belongs, within the chosen grammar, to the category of *names*** (it is not a direct measurement). This assessment is generated by summing together ***tokens*** – data on actual consumption of fossil energy PES - and ***names*** – calculations of virtual consumptions of fossil energy associated with the production of electricity based on non-fossil energy. In turn this second sets of ***names*** depends on the production rules (the conversion factors) applied to the original ***tokens*** (kWh of electricity produced not using fossil energy). Therefore, the value of these ***names*** depends on the choice of production rules (conversion factors) over the network, made by the statistician.

#4 there are consumptions calculated in EC (e.g. the value of 3.1 EJ for Spain found in Fig. 28 or the value of 69 EJ for USA found in Fig. 26) which refer to a semantic concept (total consumption of

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energy carriers) and that are expressed using number obtained by summing together assessments belonging to different formal categories of energy carriers (electricity, fuel, heat). However, the issue of how to aggregate into a single number, different amount of energy of different quality is not addressed (neither by the people of BP, or by the IEA/Eurostat statistics), sicne we do not have an effective representation of the end uses. So this numerical value is not expressed in a chosen formal category of reference (MJ of something equivalent)! In any case, according to the system of categorization typical of a grammar, we have to conclude that this total amount of energy carriers **is a *name*** – that is it is not a direct measurement. Therefore, it requires the choice of a protocol of how to aggregate together the various ***tokens*** – the actual consumption of Energy Carriers of different types and having different qualities. Unfortunately, at the moment, these tokens are aggregated just by using the standard energetic conversions and adopting the same quality factor 1/1. Because of this set of choices, we can say that the numerical value associated with this ***name*** is meaningless since:
(a) when looking for the implications on external constraints – the viability of the energy sector – this information is totally useless, since it does not account for the difference in quality - different losses - in relation to the transformation PES → EC.
(b) when looking for the implications on internal constraints - the viability and desirability of the metabolic pattern of society – this information is totally useless, since it does not account for the difference in quality – differences in efficiency – in relation to the transformation EC → EU. In fact, as noted earlier: 1 MJ of electricity is more effective than 1 MJ of heat in generating useful work, but in order to calculate the overall efficacy of a mix of energy carriers one has to know first the mix of end uses. In the current characterization of energy statistics we do not know where and how, these flows of energy carriers are used to guarantee the required functions of the society.

Finally, we can now compare the usefulness of the information provided by the system of accounting chosen by BP and the system of accounting chosen by Eurostat.

We do this comparison by answering the question "what can we do with the information provided by the two?"

(B) A critical appraisal of the actual system of accounting in BP statistics

What can we do with the quantitative information found in energy statistics of the type illustrated in Fig. 26?

In relation to the two numerical values of PES and EC we can say:
(a) The total amount of energy consumption, expressed in PES (found on the left of the graph) is useful for comparing the total consumption of countries, in relation to a given PES of reference [= Tons of Oil Equivalent]. However, because of the very simplistic production rule adopted for this assessment, this numerical value can only provide a meaningful comparison in relation to the

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different importance that the production of electricity with non-fossil energy PES plays in different economies
(b) the total amount of energy consumption, expressed in EC, not only is useless, but also misleading, since the characterization of consumption, both in absolute value and in percentage over the pie, do not reflect either the total initial consumption of energy – expressed in PES – nor the final achievement in terms of end uses.

In relation to the quality of the grammar used the analysis:

(1) the value of Total Primary Energy Sources (on the left of the graph) is a name (it depends on the assumptions of the statistical office!) and it is not particularly useful for either assessing the performance of the economy or to study the feasibility of energy source alternative to oil. In fact, qualitative characterization is based on a standard of quality (Tons of Oil Equivalent) based on a standard energy form – oil, one of the formal categories of fossil energy – which has to be phase out in the future!;
(2) the assessment of the amount of energy getting into End Use (in the middle of the graph) – referring to: (i) Residential &Commercial; (ii) Industrial; and (iii) Transportation; is not useful for assessing the performance of a country. In fact, from this value we cannot know: (a) which fraction of the total losses – 59 EJ for the USA in 2005 – should be associated to each one of these three compartments; (b) the specific connection of the mix of the three energy carriers (e.g. the percentage of electricity) used in each one of these sector. If we want to obtain this information we have to infer it from the other flows, since it is not considered as a relevant piece of information to be provided in the dataset.
(3) this data set does not provide any information on the external constraints affecting the consumption of energy of society – e.g. what is the relative rate of depletion of different fossil energy stocks, the consumption of uranium, the emission of CO2, the requirement of land for biofuels, requirement vs availability of falling water, etc.;
(4) ***this data set does not provide any information about the quality of the various Primary Energy Sources.*** For example, it is well known that the quality of the energy source depends on their EROI [= Energy Return On Investment]. That is, to perform this evaluation one should know for each one of the 7 formal categories of primary energy sources to be assessed: (a) how much energy carriers are produced; and (b) which mix of energy carriers, is required and consumed in the production of energy carriers. In fact, the exploitation of Primary Energy Sources provides a supply of energy carriers to society, but at the same time, it also consumes a flow of energy carriers. For this reason, it is essential to know, which fraction of the energy consumed by a society must be invested in the energy sector itself. This amount of energy carriers required for making energy carriers, will increase: (a) the overall consumption of energy of society; (b) the environmental impact, (c) the internal demand of capital, labor and other services to be invested in the energy sector, in

