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The energetic metabolism of societies and the degrowth paradigm: analyzing biophysical constraints and realities

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A B S T R A C T

The belief that it is possible to have a perpetual "economic growth" based on fossil energy has been challenged since the 1970s. However, only in the last decade is this issue re-emerging once again because of the predicaments of climate change and peak oil. Many, finally start to perceive that an "economic degrowth" entailing a downscaling of the current size and pattern of socio-economic systems seem unavoidable. In this paper we analyze the implications, the feasibility and the desirability of possible trajectories of downscaling from an energetic perspective. The quantitative analysis is based on the methodological approach of societal metabolism, and it provides a dynamic accounting of the profile of energy flows required and consumed by societies in relation the expression of a given set of societal functions. This analysis makes it possible to check two types of constraints: external constraints (supply and sink side limits for the whole) and internal constraints (the feasibility of energy budget of the various parts of the society expressing the required functions). The analysis of the metabolic pattern of a sample of developed countries is used to discuss possible implications of: (i) demographic changes; (ii) the declining supply of net energy sources, and (iii) the effects of the Jevons' Paradox. Within such an analysis, a few assumptions and recipes of the degrowth movement seem problematic: (i) population is and will remain as a relevant variable to be considered; (ii) the proposed reduction in working hours seem to be impractical unless a major catastrophe will reset current civilization to pre-industrial standards; and (iii) voluntary reduction of personal energy consumption, even if a welcome adjustment, alone will not solve the existing problems. In the final part of the paper, future energetic road maps are questioned within the realm of post-normal science. Can we "plan" degrowth? If we are serious about the need of doing "something completely different", societies will have to learn how to deliberate under uncertainty within the realms of flexible management and stop planning for either growth or degrowth. Moreover, before suggesting policies, it would be wise first to try to understand the option space.

1. Introduction

In the last decades, the sustainability of current patterns of economic growth has progressively been questioned. In relation to the compatibility with ecological processes human pressure on the natural environment is already excessive and keeps growing (Millennium Ecosystem Assessment, 2005). In relation to perpetual economic growth strategy implemented by almost every government, biophysical limits are getting extremely evident both: (i) on the supply side, as seen with the shortage of arable land for food, peak oil, peak water, peak minerals (i.e. peak everything (Heinberg, 2007)); and (ii) on the sink side varying from accumulation of Green House Gasses in the atmosphere, soil loss and different types of pollution and waste in the environment (Vitousek et al., 1997).

The debate over sustainability is not at all new (Georgescu-Roegen, 1971; Boulding, 1966; Daly, 1973). In the 1970s Ehrlich and Holdren (1971) proposed the "I = PAT relation" metaphor as a conceptual tool to isolate and study the factors determining the pressure that economic activities entail on the environment. The four terms of the "I = PAT relation" stand for:

I – Impact on the environment; **P** – Population; **A** – Affluence; **T** – Technology.

This relation indicates that the stress on both environment and natural resources is due to a simultaneous increase of human population (number of people – an extensive variable) and the affluence of society (the level of consumption per capita – an intensive variable). According to these authors, the increase in the two terms – P and A cannot be compensated by increases in efficiency – T – that is, better technology.

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The analysis of Ehrlich and Holdern developed a furious debate, which, in the 1970s, divided the scientists concerned with sustainability amid the two sides:

(i) *The cornucopians* – believers in the perpetual growth. For those, regardless of whatever increase in P (population size) and A (affluence); this will always be compensated by an increase in efficiency T (better technology/silver bullets); and
(ii) *The prophets of doom* – those saying that in a finite planet perpetual growth is not possible, no matter what technology will be invented. For them, all the three terms on the right side of the equation (PAT) should be changed simultaneously, in an integrated way, to maintain the activity of humankind within the carrying capacity of our planet. We can recall here the famous quote of Kenneth E. Boulding saying that: "*Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist*".

These concepts were certainly not new for humankind. The risks associated with the overexploitation of local ecosystems have been painfully discovered, well before the 1970s, over and over by pre-industrial societies through famines, diseases and collapses of whole civilizations (Cottrell, 1955; Tainter, 1990; White, 1959). However, in the 1970s and later on in the 1980s, the situation experienced by "the most technologically advanced part of humankind" was dramatically different from the past. The feast of fossil energy civilizations giving way to new patterns of production and consumption of resources was expanding very fast into an "empty world" (Daly, 1992; Goodland et al. 1992). Because of this peculiar situation, the war between cornucopians and prophets of doom, ended with a clear victory of the cornucopians with the "perpetual growth paradigm" becoming the standard narrative in political, ideological and scientific terms behind policies for economic development adopted all over the world in the last three decades.

Finally, after a long period of oblivion, in the third millennium, the issue of sustainability and carrying capacity is getting back into the public discourse. New sustainability narratives, such as that of degrowth, have emerged in search for an alternative to the pattern of perpetual economic growth fully endorsed by fossil energy civilization. The degrowth paradigm, targeting the Affluence (A) and Technology (T) components of the "I = PAT relation", aims at powering down levels of consumption of energy and materials whilst also bringing in strong interest for equity, freedom and quality of life (characteristics invisible when using the I = PAT relation) (Schneider et al., 2010).

However, before suggesting any specific policy for downscaling the production and consumption patterns within the economy, it is utmost imperative to primarily understand how societies are currently self-organizing and functioning. Thus, this paper proposes the analysis of sustainability of socio-economic systems from an energetic perspective using an approach called Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) – (Giampietro et al., 2011). In fact, without a good understanding how the society uses energy for reproducing itself and expressing its typical functions, propositions for downscaling may become futile and even dangerous. Many experts of energetics warn that a significant reduction of the energy consumed by a society can result painful and catastrophic (Smil, 2010; Tainter, 2010). For an online debate on this topic see (http://www.ourenergyfutures.org).

For example, would someone believe that it would be possible to permanently cut 75% of the food energy consumption of a group of human beings without harming them? For this reason, those prescribing diets must have a very good understanding of the metabolism of the human body, before suggesting any prototypical argument on how to reduce energy consumption. Moreover: (i) the diets to be implemented should be different for different persons, depending on the gender, age, level of physical activity; and (ii) the range of reduction of food intake will have to be limited, in any case, by the physiology of the human body. If someone decides to follow an aggressive diet without having the required expertise is at risk of generating serious damage to her/his health.

Therefore, proposing a similar analogy for societal metabolisms, this paper starts with an analysis of energetic trends and profiles of developed countries: how different economies are powered through different metabolic patterns (similar to the example of food intake by humans). In particular, this analysis makes it possible to focus on two types of constraint:

(1) *External constraints* – those addressed by the I = PAT relation. In the analogy with the metabolism of human beings, this would represent a constraint referring to boundary conditions – e.g. having enough food, being able to get rid of wastes.
(2) *Internal constraints* – those referring to the internal characteristics of the metabolic process. In the analogy with the metabolism of human beings, this would represent a constraint referring to the internal physiology of the body – e.g. failure of some organs to carry out their expected functions, such as "heart failure" or "kidney failure".

2. The metabolic pattern of societies

2.1. The concept of societal metabolism

The idea that the pattern of activities carried out by human societies should be studied by looking at the resulting pattern of energy transformations has been proposed in the last century by several authors – Podolinsky (quoted in Martinez-Alier, 1987; Ostwald, 1907, 1911; Vernadskiĭ, 1926; Zipf, 1941; White, 1949; Cottrell, 1955) and then implemented recently by many other authors (Fischer-Kowalski and Haberl, 2007; Giampietro and Mayumi, 2000a,b; Giampietro et al., 2011; Ramos-Martin and Giampietro, 2005; Ramos-Martin et al., 2007; Sorman and Giampietro, 2011).

The notion of "societal metabolism" taking on from (Lotka, 1922, 1956) and (Georgescu-Roegen, 1971) has been proposed to frame such a study within a biophysical narrative rather than within the predominant economic narratives. Using the jargon proposed by Lotka and then adopted by Georgescu-Roegen, it can be said that the metabolism of human societies is based on exosomatic energy use (=energy metabolized under human control, but outside the human body), which can be seen as an extended form of the physiological metabolism of humans – based on endosomatic energy (=energy metabolized inside the human body). The metabolic pattern of human societies can be associated to both:

(i) The overall size of a society – determined by the number of people and their aggregate activity – a characteristics defined at the level of the whole society: the black-box; and
(ii) The diversity of its structural and functional organization – associated with the operation of exosomatic devices (technical capital) – a set of characteristics defined at the hierarchical level of economic sectors: the parts operating inside the black-box.

