European Commission

Mono-dimensional accounting and multidimensional measures of sustainable growth

Mario Giampietro

2014

Editor: Andrea Saltelli

Report EUR 26917 EN

Joint Research Centre

European Commission
Joint Research Centre

Contact information
Andrea Saltelli
Address: Joint Research Centre, Via Enrico Fermi 2749, TP 361, 21027 Ispra (VA), Italy
E-mail: andrea.saltelli@jrc.ec.europa.eu
Tel.: +39 0332 78 9686
Fax: +39 0332 78 5733
https://ec.europa.eu/jrc

Suggested Citation:
Mario Giampietro 'Mono-dimensional accounting and multidimensional measures of sustainable growth', 2014, Report produced by the European Commission-Joint Research Centre, Econometrics and Applied Statistics (DDG.01)

JRC92579

EUR 26917 EN

ISBN 978-92-79-44003-8 (PDF)

ISSN 1831-9424 (online)

doi:10.2788/244356

Luxembourg: Publications Office of the European Union, 2014

Printed in Italy

Abstract
The terms of reference of the contract define two contributions: (i) a theoretical analysis addressing the epistemological challenges posed by quantitative indicators for sustainable growth (Part 1); and (ii) an applied analysis of the ongoing work on a composite indicator for monitoring Environmental Pressure in the EU at the national level (G03 collaboration with Environment Directorate-General) and the Environmental Pressure Index developed in collaboration with Yale and Columbia University (Part 2).
Building on the wisdom of George E.P. Box, "all models are wrong, some are useful", the report first shows *why* all models are necessarily wrong and individuates the factors determining the usefulness of wrong models. Practical examples of food and energy accounting demonstrate that quantitative analysis of environmental pressure generated by socio-ecological systems always demands the simultaneous consideration of multiple space-time scales and multiple dimensions of analysis. Based on these epistemological premises, a critical appraisal is then provided of two ongoing efforts aimed at quantifying environmental impact - the Environmental Performance Index and the Composite Index of Environmental Pressure - with the goal to strengthen the usefulness (political relevance) of these protocols.
Observations on the Environmental Performance Index include: (i) Excessive concern for rigorous data handling hides the neglect of the discussion about the relevance of what should be measured; (ii) The implications of the DPSIR framework (Drivers, Pressure, States, Impact, Response) are not properly addressed; (iii) The environmental pressure externalized to other countries through imports is not considered; (iv) The inclusion of outcome-oriented indicators, for measuring the effect of policies (Response), makes the whole assessment shaky by mixing numbers relevant for different purposes.
As regards the Composite Index of Environmental Pressures: (i) The conceptual issue of cross-country data comparability is not properly addressed; (ii) It is impossible to use quantitative assessments of *pressure* without making reference to *state* and *impact*. Therefore, rather than grouping indicators into five themes (air, water, land, climate, chemicals) without providing an external referent, it is recommendable to refer to the potential impact on structural elements, such as terrestrial ecosystems, aquatic funds (such as aquifers), agricultural soils and the atmosphere, at the global (for GHG emissions) and local scale (inhabited areas; to account for those indicators that exert pressure on humans); (iii) The index should assess both local (within the national boundary) and externalized environmental pressure.
Finally a few ideas are suggested for the continuation and refinement of this line of investigation at the EC-JRC-GO3.

Contents

Contents 1

Preface 3

Executive Summary 4

Part 1- The predicament faced by science when trying to generate purposive quantitative analysis: implications for indicators 6

1.1 Lessons from complexity theory: how to identify the external referent 6

1.1.1 The standard predicament implied by complexity: Abstraction vs Simplification 6

1.1.2 The paradox of the science of indicators: what is the external referent of your measurement? 8

1.1.3 Examples of terrible simplifications: using numbers without external referent when discussing of energy intensity and environmental impact 10

Section 1.2 The limits of mono-dimensional accounting (1): The need of always considering both the internal and the external view in quantitative analysis 14

1.2.1 The concept of holon entails that a mono-dimensional accounting is impossible 14

1.2.2 Examples of terrible simplifications: the bifurcations in the accounting of food and energy consumption 19

Section 1.3 The limits of mono-dimensional accounting (2): The need of always using an integrated set of assessments referring to multiple scales 24

1.3.1 Intensive and extensive variables: addressing the heterogeneity of systems across scales 24

1.3.2 Intensive and extensive variables: a theoretical definition 27

1.3.3 The DPSIR framework 30

1.3.4 Examples of terrible simplifications: the fairy tale of "Kuznet curves" and the problem of defining environmental impact with just a number 35