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competition with the other sectors of the society, without providing a net useful supply to the rest of society. For this reason, an analysis of the quality of the different Primary Energy Sources used by a country should be a key piece of information of energy statistics! Having a good knowledge of this piece of information would avoid embarrassing situations such as the implementation of the policy for agro-biofuel – a formal category of PES with an output/input of 1.1/1! - which would imply the production of 11 (eleven) liters of gross ethanol in order to generate the net supply of 1 liter of ethanol to society (Giampietro and Mayumi, 2009).

(5) this data set does not provide any information about the overall performance of the economy in relation to the two series of conversions of PES → EC → EU. In fact, as observed earlier, these conversions take place over a network with different (7 categories) of PES connecting in different way to a mix of 3 different EC used in different mixes by different compartments of the society, requiring an unspecified set of End Uses. Unless one is capable of reconstructing and addressing the functional and organizational structure of the network of transformations – as done in the example of Fig. 9 – the solution of adopting a simple linear aggregation of numerical values - as done in Fig. 26 - will unavoidably miss crucial information, and therefore waste the potential information carried by the original dataset used for generating this analysis.

(C) A critical appraisal of the actual system of accounting in Eurostat statistics

When reading the explanations of the system of accounting adopted for generating the Energy Balances by both the International Energy Agency and Eurostat it is difficult to understand the logic used for organizing the dataset. As a matter of fact, the choice of a lot of tokens used in the statistics is similar to that done by BP energy statistics (meaning that the "ingredients" so to speak are all there), however, the semantic used for the choice of categories is not clear (at least for us).

The purpose of the exercise of quantification seems to be clear. In a section entitled "Why energy balances" (on pag. 135) the Manual (OECD/IEA, 2004) says: "*The format adopted is termed the **energy balance** and allows users to see the fuel conversion efficiencies and the relative importance of the different fuel supplies in their contribution to the economy. The energy balance is also the natural starting point for the construction of various indicators of energy consumption (for example consumption per capita or per unit of GDP) and of energy efficiency*". However, according to the experience done trying to use this dataset exactly for these purposes, we are not convinced that this claim is justified.

The first problem comes with the semantic concepts used to define what type of information is given with the dataset. For example, the dataset uses the expression of "***commodities*** balance" to refer to the integrated accounting of different forms of energy. As a matter of fact, the structure of the proposed system of accounting is very similar to that used in other commodities balance. But how robust is the relative semantic to account for energy transformations? After reading both the explanations and the organization of the dataset, one gets the impression that this concept is used

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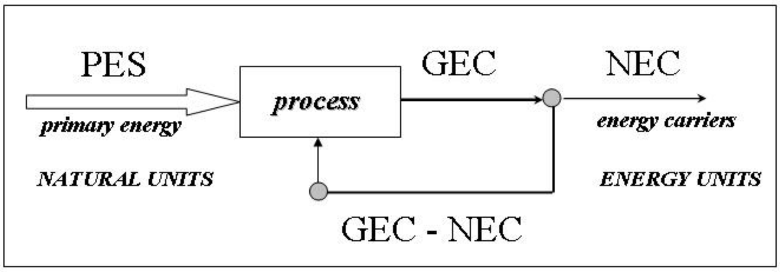
without logical consistency to handle heterogeneous types of semantic and formal categories of non-equivalent energy forms. A few examples are discussed below:

#1 The confusing handling of the category Primary Energy Sources

The semantic associated with the concept of Primary Energy Source is pretty straightforward. It derives directly from the application of the fundamental laws of thermodynamics. Human technology can not produce energy. Human technology can only use a given source of energy (a useful gradient of something, found already in the environment) to generate energy carriers. Therefore, the energy sector [= the specialized sector of the society in charge for the production of the energy carriers required by society] must rely on a variety of different primary sources of energy, which must be ***already available*** to generate the required supply of energy carriers. This implies that the exploitation of a Primary Energy Sources requires an unavoidable investment/consumption of energy carriers (which have to be used in an internal loop in order to generate a larger supply of energy carriers). This fact is illustrated in Fig. 30.

Fig. 30 The "impredicative loop" of energy carriers used to make energy carriers, when exploiting a Primary Energy Source



GEC = Gross Flow Energy Carriers
NEC = Net Flow Energy Carriers
GEC-NEC = Input Energy Carriers
PES = Primary Energy Source

The set of energy transformation in Fig. 30 shows a counterintuitive phenomenon (for reductionist analysis) typical of self-organizing metabolic systems: when exploiting a PES the *output* of energy carriers must be generated *before* being able to use the relative *input* needed for the exploitation. Therefore, we deal with a situation in which we must characterize a process ***in which the output comes before the input!***

Already this consideration should suggest that it is not wise to organize the accounting and representation of this impredicative loop (chicken-egg paradox) using a linear representation of the type input-output.