The link between energy dissipation on one side and the expression of structures and functions, on the other side, has been clearly established first in the field of non-equilibrium thermodynamics (the self-organizing nature of dissipative systems – Prigogine and Stengers, 1981) as well as in theoretical ecology (the multi-scale organization of dissipative networks – Odum, 1971, 1983; Ulanowicz, 1997). The same link has been illustrated in relation to the energetics of human societies by many authors already quoted above (for a historic overview see chapter 6 in Giampietro and Mayumi, 2009).

The analysis of the energetic metabolism of societies presented here is based on a methodology called Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) – (Giampietro et al., 2011). This approach makes it possible to:

(i) Investigate the feasibility of the dynamic energy budget of societies, by checking the possibility of matching the *requirement* and *supply of energy flows*. This check can be carried out across hierarchical levels. The overall requirement of the whole society must result compatible with the internal structure and the characteristics of different compartments and functions (Giampietro and Mayumi, 2000a,b; Giampietro et al., 2011).

(ii) Study the effect that changes taking place in the characteristics of such a dynamic energy budget will have on the structure and functions of the society. The MuSIASEM analysis is based on a systemic comparison, carried out sector by sector (and function by function) of the profile of: (a) *energy consumption* (using two variables: pace per hour of human activity and the total amount of energy consumed); (b) *hours of human activity* (amount of hours in the different compartments); and (c) *added value generation/consumption* (using two variables: rate per hour and total GDP generated).

Therefore, the MuSIASEM approach can be used to generate biophysical indicators and benchmark values providing the basis for a bio-economic analysis able to complement the information coming from mainstream economic analysis.

2.2. Key concepts for the analysis of metabolic patterns of societies

2.2.1. Making a distinction between external and internal constraints

According to basic principles of energetics, an effective analysis of energy flows should first of all make a distinction between two different categories of energy assessments: *Primary Energy Sources (PES)* and *Energy Carriers (EC)*. Currently, both sources are aggregated and both measured in tonnes of oil equivalent (or J) which creates the main source of confusion! This preliminary distinction is required in order to be able to study:

(1) *The consumption of PES*. Primary Energy Sources are needed to generate the supply of Energy Carriers used by the various compartments of society – this information is relevant in relation to an analysis of external constraints;

(2) The pattern of use of EC-Joules (electricity, fuel or heat) which are used to guarantee the reproduction of structures and the expression of functions carried out by the various compartments (e.g. *End Uses (EU)* of the socio-economic system – this information is relevant in relation to an analysis of internal constraints.

After having done this distinction we can see that modern societies are utilizing a much higher throughput of energy per capita than the societies of a century ago. This is possible because of two reasons: (i) they can access a much higher amount of PES (by depleting fossil energy stocks) – the *Total Energy Throughput* (measured in TeraJoules/year) an extensive variable – is already very high and thanks to the plundering of fossil energy stocks is still growing; (ii) they are capable of controlling huge flows of EC per hour of activity (because of a large stock of technical capital) in the various compartments of the society – the value of *Exosomatic Metabolic Rates (EMR)* (measured in MJ of Energy Carriers/h of human activity) an intensive variable – is, in all the compartments of the economy, is orders of magnitude higher than used to be in pre-industrial times.

The *external constraints* are determined by the availability of favorable boundary conditions – these constraints are related to the overall size of the flow of energy metabolized by a society. In terms of quantitative assessment this is the overall size of the *Total Energy Throughput (TET)* (J per year). The assessment of the Total Energy Throughput of a society can be "translated" into several indicators of "required boundary conditions". In practical terms, this check can refer to the two ends of the metabolic process: (1) on the supply side – e.g. requirement of material flows divided by typologies of fossil energy PES (tons of coal, tons of oil, cubic meter of natural gas) OR by typologies of alternative PES (tons of uranium, cubic meter of falling water, solar radiation, arable land); (2) on the sink side – e.g. material emissions such as GHG, radioactive wastes, pesticides residues, pollutants. When discussing of external constraints in relation to energy, on the supply side, we have to use biophysical quantitative assessments referring to PES (Giampietro et al., 2010).

The *internal biophysical constraints* are related to the capability of the various compartments of a society to express the required functions – this compatibility can be checked by studying the profile of Exosomatic Metabolic Rates (MJ of energy throughput (expressed in carriers) per hour of activity) – the profile of power levels in the different sectors – i.e. the capability of controlling an intense flow of energy carriers per hour of human activity to carry out the necessary tasks. The profile of EMR_i (the Energetic Metabolic Rate for sector i of analysis) is determined by the profile of allocation of hours of human activity (e.g. paid and unpaid work) and technical capital over the different compartments making up a socio-economic system. When studying the feasibility of a given metabolic pattern from the inside, we have to consider: (i) the characteristics of each compartment; and (ii) the relations among the parts – e.g. their interaction and their relative size – in relation to the characteristics of the whole.

As noticed earlier, it is important to be aware of the existence of these internal constraints. In fact, if it is true that nobody would believe the possibility of implementing a policy aimed at reducing human food consumption of 75% while expecting that they will maintain their original pattern of activity; it should also hold true that many seem to believe that it will be possible to reduce of 75% the emissions of modern societies while keeping the same set of structures and functions – see the discussions of governments at the last Copenhagen summit!.

Five key concepts are needed to analyze the *feasibility and desirability* of changes in the metabolic pattern of society.

2.2.2. When opening the black-box we find that the metabolic pattern is based on the ability to stabilize a dynamic energy budget

The energy security of a society depends on its ability to match two relevant flows of energy (Giampietro and Mayumi, 2009):

1. The flow of energy *required and consumed by the whole society*, which is determined by its socio-economic identity, i.e. population structure and dynamics, the material standard of living, and the diversity of activities performed inside the various compartments of the society;
2. The flow of energy *supplied by the energy sector* of that society, which is determined by its biophysical-technological identity,

i.e. the mix of accessible primary energy sources, available technology and know-how and the mix of specific energy carriers required by society for its various end uses.

The matching of these two flows can be done using two different solutions:

Solution 1 – the material standard of living of the whole society may have to be adjusted because of biophysical constraints; in this case, the identity and productivity of the energy sector affects that of the entire society: society has to adapt to external constraint (e.g. pre-industrial societies); or

Solution 2 – technical innovations (human ingenuity in using available natural resources) lift the existing restrictions that the energy sector would impose because of existing biophysical constraints: in this case, it is the identity of the society, which affects that of the energy sector. Note that the second solution requires the availability of an adequate energy source supporting the change (e.g. industrial societies based on fossil energy).

Referring to the discussion made earlier, we can recognize that Solution 2 is the solution suggested as always possible by cornucopians, whereas Solution 1 is the solution suggested by the narrative of degrowth.

In order to study the feasibility and consequences of adopting Solution 1 it is important to study the internal relation of structures and functions associated with the metabolic pattern of society. For this purpose, following the work of Ulanowicz (1986, 1997), on the energetics of ecosystems, we can divide the different metabolic structures expressing societal functions in two parts:

(i) *A hypercyclic part* – the part generating a net surplus of energy for the rest of the society; and
(ii) *A purely dissipative part* – the part providing control, which is dissipating the energy surplus (Giampietro, 1997; Giampietro et al., 1997; Giampietro and Mayumi, 2000a, 2009). A general scheme of this rationale and classification of structures and functions of the components of a society within the metabolic pattern is illustrated in Fig. 1.

The *hypercyclic part* includes the Energy and Mining Sector (ES), the Building and Manufacturing (BM) sector and the Agricultural Sector (AG). These sectors (although also consuming energy and materials for their own operation) are considered to be *net* producers of the material flows (products) consumed by the societal system. The primary sectors produce the required metabolized flow (energy, food and material inputs), the secondary sectors bearing the role of producing manufactured products and infrastructure for the rest of the society to utilize. The Building and Manufacturing Sector beholds the role of producing the basic infrastructure and machinery manufacturing for the societal system (it is essential to the establishment of the hypercycle itself). In conclusion the PS sector (Primary and Secondary Sectors) can be seen as the sectors guaranteeing the TRANSFORMATION activities – referring to the conceptual categories of human activities proposed by North (1990) – associated with the production of the goods consumed by a society.

The strength of the hypercycle defines the surplus that the rest of the society can use for: *(i) Services and Government sector* – TRANSACTION activities in the conceptual category proposed once again by North (1990); and *(ii) Household sector* – FINAL CONSUMPTION activities.