1.4 Aggregation of different indicators: when is it possible? 40

1.4.1 The entanglement between descriptive and normative side 40

1.4.2 The "relevance" of indicators depends on the relevance of the chosen narratives 42

1.5 Conclusion: even admitting that for quantitative analysis reductionism is the only game in town, we should understand pros and cons of it 44

Part 2 - Ideas on how to monitor Environmental Pressure in the EU based on the experience of the *Environmental Performance Index* and the *Composite Index of Environmental Pressure* 46

2.1 A technical analysis of the Environmental Performance Index 46

2.1.1 The construction of the indicator is affected by a problem of "lamposting" 46

2.1.2 ***The implications of the DPSIR framework are not properly addressed in the development of the protocol of accounting*** 47

2.1.3 The neglecting of the implications of the openness of the socio-ecological systems 48

2.1.4 The focus on outcome-oriented indicators - needed to measure the effect of policies (measuring RESPONSE) - makes the whole assessment shaky 48

2.2 A technical analysis of the Composite Index of Environmental Pressure 49

2.2.1 The conceptual issue about the comparability of data across countries has not be properly addressed (what is compared when using only intensive variables?) 49

2.2.2 Can we define indicators of environmental "Pressure" without making any reference to information referring to State and Impact? 51

2.2.3 The distinction between "local environmental pressure" and "externalized environmental pressure" 55

2.3 Suggestions for continuation and refinement of this line of investigation....55

Bibliography......60

Preface

Seeking advice on how to develop composite indicators in the field of environmental and societal sustainability our team at the Joint Research Centre had the temerity to ask advice from Mario Giampietro, a scholar of ecological economics, working in the tradition of Nicholas Georgescu-Roegen and known for his closeness to thinkers such as Kozo Mayumi, James Kay, Timothy F. H. Allen, Joseph A. Tainter, Joan Martinez Alier, and Jacques Grinevald.

In retrospect this was a bit like asking the fox for the opinion of how to build a henhouse – i.e. it became rapidly apparent that a composite indicators of environmental pressure could simply not be built without violating the almost totality of precepts of sound ecological system analysis.

Yet given our team's very peculiar position – of adviser rather than developers of these ambitious measures - it seemed correct to receive from a primary source a clear indication of how things could be improved.

We thus learned that if the goal of an index of environmental pressures is to provide an effective characterization of the different types of pressures that a country exerts on the environment a more articulated method of accounting is needed. To give an example, Mario Giampietro argued that in order to assess the seriousness of the situation on a given country one need information on both the pressure exerted on a given compartment of the ecosystem and the ecosystem's capacity. How can this be captured by a single number per ecosystem – let alone per country?

One needs to look at what society does and what the ecosystem does, to distinguish flows from funds, and analyze simultaneously different temporal and spatial scales.

Mario Giampietro, known for his original work on integrated resource assessment, concerned with the food-water-energy-land and population nexus, and for his at times controversial views on climate and biofuels, is one of the most prolific and interesting living socio-ecologists. Withstanding his broadsides against composite indicators was challenging, while instructive; a conversation, which our team wishes to continue in the future.

Andrea Saltelli, Ispra, October 27, 2014

Executive Summary

Part 1

This part addresses in theoretical terms the problems faced when developing mono-dimensional accounting protocols for multidimensional measures of sustainable growth. Starting from the quote of E.P. Box "***all models are wrong, some are useful***" it addressed from a conceptual point of view, two questions: (i) why "all models are wrong" by definition, using concepts taken from Complexity Theory; (ii) what are the factors determining the usefulness of wrong models using basic epistemological considerations developed within the theoretical framework of Post-Normal Science.

Main conclusions illustrated with practical examples are that when dealing with the quantitative analysis of the environmental pressure generated by socio-ecological systems (the pattern of interaction of socio-economic systems and ecological systems) it is necessary to address the obvious fact that the information required for this task can only be generated adopting simultaneously different space-time scales and different dimensions of analysis. In particular the system of accounting has to be able to:

(i) establish a bridge between quantitative information referring to states associated with the metabolic pattern of societies (internal view) and the metabolic pattern of ecosystems (external view);

(ii) describe the characteristics of the metabolic patterns across different levels of organization – e.g. sub-parts/parts/whole;

(iii) make a distinction between flows that come from stock depletion and stock filling (non-renewable) and flows that come from fund-flow processes (renewable);

(iv) define the degree of openness of the socio-ecological system in order to include the effect of externalization due to the role of imports and exports.