In nature, when dealing with the analysis autopoietic metabolic systems, the input-output does not work the reductionist way. This implies that there are 2 different pieces of information which are required for assessing the ***quality*** (= importance, efficiency, usefulness, environmental impact, work requirement, economic performance) of a primary energy source:

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(A) a characterization of the flow of primary energy – ***which has to be expressed not in energy units, but in natural units*** – this is the attribute relevant for determining the external constraints associated with the formal category of PES (e.g. hydroelectric, nuclear, coal); and
(B) a characterization of the flow of energy carriers – ***which has to be expressed in energy units***, in the form of a the net supply of energy carriers delivered to society.

The problem is that according to these two pieces of information the various categories of PES cannot be aggregated and compared as such. In fact, each one of the considered categories of PES (e.g. the 7 considered in Fig. 28) provides a certain amount of either kWh of electricity, kcal of heat or MJ of fuels (the OUTPUT), and consumes different amounts and types of INPUT – e.g. kg of uranium, or cubic meter of water, or hours of winds or cubic meter of natural gas (the primary energy).

In order to be able to sum together quantitative assessments of energy referring to different formal categories of PES we have to adopt some logical criterion of equivalence for both the output and the primary energy. The logic to be used for this choice will determine the semantic category in relation to which we want to perform the aggregation. If we want to aggregate these different quantitative assessments in relation to their CO_2 emission (the OUTPUT), then we have to adopt a given production rule (introducing semantic sub-categories – fossil energy PES vs non-fossil energy PES). If we want to aggregate these different quantitative assessments in relation to their labor demand (total workers required by the energy sector to deliver the required supply of energy carriers), we will have to aggregate the various PES using a different production rule, and so on. The Eurostat does not have any criterion of aggregation (even though it does aggregate a lot of numbers in just one way).

#2 The confusing handling of the relations between semantic and formal categories

What about the organization of semantic and formal categories chosen by Eurostat?

Looking at the selection of the set of categories and the relative production rules chosen for aggregation, the grammar adopted by Eurostat appears quite obscure in its logic. First of all the categories have funny names, which are difficult to be associated with semantic concepts referring to energy conversions. As noted earlier, the accounting is done over labels called “energy commodities”. This is a label recalling an economic narrative, which is very difficult to use when dealing with a biophysical accounting of energy transformations. Paradoxically thermodynamics accounting has been used as a banner by bio-economists (e.g. Georegescu-Roegen) to say that the economic accounting is incompatible with energetic accounting!

But the most disturbing fact, is that this label of “energy commodities” seems to refer indistinctly not only to: (i) different semantic categories (both PES and EC); but also to (ii) different formal categories within each one of these semantic categories.

In fact, the proposed system of accounting is based on a distinction between: “Primary Energy Commodities” and “Secondary Energy Commodities”. However, this choice of categories

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generates a serious epistemological impasse, since, with this choice of category, the generation of electricity from hydroelectric or nuclear (an assessment which is using as token the amount of electricity generated by the plants) is considered to be a "Primary Energy Commodity". After getting this label the accounting of the relative amount of energy (based on the direct measurement – tokens - of MJ of energy carriers – an energy unit) is included in the same category where we find coal, natural gas and oil (tokens based on the direct measurement of tons of coal, cubic meters of natural gas, tons of oil – natural units). It should be noted that in the "old fashion" system of accounting tons of coal and oil are associated with the category of Primary Energy Sources (something capable of establishing a criterion of equivalence between natural and energy units – by definition). On the contrary in Eurostat statistics the summing of the various formal categories (the numerical values expressed in energy units) included in the "semantically undefined" category "Primary Energy Commodities" is variable. The tokens of kWh of electricity are accounted in different ways - e.g. those from nuclear plants are multiplied by 3 - or by another conversion factor when available - those from hydroelectric plants are not multiplied at all. To clarify better the implications of this choice, we have to note in the latter case kWh of hydroelectricity are simply summed to tons of oil! To make this conversion the proposed protocol uses the energy equivalent of a ton of oil (1 TOE = 42 GJ) and the value of a kWh (kWh = 1,000 J/sec x 3,600 sec = 3.6 MJ), with the bizarre result that 1 kWh of electricity (an energy unit used to assess an energy carrier) is summed to 1 Ton of Oil (a natural unit) by using as conversion factor the calorific value of 1 ton of oil!

We do not know what types of experts worked in the task force deployed by the International Energy Agency and Eurostat to decide the protocols of accounting for the energy balance. For sure we can say that the chosen protocol is disturbing for engineers and physicists. In fact, when moving from GJ of heat associated with a ton of oil to GJ of electricity one must necessarily assess also the efficiency of the conversion (e.g. 30% of EC energy out over PES energy in). This piece of information is not only needed to calculated losses and conversion factors over energy flows, but also to establish a relation between other relevant natural units – kg of coals, kg steam in the turbine, kg of CO_2 emissions, water vapour, SO_x emissions, etc.