Therefore, the Service and Government (SG) sector and the Household Sector (HH) represent the purely dissipative components within the metabolic pattern. These sectors, in modern societies fully depend on the amount of energy, food and products generated by the Productive Sectors. Clearly, the label of "purely dissipative activities" does not imply that these sectors do not carry out key functional activities. These two sectors are crucial in bearing the role of TRANSACTION activities and FINAL CONSUMPTION activities. Without these activities a society could not operate. In particular, these activities include the reproduction and

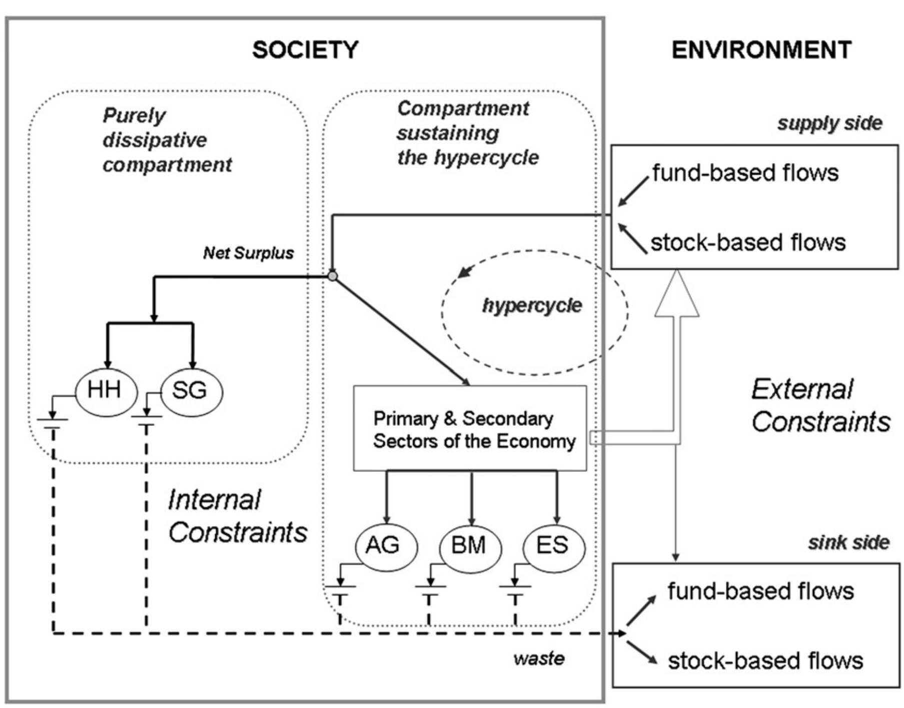

Fig. 1. The dynamic energy budget associated with the metabolic pattern.

operation of institutions. Institutions are reproduced by: (i) individual human beings, reproduced at the level of households; and (ii) social organizations, required to guarantee the proper functioning of social institutions.

In developed societies, TRANSACTION activities are essential in guaranteeing the proper functioning of socio-economic institutions, which in turn are essential for an efficient functioning of TRANSFORMATION activities (North, 1990). The advancement in the diversity of organizations and functions, complexity of the system of control, expansion and improvement in the material standards of living pass through an expansion of TRANSACTION activities. Such an expansion is associated with the accumulation within the economic institutions of knowledge, experience and human capabilities. It is crucial to note that not even the most subsistence forms of societal organizations express a metabolic pattern aimed at producing only food.

2.2.3. Demographic variables affect both: (i) the supply of working hours; and (ii) the requirement of working hours; within the metabolic pattern

Quantitative analysis of the performance of socio-economic systems is based on a "per capita" system of accounting – GDP per capita, energy consumption per capita, tons of CO_2 emissions per capita. However, such a system of accounting is incompatible with a multilevel analysis of economic dynamic budget of a country according to the general scheme shown in Fig. 1. Indeed, the per capita accounting tends to miss internal constructs and important differences among countries. For example, the very same assessment of 'per 1000 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 and Table 1 for a comparison among Italy and China.

In 1999, the Italian population supplied 680,000 h of paid work to the economy per 1000 people, while Chinese population supplied more than double of that, of approximately 1,650,000 h of work per 1000 people. In China, 1 out of every 5 h of human activity was allocated to paid work, while in Italy this was only 1 out of every 13 h (Table 1).

Indeed, in 1999 more than 60% of the Italian population was not economically active, including children, students and elderly (retired). The human activity associated with this part of the population is therefore neither used in the TRANSFORMATION activities carried out in the productive sectors (production of energy, material and goods) nor in TRANSACTION activities in the service sector, but allocated to final consumption (the reproduction of humans). Furthermore the active population included in the work force – only the 40% of the total population – works less than 20% of its available time (assuming a yearly work load per person of 1700 h).

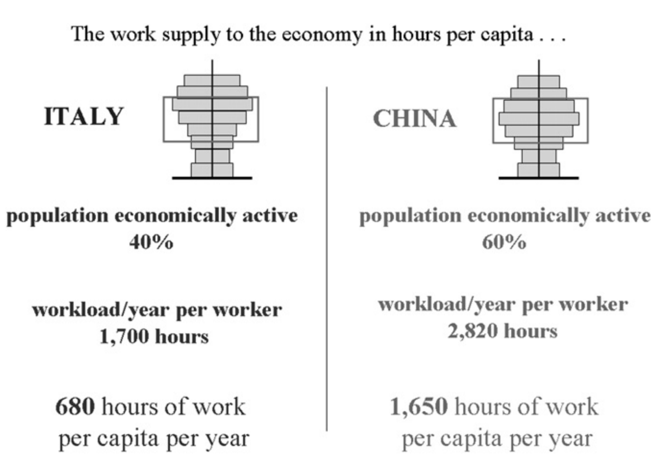

Fig. 2. Relation between demographic structure and supply of work hours at the level of society (adapted from Giampietro and Mayumi 2009).

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 × 8760 h/year, and THA = $HA_{PW} + HA_{HH}$.

	Italy	China
Total Human Activity (THA) in h/year	8,760,000	8,760,000
Paid Work sector (HA_{PW}) in h/year	680,000	1,650,000
Household sector (HA_{HH}) in h/year	8,080,000	7,110,000
Ratio Paid Work/Total Human Activity (HA_{PW}/THA)	1/13	1/5

The bottom line here is that a developed country:

(i) Has a very low fraction of population in the work force because of the high dependency ratio;
(ii) Has a very low work load per worker per year (1700–2000 h/year) compared with developing countries (e.g. such as that of China). This implies that in these societies we have 1 h of human activity allocated to paid work for 12 h allocated to other activities; and
(iii) Needs a large fraction of the hours in Paid Work to be allocated in the Services and Government (large TRANSACTION activities and assistance to the dependent population). This implies that assuming that between 60% and 75% of the Paid Work hours are allocated to the service sector.

When combining these characteristics we can notice that modern societies have an incredibly low value of the ratio $HA_{PS}/(HA_{SG} + HA_{HH})$ – hours in the Primary and Secondary sectors (the hypercyclic part) over the hours in Service and Government and Household sector (the purely dissipative part). The value of this ratio is in the range of 1/30–1/50. That is, for each hour allocated in the production of energy, food, and products (in PS), there are between 30 and 50 h allocated to activities consuming energy, food and products (in SG and HH).

2.2.4. The need of reproducing structures and expressing functions entails the existence of a forced set of relations between extensive and intensive variables

The metabolic pattern for a typical developed country can be analyzed by looking at the two profiles of allocation of: (i) hours of human activity; and (ii) energy consumptions; over the various compartments, across different hierarchical levels. A practical example is illustrated in Fig. 3.

After having defined the dendrogram of the profile of hours of human activity invested across levels into the various compartments and the dendrogram of the profile of the amount of energy throughput consumed across levels in the various compartments, it becomes possible to study the profile of power levels – Exosomatic Metabolic Rate (EMR_i) – for each compartment.

In Fig. 3 the EMR_i are measured in MJ/h (in MJ of EC). This value is calculated by the consumption of energy carriers within the sector *i* divided by the specific hours allocated to that sector.

As illustrated below, these values of EMR_i can be used as benchmarks:

* *At the level n (the whole society)* – an $EMR_{SA\ level\ n}$ (=22 MJ/h) is a typical value expected for a very rich developed society. This average power level (pace of energy consumption Average