Part 2

This part provides comments on the two documents - Environmental Performance Index and Composite Index of Environmental Pressure – with the goal of suggesting improvement and future line of research in relation of the task of developing effective quantitative analysis of environmental impact.

In relation to the analysis of the *Environmental Performance* Index main observations are:

(i) The construction of the indicator is affected by an excessive concern for rigorous data handling and an insufficient attention given to the individuation of the external referents that should be measured;

(ii) The implications of the DPSIR framework (Drivers, Pressure, States, Impact, Response) are not properly addressed in the development of the protocol of accounting. The index is mainly focused on the analysis of response but the criteria used to select the indicators in relation to pressure and impact are not explained;

(iii) the index does not consider the environmental pressure externalized to other countries because of imports;

(iv) The focus on outcome-oriented indicators - needed to measure the effect of policies (i.e. for measuring RESPONSE) - makes the whole assessment shaky. In fact, the index wants to weight various indicators of response, by looking at the results, without defining how serious was the situation that generated the response in the first place (a failure to fix a minor problem is not as important as a failure to fix a crucial problem).

In relation to the analysis of the *Composite Index of Environmental Pressures* main observations are:

(i) The conceptual issue about the comparability of data across countries has not be properly addressed. The protocol of the composite index assumes that after having transformed extensive variables into intensive variables (by dividing the numbers by a denominator) the resulting number becomes comparable across countries. However, intensive variables can get different meanings depending on the external referent measured by the number used for division! For example, a given flow calculated per capita reflects the characteristics of a society (a state), whereas when it is calculated per hectare it will reflect a certain level of pressure on the environment;

(ii) The protocol of the index assumes that it is possible to use quantitative assessments associated with the meaning of "*pressure*" without making reference to information referring to *state* and *impact*. However, when comparing indicators across different countries it is necessary to contextualize the meaning of their value. For this reason, rather than grouping the indicators in 5 themes not providing an external referent (air, water, land, climate, chemicals), it would be better to group the indicators in relation to functional/structural elements that can be used to contextualize the value of pressure. The categories of structural/functional elements suggested are: (i) Atmosphere (for GHG emissions); (ii) terrestrial ecosystems; (iii) aquatic funds (including aquatic ecosystems and ecological funds such as aquifers); (iv) agricultural soils; and (v) inhabited areas (to account for those indicators that are not referring to a pressure on ecological funds but on a pressure on humans);

(iii) the protocol of the index does not have a dual system of accounting for assessing both the Local Environmental Pressure (referring to states, pressure and impact observed within the boundaries of the Socio-ecological system); and the Externalized Environmental Pressure (referring to states, pressure and impact generated elsewhere because of the activities embodied in the imported goods and services).

Finally the document suggests a few ideas for the continuation and refinement of this line of investigation at the EC-JRC-GO3.

Part 1- The predicament faced by science when trying to generate purposive quantitative analysis: implications for indicators

1.1 Lessons from complexity theory: how to identify the external referent

In sustainability science a quote of G.E.P. Box (Box, 1979) is being increasingly used to flag a systemic problem that quantitative scientists face when dealing with purposive analysis. The quote says: "***all models are wrong, some are useful***" (Box, 1979, pp. 202-203). In relation to this quote, in this first part of the report, I address, from a conceptual point of view, two questions: (i) why "all models are wrong" by definition. For this task I use a few concepts taken from Complexity Theory (Sections 1.1 and 1.2); (ii) what are the factors determining the usefulness of wrongness of models. For this task I use some basic epistemological considerations developed within the theoretical framework of Post-Normal Science (Sections 1.3 and 1.4). This discussion is essential in order to clarify the factors that should be considered when checking the quality of the process generating and using indicators for governance (discussed in Part 2).