This is what makes it oil a real Primary Energy Sources: there is a biophysical process associated with the generation of electricity (Fig. 30). In the same way, when we move to nuclear power the specific natural units are: kg of uranium, kg of radioactive wastes, hours of work, liters of water for cooling. When dealing with hydroelectric power we have the flow of cubic meters of water and the gradient in height. For geothermal energy, we have the total flow of heat energy getting into the plant used for the generation of electricity. Given this series of definitions based on natural units (which are not expressed in Joules) these different categories of PES cannot be summed. We cannot sum apples and oranges, a substantive criterion which can be used to implement the semantic concept of Total Primary Energy Consumption does not exist.

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On this point one should be absolutely clear. IF we go for the choice that different energy forms cannot be summed, THEN we should not use the category Primary Energy Commodities to provide aggregated value. IF we go for the choice, that it is important to have a number to be used as a proxy of total energy consumption; THEN we have to admit that this is a quantity which cannot be measured (it is a name), it can only be defined (and therefore ***it must be defined***) by the accountant when choosing a production rule determining ***an amount of energy equivalent to be used as a standard***. That is this definition requires establishing a criterion to be used in order to sum numerical values referring to different formal categories. This is the reason why, BP statistics use a standard value of reference [= a formal category of PES belonging to the sub-category of fossil energy – Tons of Oil equivalent]. In particular Tons of Oil is perfect as a reference category, since it makes it possible to establish a clear relation between: (i) energy units; and (ii) natural units. But in order to establish this relation we need two pieces of information: (a) the energy conversion value of oil (e.g. 1 TOE = 42 GJ); and (b) the efficiency at which electricity is produced by using oil!

In conclusion, before the establishment of the new system of accounting done by the International Energy Agency and Eurostat, the total amount of energy consumption was calculated using the semantic category Primary Energy Sources and using a standard formal category for quantitative aggregation across types. This standard reference formal category was Tons of Coal Equivalent - when coal was the most used formal category - and it is now Tons of Oil Equivalent. It is not by chance that the energy assessment of "Total Primary Energy Consumption" (how big is the overall consumption of a country) are given in **natural units of something** (either Tons of coal or oil). This combined assessment of natural units and energy equivalent is used to give the perception of the overall size of the energy metabolism. This combined mapping is possible since PES are expressed in a mix of energy and natural units. After having established this standard stick, then one can use the fraction of this total energy consumption to assess the relative importance of electricity, fuels and heat and the relative consumption in the various sectors of the society (by keeping measuring energy quantities in TOE!).

#3 The confusing handling of the relations between formal categories

After having noted that the logic used by the IEA/Eurostat statistics to chose the semantic definition of categories for the accounting is not clear, let's check how robust is the logic used for handling the production rules to generate quantitative assessment within the chosen formal categories. What are the equivalence criteria used to generate the correction factors needed for aggregating numerical values referring to different formal categories? Three examples of the solutions proposed (to account for electricity generated by energy sources other than fossil energy) are pasted below:
(i) hydroelectric – no conversion factors [1 MJ electricity = 1 MJ of heat of oil] - the explanation for this choice is basically that otherwise countries producing a lot of electricity with hydroelectric will result as having a high primary energy consumption equivalent and large virtual losses (needed to balance the input and the output). The criterion for formalization is again: "*the gross electricity*

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production from hydro plants is used as the primary energy form rather than the kinetic energy of the falling water because there is no ***statistical benefit*** *from pursuing the adoption of the kinetic energy as the primary energy form. It does not, however, say how the amount of energy to be attributed to the primary energy form is calculated but in this case it is natural to adopt the amount of electricity generated as the measure*" (pag. 136). It literally means: we decided to use the value of the energy carrier "electricity" and the sum MJ of hydroelectric power as such (no correction) to MJ of coal within the category (semantic? formal?) ***Primary Energy Commodities***;

(ii) nuclear and other non-fossil energy generation of electricity – they use the same conversion factors (2.6/1 or 3/1) like BP statistics [1 MJ electricity = 3 MJ of heat of oil]. The explanation is: "*as there is no transformation process recognised within the balances for the production of primary electricity, the respective percentage contributions from thermal and primary electricity cannot be calculated using a "fuel input" basis. Instead, the various contributions should be calculated from the amounts of electricity generated from the power stations classified by energy source (coal, nuclear, hydro, etc.). In the case of electricity generation from primary heat (nuclear and geothermal), the heat is the primary energy form. As it can be difficult to obtain measurements of the heat flow to the turbines, an estimate of the heat input is often used*" (pag. 136). It literally means: we decided to use the value used by the others.

(iii) geothermal energy – the explanation provided is not clear: "*Primary heat from geothermal sources is also used in geothermal power plants and a similar back-calulation of the heat supply is used where the quantities of steam supplied to the plant are not measured. In this case, however, the thermal efficiency used is 10%. The figure is only approximate and reflects the generally lower-quality steam available from geothermal sources*.

The real question at this point is: those that have chosen the set of production rules used for the accounting claim that they have decided in relation to the ***statistical benefit*** of one method of accounting versus another. But how is it possible to judge the statistical benefit of a method to be used to aggregate different categories of energy forms (Tons of coal, kWh of electricity, cubic meters of natural gas) without having established first the semantic criterion of equivalence for the chosen category "Primary Energy Commodities"? In fact, it is not logically possible to sum numerical assessments of different energy forms (apples and oranges) if they are not expressed in MJ of "something equivalent". Since the category "Primary Energy Commodities" is a name (not a token) it needs first of all a semantic definition in order to be able, later on, to define the required: (i) production rules to be used for aggregation; and (ii) formal category to be used as standard - in order to express the final quantitative assessment in a given unit of reference.