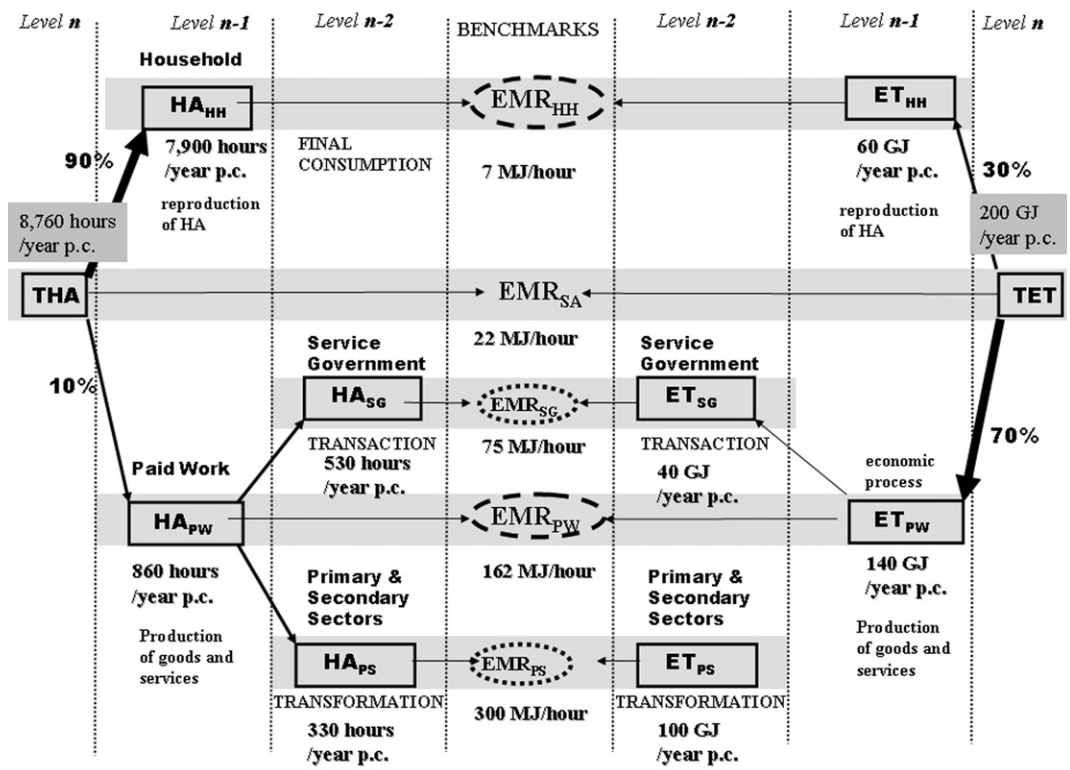

Fig. 3. The metabolic pattern of society and the resulting profile of power levels.

Society) can be used to compare different societies (at the level of the whole).

Then, we can open the black-box and move down across levels to different compartments defined inside the society. If we do so, we find that the expected values of EMR_i are very different, when considering different typologies of compartments.

* *At the level n − 1 (distinction between Household and Paid Work)* – the HH compartment ($EMR_{HH \text{ level } n-1} = 7$ MJ/h) has a value much lower than the societal average, whereas the PW ($EMR_{PW \text{ level } n-1} = 162$ MJ/h) has a higher value.
* *At the level n − 2 (individual economic sectors operating within PW)* – The productive sectors bear the highest energetic metabolic rate due to the heavy industry and manufacturing activities ($EMR_{PS \text{ level } n-2} = 300$ MJ/h) followed by the Services and Government Sector ($EMR_{SG \text{ level } n-2} = 75$ MJ/h).

2.2.5. The relative importance of the various "societal organs" within the economy and their changes in time

In terms of an economic narrative, the relative contribution of the various sectors to the generation of GDP has significantly been changing over time. A view of this fact, is illustrated in Fig. 4 for the years 1980–2007.

These changes depend on the progressive shift in the priorities given by society to the different functions carried out by the economy. It is well known that with economic development the following changes have to be expected: (i) a dramatic reduction of the weight of the Primary Sector in the economy (agriculture, fishery, forestry and mining become less and less relevant in the total GDP); (ii) a continuous increase in the weight of the Service sector, well above 60% of the GDP in all developed countries, with peaks well above 70% in the most developed countries. The trajectories indicated in Fig. 4 show the difference between the relative contribution of sectors to GDP across China and the other developed countries.

2.2.6. The amount of energy that can be spent in reproducing structures and expressing functions depends on the Net Energy supply

The energy sector can be defined as the sector of the society expressing the function of exploitation of a mix of Primary Energy Sources with the goal of generating a net supply of a mix of Energy Carriers to society (Giampietro and Mayumi, 2009; Giampietro et al., 2011).

The performance of this function has to be evaluated in relation to *the net supply of energy carriers delivered to society* (Giampietro et al., 2009; Hall et al., 1986, 2009). That is, we may have a very large PES to be exploited – e.g. huge amount of solar energy reaching our planet – but this assessment may result irrelevant for society. Using an economic analogy, the pearls dispersed in the sea can represent a valuable treasure when considered as an aggregate set, but if the cost of their finding and gathering them is higher than the net return, they do not represent an effective economic resource (Georgescu-Roegen, 1975a). That is, we can generate a large supply of energy carriers from a given PES, but if 99% of this flow has to be re-invested in the production process, the net supply for society can result totally negligible.

The wisdom proposed by Net Energy Analysis is essential if we want to generate a useful analysis of the quality of alternative energy sources. In fact, the exploitation of a PES for the generation of a net supply of EC has to be studied as a chicken-egg process. This is illustrated in the lower part of Fig. 5.

When exploiting a Primary Energy Source (PES), we must invest an energy carrier (EC) – which we must already have – to get an

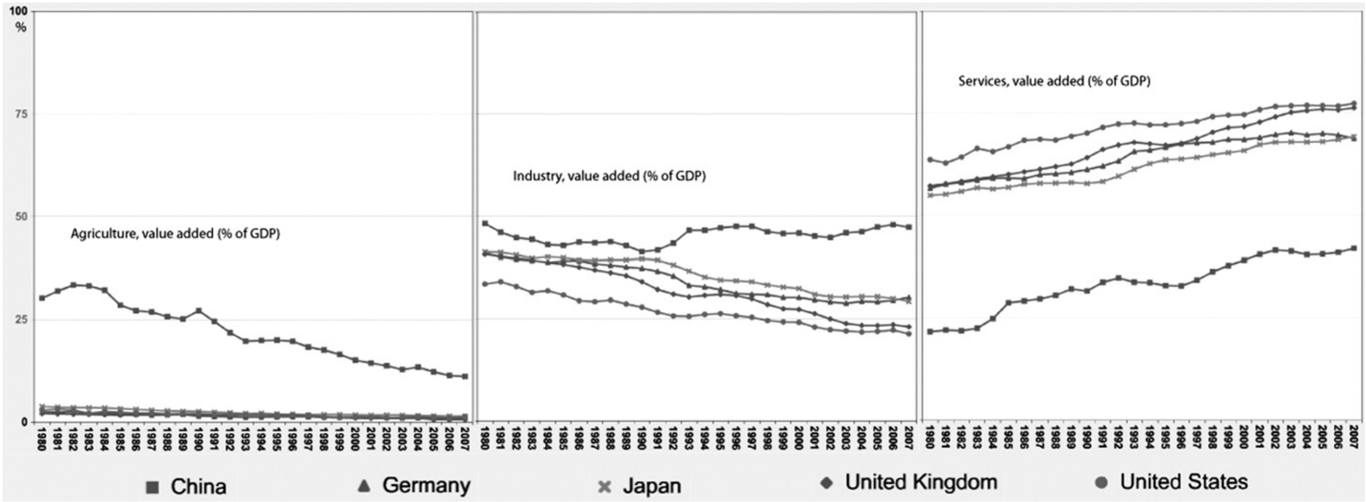

Fig. 4. The relative change in the share of GDP of different economic sectors.

output of energy carrier out of this exploitation. Then a part of this output of energy carrier has to be used as an input for maintaining the process of exploitation. This internal loop of energy for energy makes it more complicated the analysis of such a process of exploitation. In fact, in order to be able to study such a process, we must consider three key attributes:

(1) The Output/Input of energy carriers – reflecting the performance of the exploitation of the process. This is the ratio between the two flows measured in Joules of EC: "GROSS EC Output" and "EC Input";
(2) The "EC input" – this is the information required to check the existence of *Internal Biophysical Constraints* of the exploitation, the larger is the "EC input" to be invested in the exploitation of the given PES, the larger the requirement of work, capital, land and infrastructure to be invested in the energy sector. These resources have to be taken away from the rest of society and used in the hypercyclic part, reducing the possibility of carrying out TRANSACTION activities and FINAL CONSUMPTION activities;
(3) The ratio "consumed PES" into "NET supply" – this is the information required to check the existence of *External Biophysical Constraints* of the exploitation. That is, the higher the ratio, the larger will be the demand on boundary conditions on both the supply and the sink side.

In the upper part of Fig. 5 we illustrate the metabolic pattern of a modern society, which is based on the exploitation of fossil energy as principal PES. Fossil energy is a very high quality PES – with an output/input of energy carriers 15/1, providing a very high net energy supply. For this reason, in modern societies the amount of energy and labor and technical capital going into the energy sector is a negligible fraction of the total used by society.