1.1.1 The standard predicament implied by complexity: Abstraction vs Simplification

Every time we identify a "system" to be observed, modeled and measured we are defining an abstraction about a particular portion of the external world. Such an abstraction will reflect a given perception of that particular portion of the external world. A particular branch of Complexity Theory – Hierarchy Theory – deals exactly with the implications of this act of abstraction: "*Hierarchy theory is a theory of the role of the observer and the process of observation in scientific discourse. It is a theory of the nature of complex questions, that focuses on observations as the interface between perception and learning*" (Ahl & Allen, 1996, p. 27). This predicament is especially relevant when dealing with complex systems organized across multiple scales – i.e. human societies and ecosystems. In fact, when studying these systems we can generate simultaneously many non-equivalent abstractions of them. These potential abstractions "*are all present in the original [hierarchical] system"* but then *"which one we actually "see" is specified entirely by how we choose to interact with the system*" (italics added, (Rosen, 1977, p. 229)). A good metaphor of this point is given by the possibility of observing a given person at different scales using a microscope, the naked eye or a telescope. What we see when observing (the perception that will represented) depends not only on the nature of what is observed (the body of the observed person) but also by the choice of how to observe it (the method of observation determining a descriptive domain) – (Giampietro, et al., 2006). The same point has been made by Mandelbrot when introducing the concept of fractal objects. In a seminal paper he made the point that it is not possible to define the length of the coastline of Britain if we do not first define the scale of the map we will use for our calculations (Mandelbrot, 1967)The same perceived entity (the coastal line of Britain) does map onto non-equivalent abstractions (or representations) determining different numerical assessments when considered at different scales.

The idea of systems having multiple legitimate but non-equivalent perceptions and representations (abstractions) has been suggested as the very definition of hierarchical systems:

- ❖ "systems are hierarchical when they are analyzable into successive sets of subsystems" (Simon, 1962, p. 468) - in this case we can consider them as near-decomposable.
- ❖ "a system is hierarchical when alternative methods of description exist for the same system" (Whyte, et al., 1969)
- ❖ "a dissipative system is hierarchical when it operates on multiple space-time scales - that is when different process rates are found in the system" – this is a definition that will be discussed further in Section 1.3 (O' Neill, 1989)

When dealing with a system that can be described using different formal identities it is possible to have legitimate, rigorous, but contrasting assessments. In this case, the differences across non-equivalent assessments are not due to errors in measurement or calculation, but rather to the existence of logically independent choices of the narrative within which quantitative models have to be developed.

Hierarchy theory can explain the scientific predicament entailed by abstraction, that is, why "all models are wrong". In fact, no matter how carefully we chose the narrative used to perceive a particular portion of the external world, it is unavoidable that other narratives referring to different aspects of that portion of the external world will be neglected. These neglected aspects always provide potentially relevant information that is not included in the chosen model. For this reason the definition of what is a "useful model" does not depend only on the quality and the pertinence of the observation process (how good are we observing and measuring) but also on the relevance of the information given by the chosen perception (why we want to observe our system in the first place!). Though no commonly accepted definition of complexity exists, in relation to this discussion we can adopt an interpretation of the term complexity associated with its epistemological implications. In this interpretation complexity is associated with the impossibility of compressing the virtually infinite universe of perceptions of a relevant portion of the reality into a given formal representation ***without losing relevant information***. This interpretation resonates with the definition given for mathematical complexity by (Chaitin, 1987) known also as Kolmogorov or Algorithmic complexity. In relation to this point (Rosen, 1985) (Rosen, 1991) proposed a modeling relation theory focusing on the conceptual process of development and use of models. He indicated the various logical steps making it possible to individuate, measure and make models starting from a given perception of a particular portion of the external world – the modeled system. In a model the chosen perception of a portion of the reality is represented using only a finite set of attributes. Then any proxy variable chosen for describing a relevant attribute of "the system to be modeled" can be used as indicator. In this process, the analyst replaces: (A) *a given perception of the external reality* - the chosen narrative about a relevant portion of the external world to be studied, that is shared with other analysts; with (B) *a given representation of that perception* – the chosen finite set of proxy variables used in the abstraction to model the system. Such an abstraction is formalized in terms of proxy variables, measurement schemes and inferential rules into a representation used generate some form of prediction/explanation about relevant behaviors of the investigated system. For example, if we describe a cockroach using a narrative saying that "a cockroach is a system that tends to hide to avoid the light" we can develop a simple anticipatory model of its behavior. Such a model can result useful, in spite of the radical abstraction, if we want to guess its running direction when the light is switched on in a room. Clearly, the same model will result completely useless if one wants to predict its feeding habits.

Accepting the fact that an abstraction necessarily implies simplification, we have also to accept that we need criteria to decide when the process of abstraction is useful (keeping the model simple) or harmful (making the model simpler). Dealing with this predicament is especially important when dealing with quantitative analysis to be used for governance in human systems. "Terrible simplifications" can lead to a poor understanding of situations to be tackled and poor judgment at the moment of generating policies (Reinert, 2011).