Unfortunately a semantic definition of this innovative category introduced by this manual in the field of energetics (primary energy commodities) is not available, we can only try to explore this mystery by looking at the possible usefulness of the numbers generated in this way.

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Is the category "Primary Energy Commodities" useful to assess the semantic concept of "total energy consumption" of a country? That is, is this numerical assessment the "analogous" to the value of Tons of Oil Equivalent found in the BP statistics?

According to the logic used so far in energetic analysis, a quantitative assessment of total energy consumption - ***the final number used to assess the overall consumption of energy of a country*** - should be given in the form of "Primary Energy ***Commodity*** of *type n* equivalent". On the contrary, when using Eurostat and EIA data, to assess the total energy consumption of countries, we are using a number which refers to an unspecified mixture of non-equivalent Joules (for which is not even possible to know the semantic category of reference: are they EC or PES?). To cover this lack of semantic, this number has been labelled using an unknown, esoteric and unspecified category: "Primary Energy Commodities".

We found this organization of the dataset unsatisfactory for the type of analysis illustrated in Section 3. The organization of data over the two categories "Primary Energy Commodities" and "Secondary Energy Commodities" makes it impossible to study: "*the fuel conversion efficiencies and the relative importance of the different fuel supplies in their contribution to the economy* when characterizing the metabolism of Spain, UK, Germany, and Ireland (as done in Section 3). It is impossible to define conversion efficiency over the aggregate value of these two categories. Let alone the claim that: *The energy balance is also the natural starting point for the construction of various indicators of energy consumption (for example consumption per capita or per unit of GDP) and of energy efficiency*"?

In fact, IF it is not clear what semantic concept is measured by the two categories: Primary Energy Commodities and Secondary Energy Commodities, THEN it becomes very difficult to handle the bifurcation in the possible quantifications of the mix of energy carriers discussed in Fig. 29.

Another big problem of this dataset is that still it organizes the quantitative representation in linear terms (input – output). It does so, by using the same solution of the "old fashion" energy statistics discussed before – accumulating all the "conversion losses" in a single compartment (called "transformation input"). Also in relation to the definition of the end uses this dataset still adopt the same unsatisfactory definition of end uses discussed in Fig. 26: Industry, Transport and "Other sectors" (in Fig 26 this was "residential and commercial"). This definition of end uses is not useful to calculate the fraction of the total energy consumption (expressed in quantitative terms in a Primary Energy Source of reference) which goes into: (i) the Service and Government, for generating a certain amount of added value and the required amount of services; (ii) in the Household Sector for guaranteeing a certain material standard of living; (iii) in the agricultural sector for generating a certain amount of added value and guaranteeing food production; and (iv) in the Building and Manufacturing sector, for generating a certain amount of added value, and to guarantee the required production of the products required by society.

Positive notes on Eurostat energy statistics are:

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* in relation to the characterization of the performance of the energy sector - there is a very good disaggregation of the original set of data (tokens) divided both per category of Primary Energy Sources (the 7 formal categories considered in Fig. 28) and per category of Energy Carriers;
* in relation to the characterization of the metabolic pattern of society – there is a good disaggregation in the analysis of final consumption in many subcategories defined within the three compartments of final Energy Consumption (industry, transport, other sectors).

This implies that it is possible, starting from the information given by the Eurostat dataset to build a multi-purpose grammar capable of generating an integrated set of indicators. In the next section we illustrate the way we trying to do so, in the remaining activities of the SMILE project.

4.3.3 Can we generate energy statistics more user friendly for those willing develop sustainability indicators?

In this section we present an example of multi-purpose grammar based on a multi-level representation of the network of energy transformations associated with the expression of the metabolic pattern of a modern society. In this way, it becomes possible to establish a direct relation between the type of analysis of the metabolism of social systems presented in Part 3 and the information organized in energy statistics.

In Fig. 31 we indicate the various pieces of information required, at different levels of analysis, to provide an effective characterization of the various transformation. Starting from the bottom of the figure, we can see:

Point # 1 - characterization of the different typologies of Primary Energy Sources – using the 7 formal categories. This characterization has to be done by using both non-energy variables - tons of coal, kg of uranium, tons of water, hectares of land – and energy variables. In this way it becomes possible to assess the different EXTERNAL CONSTRAINTS, which affect the potential supply of energy carriers, using specific indicators for the various typologies of PES considered (for each MJ of energy carriers generated). This information is essential for discussing of energy scenarios no longer based on fossil energy;
Point # 2 - characterization of the type of energy carriers supplied by the various typologies of PES. This requires a graph indicating the connections over the relative flows of energy carriers. For example, nuclear energy generates only electricity, oil is the major source of liquid fuels (but it can also generate electricity and heat). This information has to be complemented by the relative characterization of their technical coefficients;
Point # 3 - establishing a relation between the MIX of PES and the relative MIX of EC in relation to the definition of EXTERNAL CONSTRAINTS. In this first assessment, we quantify the MIX of EC