Lets now imagine as seen in Fig. 6, that we would use an alternative energy source, with a much lower output/input of energy carriers – e.g. 1.3/1 (e.g. biofuels from corn). A low quality PES would imply a dramatic increase in the amount of energy and labor and technical capital which will have to be invested into the energy sector. In fact, as illustrated in the lower part of Fig. 6 when the output/input is 1.33/1, supply of 1 MJ of Net supply of EC to society requires generation of 4 MJ of Gross Output EC by the energy sector. Thus, the energy sector would consume for its own operation 3 MJ of energy carrier per each MJ of energy carrier delivered to society as Net Supply EC. Thus, performing a naïve analysis based on the alternative energy sources based on this hypothesis (for a more detailed discussion see Giampietro and Mayumi, 2009, pp. 129–131); if want to keep the original pattern of energy consumption in the remaining sectors of the society, the energy sector of the "alternative system" would have to consume 840 GJ/year per capita, only for its own operations. This would raise total energy consumption of society (TET) to 1120 GJ/year per capita: an increase of 4 times the original level of energy consumption per capita!

2.2.7. The non-linear relation between mix of PES, mix of EC and mix of end uses in the metabolic pattern

If we look at the big picture of the whole process of autopoiesis of society (see Fig. 7) we can finally conclude that energy is used in the various compartments of a society to carry out specific tasks referred to as *end uses*. End uses – the effective delivery of energy services – are the functions required to stabilize a given social identity. By closing the loop (Energy Carriers → End Uses → Primary Energy Sources → Energy Carriers) they provide meaning for the set of energy conversions taking place, moving from PES → EC and thereafter the second set of conversions from EC → EU (Giampietro et al., 2010).

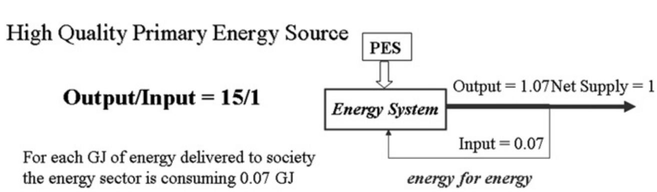

Fig. 5. Metabolic pattern for a high quality (fossil energy) PES.

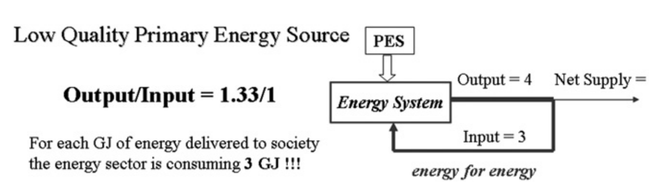

Fig. 6. Metabolic pattern for a low quality (alternative) PES.

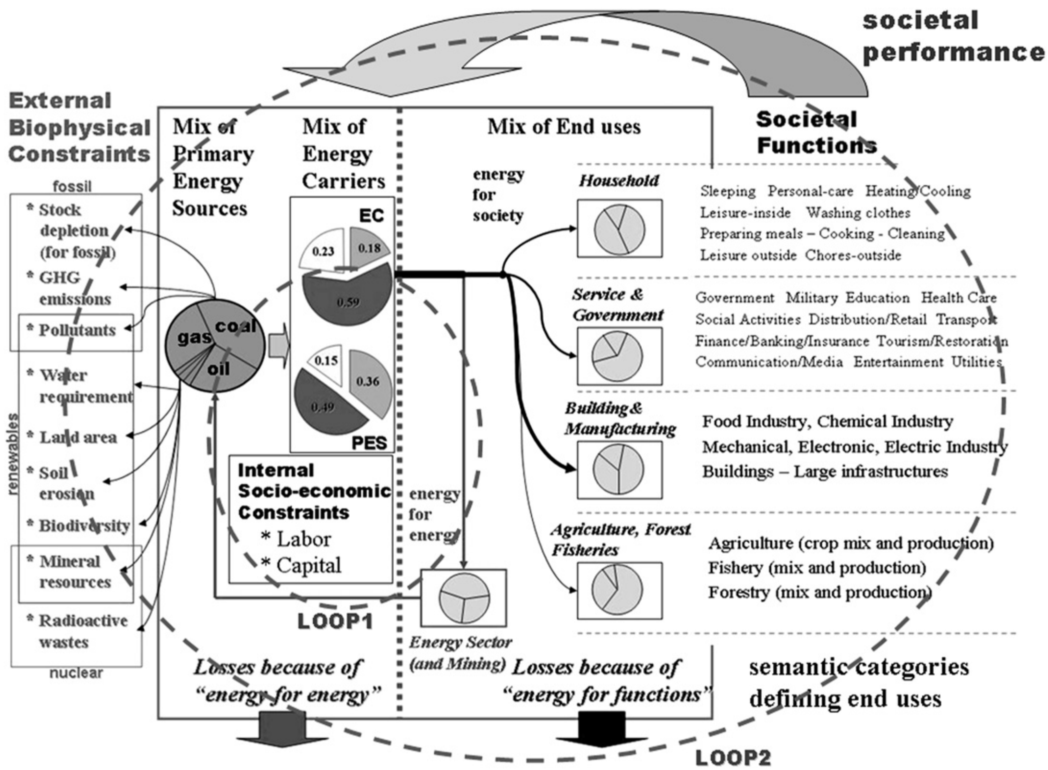

Fig. 7. The process of autopoiesis of a society in relation to the functions to be expressed and the required energy conversions.

As illustrated in Fig. 7 we can describe the process of autopoiesis of a society as based on a double chicken-egg process taking place simultaneously at two different scales.

* *At the level n – 2 – the energy sector* (the interior LOOP 1) – at a small scale a specific part within the black-box – there is an autocatalytic loop within the set of energy transformations taking place in the energy sector (the internal loop of energy for providing energy illustrated as loop 1 in the lower parts of Figs. 5 and 6). In this autocatalytic loop, energy carriers are used to generate more energy carriers. However, in order to have this internal loop it is necessary to have an adequate amount of PES available (external constraints) and the capability to express the exploitation at a given power level (internal constraints). The net supply of energy carriers generated by the energy sector is then used by the other compartments of the society to guarantee the other functions required for the reproduction and maintenance of social systems.
* *At the level n – 1 – the hypercyclic compartment versus the purely dissipative part* – Referring to the distinction indicated in Fig. 1. The availability of labor for the Paid Work sector is determined by the demographic structure and socio-economic characteristics (Fig. 2 and Table 1). Moreover, within the amount of work hours available for the PW sector we must make a distinction between the hours of paid work to be invested in the hypercyclic part (Primary and Secondary sectors) and the purely dissipative part (Services and Government).
* *At the level n – the whole society* – at the large scale, the functioning of the whole society. At this level we can observe a resonance between the two chains of transformation: "$PES_{exploitation} \rightarrow EC \rightarrow EU$" and "$EU \rightarrow EC \rightarrow PES_{exploitation}$" which is affecting/affected by the quality of PES. In this autocatalytic loop, "*end uses*" (energy services) are essential for the reproduction and expansion of the ability of a given society to define and express its own identity as socio-economic system. In practical terms this means the ability to preserve and adapt the given set of expected structures and functions.

This complex view of the metabolic process entails the existence of tension across the need of expressing functions at different levels:

* *At the level n – 2* – the function is to generate a net supply of energy carriers;
* *At the level n – 1* – the function is to generate the required net supply of material inputs (products and infrastructures); and
* *At the level n* – the function is to maintain the existing social identity.

These three functions compete with each other for the use of energy, products, capital, human activity, land, and other resources flowing into the metabolic pattern. This is what generates the existence of internal constraints. The internal loop of energy for energy (loop 1 in Fig. 7) in the energy sector has a clear priority on the others. In fact, without the possibility of having energy carriers (including food for endosomatic conversions!) it would not be possible to have any structures in a society. So ultimately, the reproduction of existing structure requires a hypercyclic compartment capable of providing an adequate supply of products and infrastructures (TRANSFORMATION activities). However, it is also true that without the final consumption sector (HH) and the service and government sector (SG) it would be impossible to reproduce humans and the institutions, required to guarantee an effective operation of the PS sector. Put in another way, it would be impossible to carry out those TRANSACTION activities, which are essential to the operation of any society.

Going back to the importance of the quality of Primary Energy Sources, we can notice that the second loop indicated in Fig. 7 – the larger arrow indicating the usefulness of the integrated set of ends uses – competes in terms of the required amount of hours of labor, Joules of energy carriers and investments of technical capital with the energy sector. This internal competition is related with the characteristics of the dynamic energy budget. An expected metabolic pattern must be able to achieve a balanced profile of relative size and power levels across functional compartments.

3. Societal dependence on energy and degrowth

3.1. *What should we expect in the future?*

3.1.1. *An overview of historic changes in the metabolic patterns of European Countries*

To introduce our analysis of trend we provide an overview – Fig. 8 – of the changes in the metabolic patterns of the different sectors for Germany (as an initial example of one of the European countries) over the period 1992–2005. (For more information and further applications see Giampietro et al., 2009, 2011).

We use here are representation based on a graph having:

* On the vertical axis the value of EMR_i (MJ of exosomatic energy per hour of human activity in the compartment *i*);
* On the horizontal axis we the value of ELP_i (Economic labor Productivity, measured in € of added value per hours of human activity in the compartment *i*).