1.1.2 The paradox of the science of indicators: what is the external referent of your measurement?

Another popular say in the scientific literature on indicators is that you cannot sum or compare "apples" and "oranges". This sentence clearly states that comparisons can only be made between objects of the same kind or in relation to a common criterion of equivalence. Therefore, an indicator can only work if it is used to define how different are objects that are the same in relation to a given definition of equivalence class ("apples" with "apples"). On the contrary it cannot catch differences when the two objects do not have a common criterion of equivalence for their measurement: an indicator good for studying differences among "apples" is not good to study differences between "apples" and "oranges"! In practical terms, this fact also implies that when we are measuring the characteristics of a specific observed system – e.g. a dog – we are dealing with two conceptual entities overlapping in the same observation: (i) a given typology (what we consider as a "dog" or an "apple"); and (ii) how the specific instance under investigation compares with the given typology (how special is the specific instance of "dog" or "apple"). This implies also that the benchmarks used as indicators do not refer to the characteristics of any special physical object found in the external world (the instances of a type), but rather to the characteristics of the typology associated with the system in our mind (the equivalence class to which the measured individual is supposed to belong). As a matter of fact, we can say that in general science deals only with the characteristics of "equivalence classes" or typologies. For example, when generating indicators characterizing the physical performance of human beings, scientific research deals only with "average characteristics" of typologies of human beings – e.g. men, women, children, adults. The *actual* performance of a special instance – e.g. Hercules using magic powers for generating a unique event - would be considered totally irrelevant for science. In the same way specific records obtained at athletic events, where peak (record) performances are of prime interest, are not relevant for assessing average characteristics of human performance. They can be used just to define the range of possible values achievable by typologies of human beings. Science measures the expected characteristics of types and this explains why quantitative assessments should come with error bars. Error bars are needed to define the characteristics of the typology (the range of possible values associated with the equivalence class – e.g. when observing instances of apples) and to check the compatibility of the measurement scheme (e.g. extent and accuracy of the data) with the required quantitative assessment. The ***real "external referent"*** [= what has to be characterized that is giving meaning to the number] of quantitative analysis is the ***typology to be characterized*** and not any of the instance measured.

Needless to say that the individuation of the right external referent – i.e. what is the typology that is observed through the measurement of specific instances supposed to belong to the equivalence class – becomes more and more complicated when dealing with multi-level complex systems such as living systems. Complex systems do operate simultaneously across different scales and therefore they require, by default, a multi-scale perception/representation. When dealing with the analysis of these systems we always find complex taxonomies of different classes of categorizations referring to different hierarchical levels. For example if we want to study the typology "dog" we must be aware that this typology is a "species" described by other typologies (Class of *mammals* → Order of *carnivores* → Family of *canidae* → Genus *canis*) and a "species" (*canis familiaris*) divided in many sub-types *races*. In relation to this point it is important to observe that, in general terms, because of this predicament science has to handle two completely different kinds of information about the external world:

(1) information referring to "typologies" - patterns of expected relations among attributes of a system belonging to the given typology – e.g. the expected attributes of a dog. The information about types is by definition out of scale; and

(2) information referring to actual realizations of a given typology – e.g. the characteristics of a given instance of dog, that is supposed to belong to the equivalence class described by the typology. Being a physical realization an instance of a type, it is necessarily scaled.

This implies that if we want to make a quantitative comparison between two objects we have always to handle two different kinds of information: (i) information making it possible to distinguish between apples and oranges (referring to the definition of the expected relation over attributes of the type, that is out of scale since they can be normalized); (ii) information making it possible to define differences among apples (referring to specific realizations of the type which are always scaled). The distinction between these two types of information is essential for quantitative analysis. In fact, this distinction flags the existence of an unavoidable problem of scale when combining the two (this problem will be better clarified in section 1.2 when talking of the ambiguous coupling of types and instances in the concept of "holon"). However, in spite of the importance of this distinction (and the consequent problems to be dealt with), this distinction is rarely explicitly addressed in science. For example we can define the shape of an elephant (a type) as a set of expected relations over its parts (head, legs, hears). This means that we can make plastic models of elephants with a size of a few cm or a flying hot-air balloon with the shape of elephants with a size of 10 meters. Types are out of scale and this is why we can make models using their information – i.e. a paper plane versus a real airplane. However, we know that a real living elephant is scaled already by nature at the moment of its fabrication. This is why we do not need to measure elephants to know the order of magnitude (cm, m or km) of their size. A set of forced relations over the metabolic processes required to produce and maintain elephants entails that elephants can only be realized at a given range of sizes.