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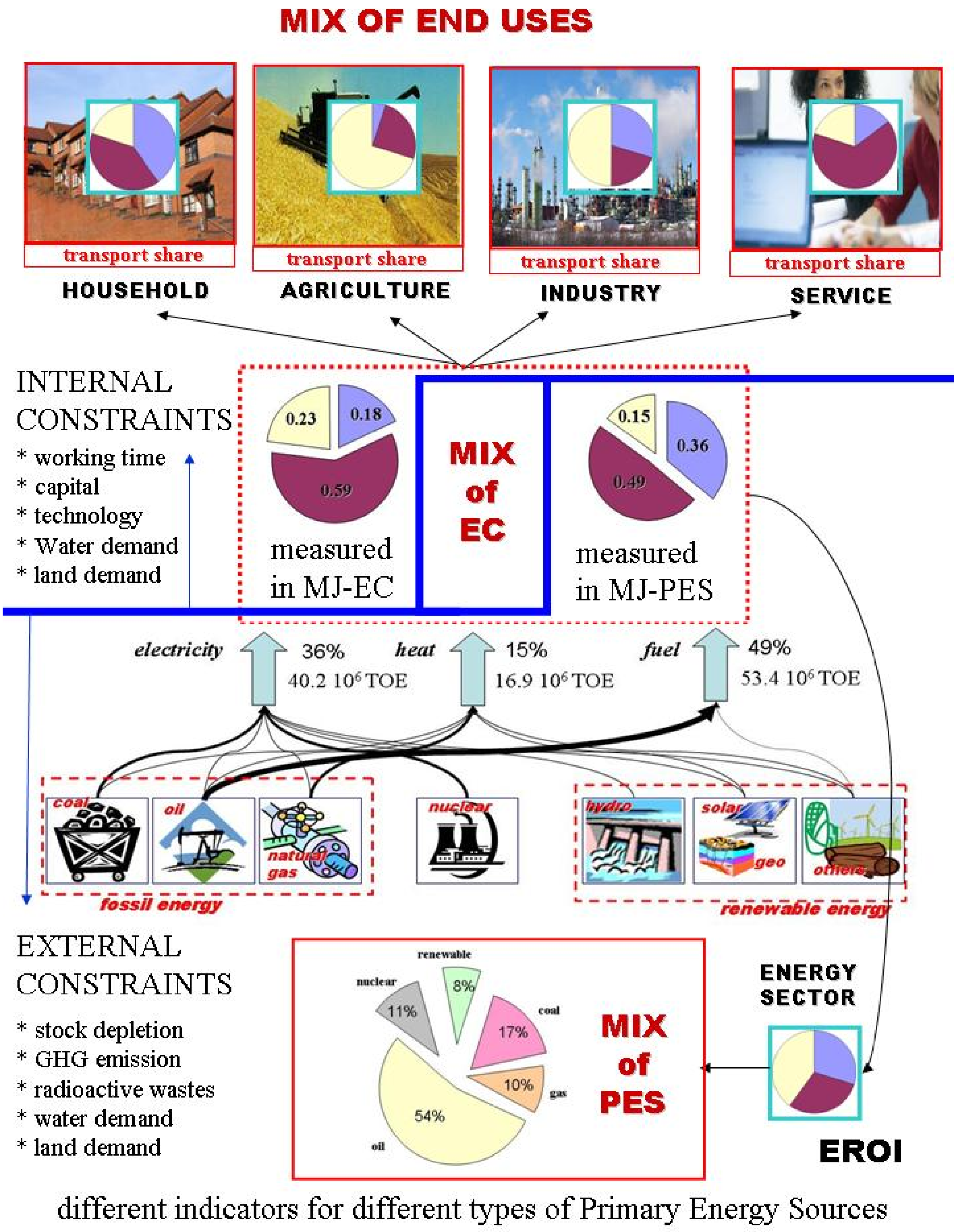
using MJ of PES equivalent. In this way, we assess the performance of the energy sector over the conversion PES → EC. This implies remaining on the bottom-right side of the blue line.

Fig. 31 The different tokens required to generate a multi-purpose grammar



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Point # 4 – establishing a relation between the MIX of EC and the MIX of EU in relation to the definition of INTERNAL CONSTRAINTS. Starting from the record of the total amount of MJ of each energy carrier and the profile over the mix one can perform an analysis of the metabolism of the various sectors of the economy based on the direct flow of energy carriers. In this way it becomes possible to establish a relation between the dataset developed in energy balances and the analysis of the pattern of metabolism of modern societies, as illustrated in Section 3 (e.g. Fig.9 used to generate Fig. 18-19-20-21-22). That is, it becomes possible to consider: (a) the implications of a given power level (the amount of energy carriers which has to be controlled per hour of human activity, a value which maps onto the level of technical capital, to be used in that compartment); (b) the economic implications (the amount of added value generated in the various compartments); (c) the competition for limiting resources (human labor, water, land, other key material flows) competing across different compartments of the society. In fact, ***it is only after having established this set of relations***, between what is needed in terms of EU by the various compartments and what is provided in terms of EC by the energy sector, which it becomes possible to fulfil the goal stated by the Eurostat Energy Statistics [to study: "*the fuel conversion efficiencies and the relative importance of the different fuel supplies in their contribution to the economy. The energy balance is also the natural starting point for the construction of various indicators of energy consumption (for example consumption per capita or per unit of GDP) and of energy efficiency*"]. However, this task requires looking for a selection of compartments of end-uses more effective of than the selection used at the moment. The existing selection includes three end-uses/compartments of the economy: (i) Other sectors; (ii) Industrial; and (iii) Transportation. As already observed, this selection is not particularly useful.