Variable	Definition
Exosomatic Metabolic Rate (MJ/h) – EMR_{EC} measured in EC-Joules	MJ of *energy carriers* per hour of human activity
Economic Labor Productivity (€/h) – ELP measured in € (base year 2000)	Added value generated (in €) per hour of human activity

The points given on this plane refer to characteristics of the metabolic pattern defined at three different hierarchical levels:

* *Level n* – average for the whole society;
* *Level n – 1* – within the society using the distinction [PW *versus* HH];
* *Level n – 2* – within the PW sector using the distinction [AG, PS and SG].

When this characterization is applied to a set of several countries, we then achieve the trends as seen in Fig. 9 – which fundamentally illustrate the basic pattern across several of the metabolic patterns of societies.

From this comparative analysis we can see that:

i) The average values for a society depends on the relative size and the relative characteristics of the Paid Work (PW) sector and the Household (HH) sector. In turn, the characteristics of the PW sector depend on the difference in the characteristics and the relative size of the Productive Sectors and Service and Government Sectors;
ii) The value of the EMR (Exosomatic Metabolic Rate – energetic throughput per hour of human work) in the Productive Sectors of European Countries is *on average* five times larger the value of the EMR service sectors.
iii) On the contrary, the added value generated by the various sectors with PW is similar, with values between 10 and 35 €/h.
iv) It is possible to define typical values of EMR_i to be expected for the expression of a given function in specific compartments. They can be used as benchmark values to guesstimate expected values for energy consumption per hour of work, in the Productive Sectors in different categories of countries – e.g. Nordic Countries, Mediterranean countries.
v) For all the countries considered, in spite of a reduction of energy intensity (due to the continuous reduction of activities in PS based on an increasing dependence on imports from China!) the pace of energy consumption per hour of activity in the PS sectors has been increasing. In modern countries, technological progress is increasing labor productivity but is not reducing the energy consumption per hour of work (see Fig. 10)!

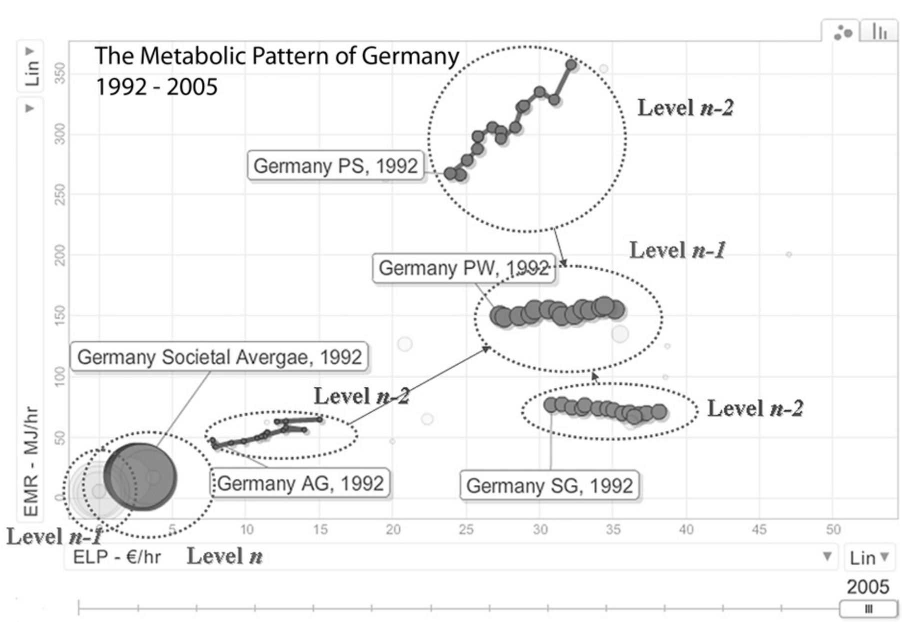

Fig. 8. Illustration of the metabolic patters of societies across sectors.

3.1.2. Peak oil and the energy crunch – the effect of a dramatic decrease of net energy supply

Historical analyses indicate that the output/input of energy carriers in the exploitation of oil revealed for domestic oil in the US has dropped from a value of 30:1 in the 1970s to a value of 10:1 in the first decade of 2000 (Hall, 2009). The net energy return of the exploitation of fossil energy has been decreasing rapidly (Campbell and Laherrère, 1998; Heinberg, 2007; Heinberg and Fridley, 2010) – since the best reserves have been depleted first – and it is now clear that the era of cheap and abundant supply of oil is over.

The implications of this fact are numerous. As observed earlier, any attempt to switch to renewable energy sources, based on an integrated mix of alternative PES, would entail a major reduction in the net energy supply for society. More capital, more energy and more labor will have to be invested in generating energy carriers. Alternative energy sources have a much lower output/input, and therefore they require huge investments in infrastructures. The literature assessing the net energy return of alternative energy sources is still controversial; however, there is a consensus (Hall et al., 2009) that within the limits of current technological advancements, it will not be possible to return to the "high surplus energy" lifestyles regardless of whatever combination of alternatives will be adopted. The most probable outcome is that we will remain hooked up with fossil energy still for decades.

In an "alternative" energy mix scenario, societies will be obliged to divert a very large share of hours of paid work, energy, technological capital, from the various sectors of the economy to be invested in the operation of the energy sector itself. This means that the internal organization of the society and its structural and functional characteristics will be severely affected by this *forced withdrawal* of resources away from the original pattern. In fact, this internal loop of "*energy for energy*" is not negotiable: a low quality energy sources entails a reduction in the ability of a society of expressing the various functions illustrated on the right side of Fig. 7.

3.1.3. The global crisis implication for the metabolic pattern of developed countries

The global crisis we are living in this decade has been generated by the clash of the ideology of perpetual growth against the biophysical constraints determined by a "full world" (Daly, 1992). This global crisis will imply a major increase in TRANSACION activities and TRANSFORMATION activities that future societies will have to carry out in addition to the set of activities carried out right now. A few potential examples are:

* *Military expenses* – even though this is a politically "non correct" topic to touch upon, and is often systematically ignored by those dealing with sustainability, military and defense expenses do indeed play a crucial role within societal activities. In the last decade military expenditures have been increasing and this is reflected in a larger investment of hours of labor, energy and technical capital in activities related to growing military capability.
* *Security (antiterrorism) activities* – the security at the national and at the individual level is becoming a key issue in developed countries, and an increasing fraction of the resources (including hours of paid work in the SG sector) are allocated to this task both in developed and developing countries. In fact, it is easy to guess that the lack of sustainability of current pattern of development will translate into major socio-economic changes. In turn this will translate into a series of serious financial crises, peaks of unemployment, massive migrations. Then, we should expect that the issue of security will keep increasing in priority, requiring increasing investments, within the metabolic pattern;
* *Retirement, Health care and Unemployment* – due to the progressive aging of the population in developed countries, we can only expect that the number of retired people will increase as already experienced through the 'graying of European Countries'. This will imply a double stress on the stability of the metabolic pattern since this will: (i) reduce the amount of hours in the PW sector; and (ii) increase the requirement of hours in the SG for taking care of the larger dependent population. In the same way, the economic crisis will entail a larger number of unemployed, which will require additional assistance, based on the availability of societal surpluses of resources;
* *Replacement of our current energy infrastructures* – a large fraction of energy infrastructures (especially the electric grids and installations) is obsolete, since the big boom of energy consumption took place in the 1970s. They will require, in the very near future, a formidable round of investments, just to guarantee their functionality.
* *Construction of new infrastructure for alternative energy sources* – due to the lack of clear indication of a viable plan B for fossil energy (http://www.ourenergyfutures.org), it is difficult, at the moment, to imagine that it will be possible to generate in the medium term an energy sector based on a mix of PES totally alternative to fossil energy. However, after imagining that some valid alternative will be found soon, this task will require an immense amount of investments (financial investment, hours of work, technological capital, energy carriers, minerals, etc.).
* *Repairing environmental damages* – the continuous series of environmental emergencies experienced as recently experienced with the dramatic Deepwater Horizon Oil Spill, seem to point at the possibility that in the future we could witness a systemic lowering of environmental standards in economies, which will be affected by a situation of systemic crisis. To this we have to add the consideration that, without waiting for additional environmental disasters, the environment is already severely stressed in many areas of the planet. In a way or another we can expect that additional increase in the requirement of TRANSFORMATION and TRANSACTION activities in relation to this function.
* *International aid for disasters, crisis and local wars taking place in developing countries* – Due to the dramatic increase in population human activity has expanded all over the planet, including in areas at risk with the additional provocation of environmental disasters (Odum and Odum, 2001). Moreover, the competition for scarce resources, associated with the corruption of many local governments by powerful international lobbies is increasing the reasons for local conflicts all over the planet. Finally, the food security of a large fraction of the population of developing countries is more and more at risk for both those living in urban areas (depending on the market for their food security) and for those living in rural areas, in which the traditional farming systems have been disturbed.