The same duality of required information is found with technical processes. Engineers can only calculate the characteristics of a plant (e.g. efficiency of a process and typical conversion factors) in relation to technical processes if they know the scale at which the process is realized. The concept of economies of scale indicates that the production function (e.g. a set of input/output ratios – intensive variables) changes when changing the size of a given process (an extensive variable).

In general terms we can say that, also when the scale of a system can be known "a priori" – as in the case of a living elephant – the information used to describe its activity can always be divided into two types:

(i) a set of expected relations over the characteristics determining the internal functioning of the elephant – the metabolic pace of energy and water in the body, the temperature of the body, the pH of the blood, etc. (internal view of the elephant). These indicators can be normalized in relation to the known size of the elephant and therefore they represent a set of indicators out of scale (useful for characterizing of the typology). With this information we can study the proper physiological functioning of the elephant;

(ii) a set of expected relations of the elephant with its context - how much food is taken from the environment per day, how much water is required per day, km of walking per day (external view of the elephant). This information comes from a contextualization of the interaction of the observed system with its environment and therefore defines the size of the elephant in relation to the size of the context (an external referent for its size). With this information we can study whether we have too many elephants in an area.

When coming to the development of indicators about elephants, we need indicators to know about "how the elephants does" (internal view) and indicators to know about "the compatibility of elephants' activity with the environment" (external view). The same predicament (indicators for the internal and the external view) applies to the generation of indicators assessing the environmental impact of socio-economic systems. Please note that this duality in the representation of complex adaptive systems requiring a characterization of an internal view that is conceptually distinct from the characterization obtained adopting an external view - is already present in the characterization of dissipative self-organizing systems given in non-equilibrium thermodynamics (Prigogine & Stengers, 1984); (Prigogine, 1978): a dissipative system in order to express a pattern of organization distinct from its environment (to reproduce itself) must fulfill two conditions that are logically independent from each other: (i) it must be able to generate a flow of entropy to be disposed (internal processes observable only adopting the internal view); (ii) it must operate under favorable boundary conditions making it possible to dispose into the environment the entropy generated inside (favorable boundary conditions observable only adopting the external view). Since self-organizing dissipative systems must be necessarily open systems interacting with their environment, this implies that the generation of favorable boundary conditions – determining the amount and type of inputs they can get from the environment and the amount and type of wastes they can dump into the environment - is a process outside their control. Complex adaptive systems can look for better boundary conditions (e.g. looking for favorable environments) but they cannot generate their boundary conditions. Otherwise the process of generation of favorable boundary conditions would become part of the activity of the dissipative system still requiring a different set of boundary conditions. This expansion of activities would simply change the definition of the boundary system/context.

1.1.3 Examples of terrible simplifications: using numbers without external referent when discussing of energy intensity and environmental impact

The following example, taken from (Giampietro, et al., 2012), is a comparison of the Economic Energy Intensity (EEI) of El Salvador and Finland. In the year 1997, these two countries had the same value of EEI equal to 12.6 MJ/$. The question is: how is it possible that two countries, so different in their internal characteristics, do have the same economic energy intensity? In order to answer this question, we can decompose the EEI into the two variables involved in its calculation (Fig. 1):

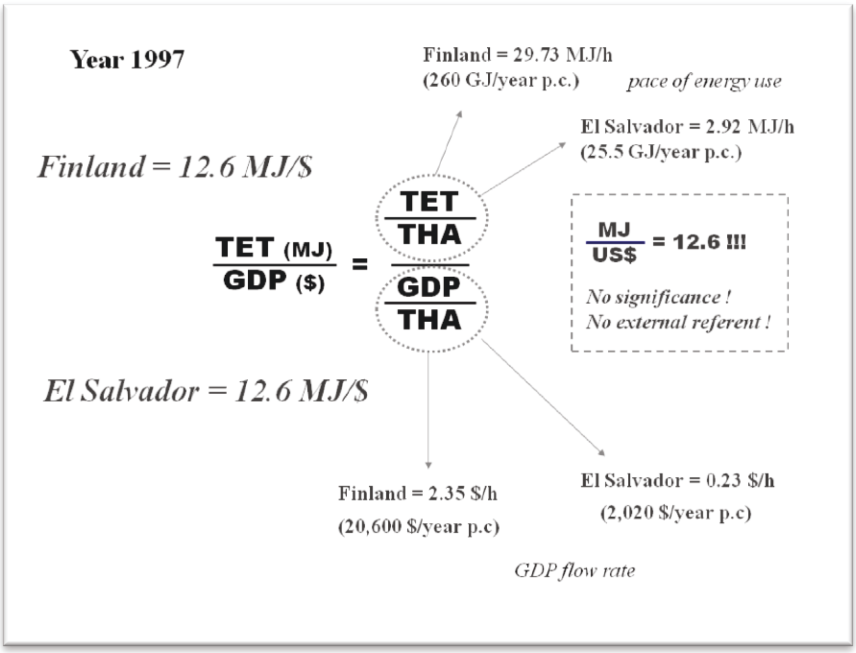


Fig.1 The problem with the ratio Total Energy Throughput/Gross Domestic Product

Legend:

TET = Total Energy Throughput/year; GDP = Gross Domestic Product/year;
THA = Total Human Activity = Population size x 8,760 hours (hours per capita/year)
TET/THA = Energy Throughput (either per capita per hour or per capita per year)
GDP/THA = Gross Domestic Product (either per capita per hour or per capita per year)
TET/GDP = Economic Energy Intensity (Energy Throughput/Gross Domestic Product)

The quantitative assessment of EEI at 12.6 MJ/$ is obtained combining proxy variables referring to two different dimensions of analysis: an energy dimension (a flow measured in joules) and an economic dimension (a flow measured in US dollars of a given year of reference). The ratio between the energy flow and the money flow does not have an external referent, in the sense that there is not a known typology of socio-economic process for which we can expect a value of 12.6 MJ/$. On the contrary if we use the two ratios: GDP/THA (the amount of GDP per capita per year or hour) and TET/THA (the amount of primary energy consumed per capita per year or per hour) we have two quantitative assessments referring to the characteristics of a set of known typologies:

(i) GDP/THA – for example a country with 20,000 US$ p.c./year is a developed country, a country with 2,000 US$ p.c./year is a developing country;
(ii) TET/THA – a country consuming 260 GJ of primary energy p.c. per year is a developed country, whereas a country consuming less than 26 GJ of primary energy p.c. per year is a developing country.

In this example, we have a situation in which the analyst starts with two assessments that are both useful – they reflect the characteristics of an external referent – and then by combining them into a ratio we lose the original useful information.

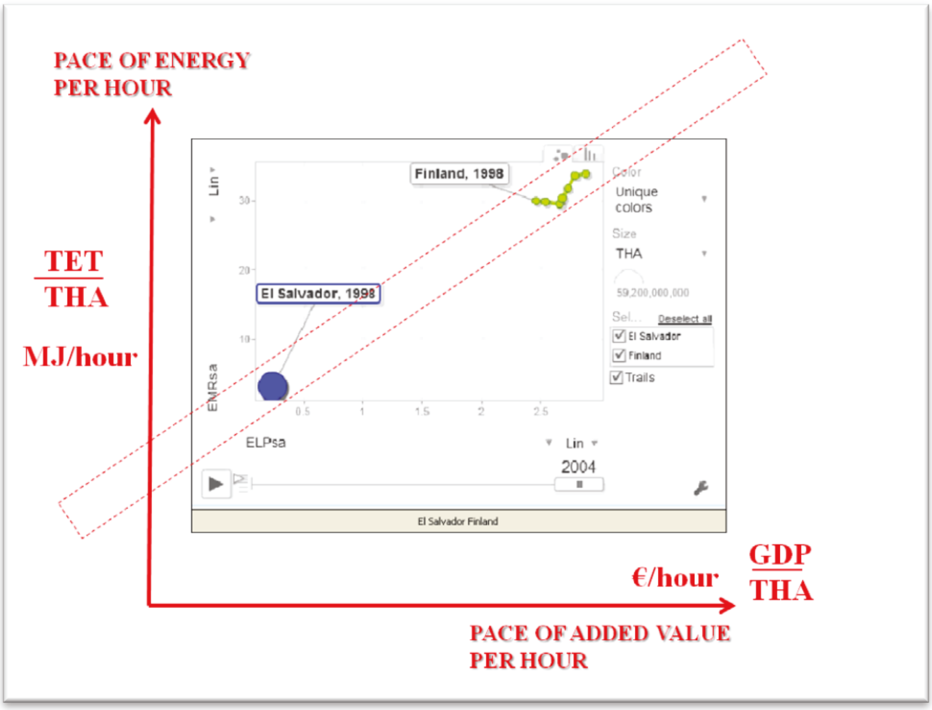
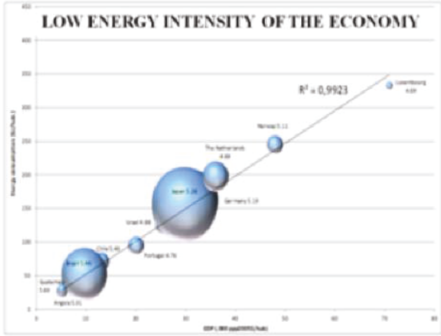
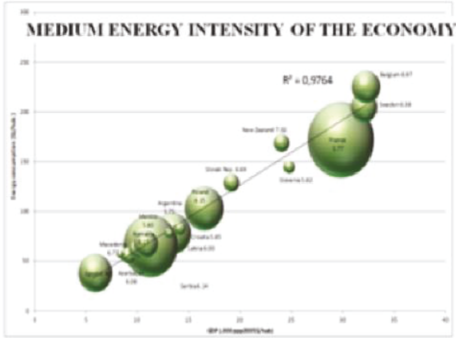