Point # 5 - calculating the profile of consumption of energy carriers (mix and amount of each of the carriers) per each one of the relevant compartment of the economy: Household, Agriculture, Productive Sector (called there Industry); Service and Government, including the energy sector (see next Point #6). This would make it possible to develop a more detailed analysis of the pattern of energy metabolism illustrated earlier in Section 3. In this way, we can assess the performance of the socio-economic system over the conversion of the input EC → EU.

Point # 6 - providing the crucial information about the consumption of energy carriers (mix and amount of each of the carriers) used in the energy sector, which is determined by the exploitation of the given mix of 7 categories of PES. This information is crucial since it makes it possible to calculate the overall EROI – the energy cost of generating the required supplied of energy carriers in the other compartments. The energy consumed by the energy sector, should not be considered as yet another loss. Rather it is a valuable input used to get access to more energy carriers (Fig. 30). But in order to study the different qualities of PES and close the loop (getting out from the linear representation of the pattern of energy metabolism in terms of input and output) it is essential to provide a clear characterization of the mix of energy carriers required by the energy sector for the operation of the 7 categories of PES considered. In this way, we can ***finally assess the performance***

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of the socio-economic system over the autocatalytic loop of conversions: PES → EC → EU → PES. Finally, we are ***no longer representing a linear set of energy transformations, but the basic autocatalytic loop of non-equivalent energy forms, needed to generate and stabilize the metabolic pattern of modern societies!*** Energy carriers are used to make themselves (taking advantage of the gradients provided by Primary Energy Sources) and in this autocatalytic loop they generate a surplus, which can be used by society to stabilize the structures/functions expressed in the various compartments of the society.

In conclusion, the point to be made using this long description of Fig. 31 is simple and at the same time pretty impacting. All the information needed to make a very useful description of the energetics of a modern society is already available - in the form of tokens - to statistical offices! But these tokens – gathered by direct measurement - are at the moment processed using dubious production rules to generate a quantitative representation which does not provide the overall view given by Fig. 31 and not even the "old fashion" view given in Fig. 26.

Why not organizing the information already available to the statistical office over a multi-purpose grammar? That is, the available pieces of the puzzle – the tokens – should be organized over semantic categories referring to a given representation of the network of energy conversions. This would make it possible to apply a flexible system of production rules, that depending on the information that one wants to obtain, can generate non-equivalent formalizations (bifurcation in the quantitative accounting), which can be used for different purposes.

As discussed earlier, the type of energy assessments useful to study the viability in relation to internal constraints (the problem perceived within specific compartments of the society – within a part operating within the black-box) are completely irrelevant to study the viability in relation to external constraints (the problem perceived when observing the interaction of the society with its context) and viceversa. We have to learn how to do generate both and simultaneously, starting from the same set of data.

In our view the discussion of this issue is important for two reasons:

#1 – in this moment the information provided by the tables of energy statistics is not particularly useful for studying the desirability and viability of the pattern of energy metabolism of modern societies, let alone for discussing of future energy scenarios based on PES alternative to fossil energy. As discussed earlier, the assessment of total consumption given in "Primary Energy Commodities" (not even in Primary Energy Commodity Equivalent as it should be) at the moment found in Eurostat statistics is not even useful to compare the total energy consumption of European countries;

#2 – there is a systemic lesson to be learned about the organization of data (tokens) using multipurpose grammars. When dealing with complex adaptive systems, it would be better to stop organizing dataset in the form of tables made by just numbers. This was a forced solution at the time

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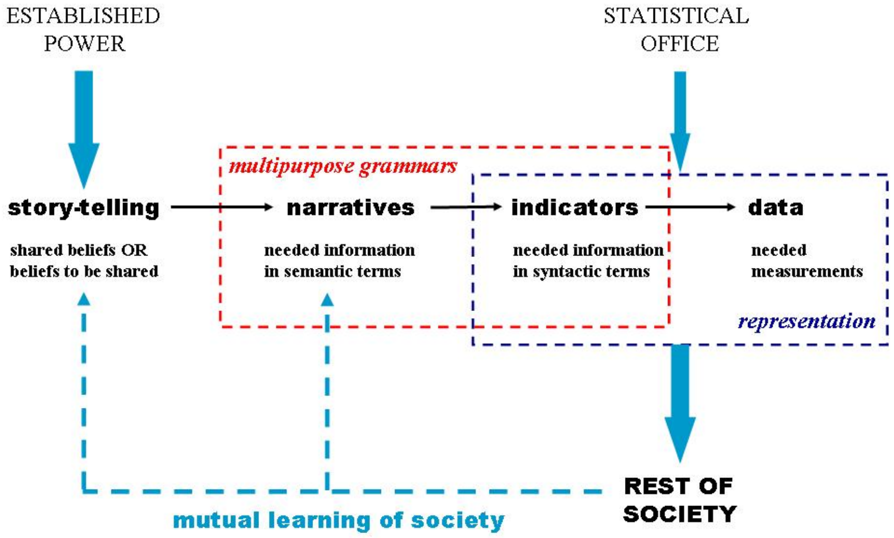
in which information was stored and transmitted using papers and microfiches. With computers it becomes possible to organize quantitative characterizations using databases associated to graphs, including networks of transformations across different levels and then adopt the concept of multi-purpose grammars. Then different indicators obtained using the applications of different production rules could be generated out of the same multipurpose grammar and the same database of tokens, according to the relevant attributes looked for by the analyst.