When summing all these expected trends together we can guess that the number of problems to be solved in the future will dramatically increase. This will require the expression of a new set of functions, in addition to the functions already expressed right now, and the amplification of the functions already expressed. This is a forced requirement when assuming the creation and reproduction of an enormous amount of infrastructures, products and new organizations.

3.2. Perspectives for a reduction of either working time or energy consumption

3.2.1. Reducing the work supply in Paid Work and reducing the work supply in PS requires a huge investment in energy and technical capital

As already shown by numerous experts in the field of energy analysis, increases in GDP (i.e. economic output) are strongly correlated with increasing consumption of fossil energy (Cleveland et al., 1984; Hall et al., 1986). More specifically high material standard of life (measured by the standard set of indicators of development) can be correlated to a situation in which the economy is operated by using very little labor in the Productive (PS) sectors (indicating a very high ratio of THA/HA_{PS}). However, in order to obtain this result the PS sector must operate at a very high power levels ($ET_{PS}/HA_{PS} = EMR_{PS} > 250$ MJ/h). High quality of fossil fuels has given societies the possibility of diversifying activities by reducing the amount of resources that must be invested in the hypercyclic compartments. When a very high productivity of labor is achieved in the PS sector, all the required inputs can be supplied to society by using only a *limited amount of hours* in the PS sectors. For example, all the food consumed in a year by a US citizen is produced by less than 12 h of work in the agricultural sector (Giampietro, 2002). All the energy consumed per capita in a developed country in one day, is made available by 2 min of paid work in the energy sector (Giampietro and Mayumi, 2009).

The dissipative part – the Services and Government (SG) plus the activities carried out in the Household (HH) sector – has gained such a momentum only because of the cheap and plentiful reserves of fossil PES, the high net energy supply of fossil EC, and the reduced request of working hours in the PS sector.

As a matter of fact, if we are looking at the past trend of changes in the metabolic patterns of developed countries, we can clearly see that a reduction in the number of hours of paid work in the Primary and Secondary sector has been possible only because an increase of the energy consumption in these sectors. This phenomenon of replacement of human with mechanical work is well known. This is how it was possible to get rid of 60–70% of the work force in agriculture, moving all these potential workers into other sectors of the economy.

Past trends are illustrated in Fig. 9, based on a selection of European Countries. On the vertical axis, we have the variable "hours of paid work in the PS sector" over "Total Human Activity" within that society; on the horizontal axis we have the EMR_{PS} ("throughput of exosomatic energy in PS" divided by "the hours of work in PS). The time window is 1992–2005 (a recent period in which many assume that the process of dematerialization of modern economies was already taking place). The graph of Fig. 10 shows that all EU countries have gone through an *energetic intensification* of the PS sector. If you want to work less you have to consume more energy and use more capital.

Another option to counteract this trend is for developed societies externalizing intensive production processes to developing countries in order to avoid producing all the consumed goods and import the difference from developing countries. However, the reduction of energy intensity obtained in this way actually worsens the problems following a "behind the scenes" pattern. Trading of such products will imply looking for lower prices generated by comparative economic advantages, thus the production of energy and material intensive goods will rather take place where there is lower protection of both the environment and the right of workers. To illustrate this point for example, the changes in sectoral organization and its preferred inclination toward the service sector, is compensated by the huge flow of imported goods rather than by the production of them. This fact is illustrated by the recent publication of Peters et al. (2011) showing that emissions in developed countries have been stabilized because of rapidly growing international trade flows resulting in growing imports of developed nations. In this way, developed nations have increased their consumption based emissions rather than their territorial emissions, and could move to non-energy intensive manufacturing (Peters et al., 2009, 2011).

3.2.2. *Changing the pattern of human allocation within a given metabolic pattern is extremely difficult*

Changing pattern of human allocation within a developed society where social institutions are more and more complex is everything but easy. With so many factors being regulated by many control types and many different categories of social actors, it is almost unavoidable to experience a situation of total lock-in. Moreover, wishful counter arguments demanding for shorter working hours in order to spread out employment opportunities across more people seem to clash against a biophysical and demographic analysis of the existing predicament. For example, Victor (2010, p. 371) argues that: "The benefits of greater productivity would thus be directed toward more leisure time, rather than increasing GDP" and it is seemed to believe that economic productivity can be defined independently from biophysical

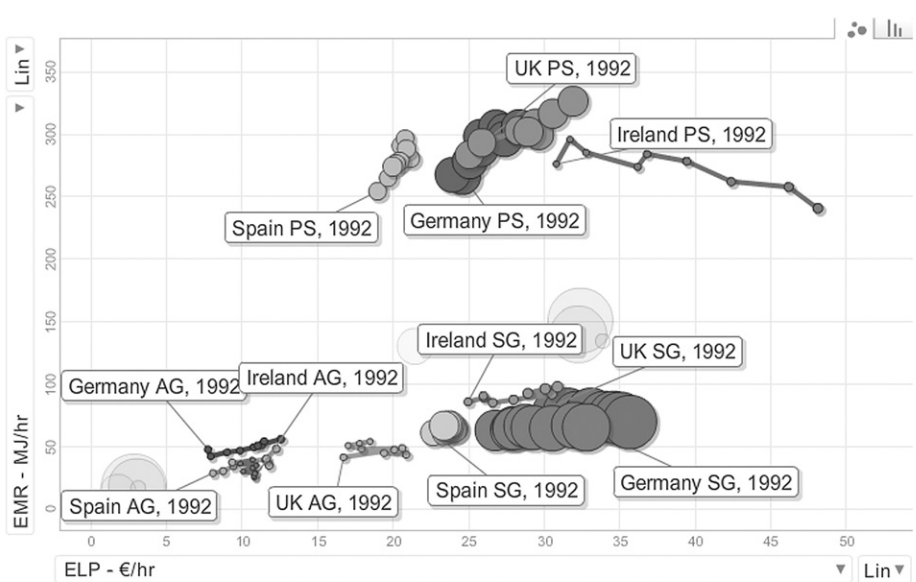

Fig. 9. Comparing the performance of metabolic societies.

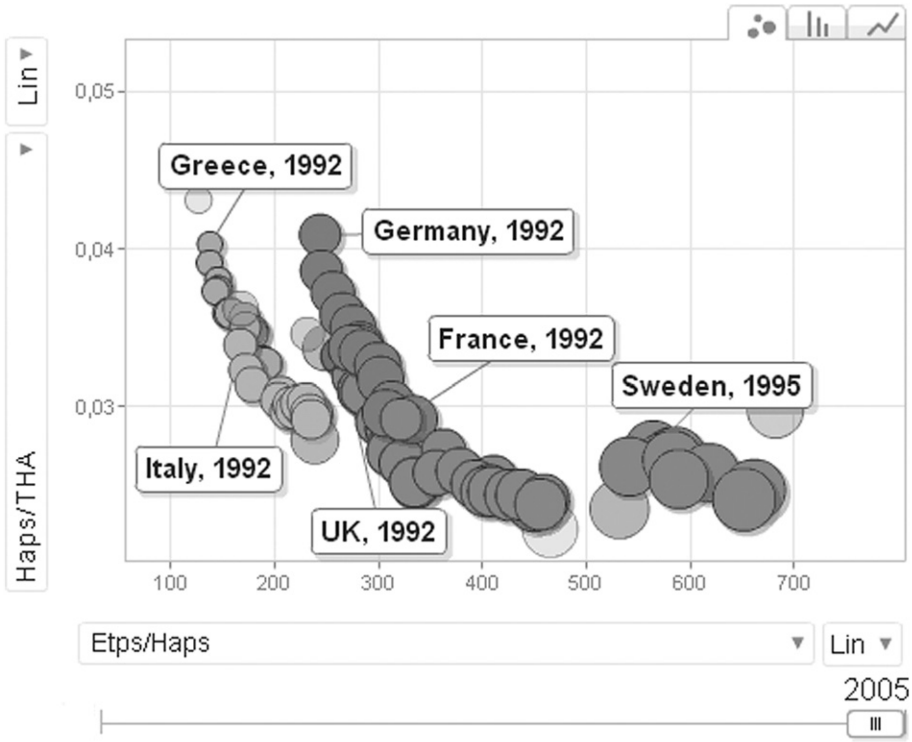

Fig. 10. Energetic intensification of selected European Countries.

productivity. As illustrated earlier, what is desperately needed by modern socio-economic systems is the generation of "well paid jobs" (associated with the possibility of generating a large net surplus to society per hour of human activity). If we imagine a society using less capital, less energy and fewer resources per hour of labor, it would be highly improbable that the society could provide an income capable of maintaining a decent salary to its workers, based on fewer working hours. The ability to pay high wages to labor depends on the surplus made available to society from the activities carried out during work – the characteristics of the dynamic budget as discussed earlier. In an economy operating without the boosting effect of technology, fossil energy, abundant resources, favorable terms of trade (and debt making) it is very naïf to expect that it will be possible to reduce the working hours without reducing of the income of the workers.