4.4 The future of statistics? From one-way flow of information to societal learning

We started this section by focusing on the crucial role that statistics play in affecting the direction of the semiotic process. Statistics provide an endorsed representation of the state of the state, and therefore, they do affect with their output (the representation of the social system in its interaction with the external world) the perceptions of a given socio-economic system and as a consequence its policy decisions.

By adopting the concept of grammar and multi-purpose grammar it becomes possible to visualize the process leading to the quantitative representation generated by the statistical office. An overview of the various concepts discussed in this section is given in Fig. 32.

Fig. 32 – An overview of the use of multi-purpose grammars in the generation of quantitative representation: the possibility of boosting the speed of social learning



Let’s first consider the traditional way with which statistical offices generate indicators. This traditional way entails a one way flow of information, following a predictable chain of decisions. The established power structure in the society (which can be imagined as a democratically elected government in EU) defines a given story-telling about the interaction of the socio-economic system

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with the rest of the world (= “who is us”, “what we do”, “what are our goals”, “which are our shared values”, “what are the risks and opportunities we are facing”). This story telling is then translated in relevant narratives about different tasks, functions, and societal objectives. This is where one side of the grammar – the part dealing with the semantic of the information required for the representation - is generated. Then within the given semantic associated with the grammar, a second step is performed by “experts”. The “experts” –including those working in the statistical office - translates the meaning of the semantic categories into formal categories, to which it is possible to associate proxy variable or quantifiable qualitative indices. Then the experts have to gather the required data to implement the chosen grammar. In this way a quantitative representation of the selected narratives about tasks, functions, or objectives is provided to the public.

In this traditional way of generating statistics, the rest of society, the public using this representation, can provide a feed-back to the system about their opinion about the quality of the information they receive. But they can do that only by voting (in the case the established power is a democratic government). By voting the rest of society can either confirm or change the government, that is, they can control the quality of those providing the story-telling.

This traditional way of giving a feed-back, seems to be, nowadays, challenged by the speed of becoming of modern societies. The dramatic expansion of new activities and the dramatic expansion of knowledge about new and old activities is continuously challenging and making obsolete the previous choices of story-telling, narratives, grammars and data. This growing impasse in the ability of updating the quality of our perception and representation of ourselves, is what calls for a revolution in the traditional method adopted for generating statistics.

What is illustrated on the bottom of the figure by a broken blue line that feeds-back directly from “the rest of society” to the process of choice of story telling and narratives, can be seen as a sort of institutionalized short-cut in the process of production and consumption of knowledge. In this way, the input of the society on the choice of story-telling and the set of narrative used in the official representation of the state of the state, is no longer obtained only through the political process of election of new governments, but also by a direct input to the discussion used to select the story-telling and the relative narratives. This short-cut, therefore, represents a possible way for speeding up the process of social learning. By introducing this direct feed-back the flow of information associated with the representation of the “state of the state” is no longer moving in one-way direction: (i) power → (ii) experts → (iii) rest of society, but it can finally move in a two-way direction. What the rest of society can provide is an immediate and punctual quality control on the choice of basic story-telling, the relative narratives and the grammars used for the implementation of the required quantitative representations. This feed-back can also provide a quality control on the indicators and data used for monitoring and generating future scenarios.

This revolution would require that the statistical offices organize their databases over open and transparent explanations of the multi-purpose grammars they have chosen to move from the semantic definition (the initial perception of the situation to be characterized) to the final representation based on data and numbers. In this way, the statistical offices will have finally the option to invite the rest of society to help in the building of better grammars. The new technologies available for this task (larger computers capable of handling elaborated grammars, and ICT associated with internet) can make it possible for the statistical offices to play a key role in this revolution. The secret of such a revolution is to never lose track of the meaning (the external referents) associated with the numbers generated in the final statistics. In fact, this involvement of

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the public could lead to a quicker social learning within the basic semiotic process required for continuously redefining the identity of the society.

In conclusion, the increased ability of controlling the quality of story-telling, narratives, by sharing the meaning of numbers, data and indicators with the rest of the society, and the increased ability of finding new indicators for monitoring or building scenarios should be considered as a much more valuable result, than the generation of a specified dataset, no matter how accurate it could be.

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