At the moment we have a pattern of allocation of human activities across the different compartments of society, which is very difficult to change while preserving the status quo or without causing dramatic outcomes. In particular, looking at the global crisis it is easy to guess that very soon the governments of many countries of the world will be facing a "mission impossible" in which more tasks will have to be performed a dramatic increase in TRANSFORMATION and TRANSACTION activities, at the moment that they will have less working hours (because of aging), less technological capital (because of the crisis) and less net energy (because of peak oil). In this situation it is very unlikely that "working less" – shorter work-year or the sharing of jobs (Victor, 2010) – will be a solution to improve the economic performance. For example, we can generate a huge amount of jobs by eliminating tractors in agriculture or trucks in transportation and move back to manual labor. But would this represent a solution to our problems?

The existence of many competing interests, power structures and veto power given through institutional settings to individual categories (especially in western democracies) makes it very difficult to generate dramatic changes in the actual structure of allocation of human activities. Within a complex system depending so heavily on the given pattern of energy transformations; suggestions for a voluntary reduction of energy throughput on its use appear to be naïve. Moreover, the energy consumed by individuals in the household sector is only 25% of the total energy consumption. As stated by Tainter (2009) the development of complexity within societies comes about as a response to solving arising problems in which he describes as such: "*Confronted with problems, we often respond by developing more complex technologies, establishing new institutions, adding more specialists or bureaucratic levels to an institution, increasing organization or regulation, or gathering and processing more information*".

A second problem is related to the "Jevons Paradox". The belief that through the voluntary consumption of less resources, less energy and less capital, we can solve the problems generated by more and more people having growing expectations, seems to totally neglect the bioeconomic and biophysical view of the sustainability predicament. In fact, an expected feature of evolving systems entailing that any increase in technological efficiency will result – contrary to what expected – in the increase of the rate of consumption of the specific resource of concern (i.e. energy) – for a discussion and illustration of the Jevons Paradox (see Polimeni et al., 2008). A voluntary reduction of energy consumption in some activity can be compensated by an involuntary increase in energy consumption that the society can now afford in some other activities.

A third problem is related to the quick move to "Ponzi scheme economics". As highlighted by Soddy (1926, 1934) with his concept of Virtual Wealth, we can recognize this pattern with the recent explosion of the strategy of financial leverage at a global scale used for boosting the economic performance through credits and mortgages at an unprecedented level. A huge amount of virtual wealth and money has been created through dubious operations of discounting of future values and the creation of precarious debt (see Martinez-Alier, 2009; Giampietro et al., 2011; Kallis et al., 2009). This, in due course, has lead to a decoupling between what can be seen when using monetary variables to assess development and the biophysical reality. This abuse of financial leverage has ultimately lead to the generation of a confusion between "virtual wealth" associated with monetary flows generated by debt, and "biophysical wealth" associated with the actual production and consumption of goods and services (Giampietro et al., 2011 Chapters 8 and 11). In this situation, advocating for giving higher salaries to workers working less and generating a lower biophysical labor productivity simply translates into an additional boost to debt making scenarios without reference to the underlying physical realities.

3.2.3. How to deal with uncertainty? Should we implement a plan for degrowth or should we rather think about flexible management strategies of adaptation?

When dealing with complex systems, our capacity of prediction and management of the future is very limited. That is, we have to acknowledge the existence of a heavy dose of uncertainty and genuine ignorance (Ravetz and Funtowicz, 1992; Funtowicz and Ravetz, 1993). In particular when getting to the prediction of possible re-adjustments of the metabolic patterns of modern societies toward new, but still unknown feasible solutions for the dynamic budget, it is impossible to anticipate what these solutions will be. In relation to the biophysical feasibility, there are often too many non-linearities in the mechanism determining the feasibility of the metabolic patterns way, accompanied also with too many unknown factors (referring to the definition of external and internal biophysical constraints). In relation to the desirability, there are too many inextricable cultural and social factors which make it impossible to define what is desirable – What should be sustained? For whom? For how long? At which cost? (Tainter, 2006). Imagining that it would be possible to arrive to a general agreement on an optimal plan for degrowth is frankly skeptical. In fact, substantial reductions in energy throughput are directly related to change of habits and customs – changes in cultural identity – which would imply the unavoidable emergence of resistance to the proposed changes (especially if suggested by someone else) or a denial of the need for changing (Polimeni et al., 2008).

Human history is the result of a series of socio-economic transitions that have taken place across a very long, historical and temporal scale. Through these transitions, societies who have not manage to survive for ecological reasons and lack of natural resources have faced collapse (Tainter, 1987; Diamond, 1997). Modern societies have had the possibility to become complex over time because of the progressive use of technologies and the benefit from high quality and easily accessible energy sources. The industrial civilization has been around for more than one century now, enough to establish a well-rooted and robust metabolic pattern.

Changing such a pattern will not be easy. Due to the heterogeneity of human development on this planet we can expect that in different areas, we will be confronted with different types of resistance reflecting the willingness to preserve established customs, settings and ideologies (Cottrell, 1955). An abandonment of the metabolic pattern established with the industrialization (something that will happen no matter what humans will do) will require huge changes in lifestyles of a huge number of people having different everyday habits and practices. This ultimately means that changes that will result acceptable to some may result unthinkable for others.

Moreover, despite the energetic excess of "developed" countries it is difficult to deny that many nations of the developing world need to consume further energy (both per capita and in aggregate terms), to attain a decent standard of living (Smil, 2011). In this situation, in our view, it is not even thinkable to imagine that someone can "know" what is the best thing to do, how to plan a equitable and ecological friendly degrowth.

In spite of all the difficulties that we may face, the debate on the approaching "tragedy of change" is undeniably upon us and it is unavoidable that humankind will have to go through it in the next decades. The term "tragedy of change" – proposed by Funtowicz and Ravetz, 1994, see also Giampietro (2004) ultimately refers to a key issue of sustainability. In order to be able to engage in new styles or ways of living (the proposed change) we must be able to sacrifice old styles and giving up an important fraction of the accustomed standards we are used to. This will require a very delicate discussion and deliberation over what the society wants to give away in relation to what the society wants to retain. This operation cannot be carried out using analytical tools or personal beliefs, since viable and desirable futures still do not exist. They will have to be created by the interaction of human beings.

4. Conclusion

The "degrowth narrative" has been put forward as a second attempt to re-challenge the narrative of perpetual growth of cornucopians. However, in order to gain more attention we believe that the degrowth movement should better address the following issues:

(i) *Population* – very often proponents of degrowth mention the work of Georgescu-Roegen, who proposed the idea and the name of "decroissance". However, they ignore the fact that when reading his bio-economic program, he was explicitly mentioning the issue of population: "*mankind should gradually lower its population to a level that could be adequately fed only by organic agriculture*" (Georgescu-Roegen, 1975b). We believe that the proposal of Georgescu-Roegen is probably too radical. However, we firmly believe that three factors of the I = PAT relation – PAT – should be addressed all together to understand the option space for the degrowth paradigm.

(ii) *The belief that with less resources, less energy, less capital, more people and many more problems to face it would be possible to fix the situation by reducing the work load of the work force* – this is an important point to be made, since the movement of degrowth accuses the leading neoclassical paradigm for its lack of touch with reality. On the other hand it seems that many of the degrowth movement, share the original sin of economist to neglect the bioeconomic perspective. According to what is presented in this paper, it is very unlikely that in the future the work load of adults will be reduced neither in the paid work category or the unpaid work category.

(iii) *The idea that we should plan for degrowth* – nobody would plan for aging (it will happen no matter what), so the only thing we can do is to discuss how to age in a pleasant way; the same approach holds true for the issue of degrowth. Unless we find some magic silver bullet, the energy consumption of humankind will have to degrow: first on a per capita basis, then in absolute terms. The implications of this fact are impredictable and nobody can indicate the optimal strategy of degrowing. We should bear in mind that modern socio-economic systems have achieved their high level of complexity through an unplanned and self organization process (it was not because of the optimizing plans of economists). As Tainter (2011, p. 2) puts it, "…[C]omplexity develops because it can, and that the factor facilitating this is surplus energy". For this same reason we believe that also the downscaling will be an unplanned and a self-organized process. What we can do is to be prepared, try to understand what is going on and to develop flexible management strategies whilst investing the remaining high quality energy in wise alternative energy options to make a smoother transition.

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