Fig.2 When describing the two ratios TET/THA and GDP/THA on a plane it is easy to see that the numerical values of the two ratios are correlated

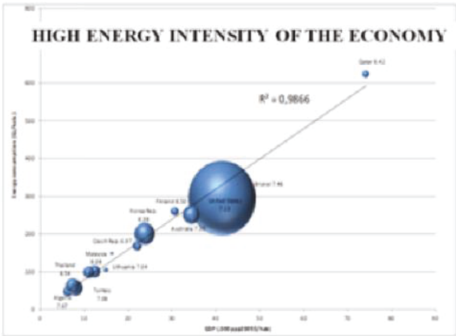
The information about the characteristics of the typology of countries is lost because it is well known that the level of primary energy consumption per capita (TET/THA) and the level of GDP per capita (GDP/THA) in modern societies are correlated. This fact is shown in Fig. 2 for the case of El Salvador and Finland (compared over a historic series: 1998-2004).
The same correlation is found when observing the relation over these two ratios across a significant sample of modern countries. This is illustrated in Fig. 3 (figures are taken from (Fiorito, 2013)).



Guatemala, Germany, The Netherlands, Angola, Norway, Chile



Macedonia, Sweden, Azerbajan, France, Egypt, Sweden, Argentina



Thailand, Australia, Algeria, Finland, United States, Malaysia, Turkey

Fig.3 Correlation between the two ratios TET/THA and GDP/THA in different clusters of countries (from (Fiorito, 2013))

This observation is extremely important considering that the vast majority of quantitative analysis studying the factors determining changes in the Economic Energy Intensity of modern economies is based on a comparison among countries of the ratio "*TET/THA"/"GDP/THA".* If the two variables are correlated this means that what are looked for are patterns to be found in an information space full of "white noise". Clearly differences in the value of economic energy intensity among countries are due to different factors (differences in the mix of primary energy sources, difference in the mix of economic activities generating the GDP and the fact that in poor countries a fraction of the energy is spent to produce and to consume goods and services outside the market and therefore not generating an equivalent quantity of GDP). However, the choice of using the proxy variable "TET/GDP" should be considered a poor judgment from a scientific point of view: these factors cannot be investigated when looking only at the value of this ratio.

Once again, it is important to remember that when dealing with complex systems requiring the simultaneous consideration of multiple dimensions of analysis – i.e. in this case an economic and a biophysical analysis – the rigor of the measurement scheme and the proper analytical treatment of data is only one part of the story. Equally important is to be sure that ***the data we are using do have meaning (a valid and relevant external referent) in the first place***.

Section 1.2 The limits of mono-dimensional accounting (1): The need of always considering both the internal and the external view in quantitative analysis

1.2.1 The concept of holon entails that a mono-dimensional accounting is impossible

An indicator can be used to define a state of a system. According to (Ashby, 1956, p. 25) a state "*is a well defined condition that can be recognized if it occurs again*". Therefore, we can say that a definition of a state is based on a given representation of the expected characteristics of a given typology realized by an instance. According to what said in Section 1.1 we can say that a state is an abstraction useful to represent a given perception of a state of affairs. In order to understand the systemic epistemological problem that indicators face when trying to represent states of complex self-organizing systems (e.g. the environmental pressure that a society is exerting on its environment) it is useful to introduce a key concept of hierarchy theory: the concept of Holon (and the derived concept of Holarchy). For this task, let's introduce an example of a familiar complex system organized across different scales: the heart operating within the human body. As illustrated in **Fig.4** we can imagine the human body as the whole system (seen at the level n), including inside its circulatory system (seen at the level n-1), that includes inside the heart. In turn the heart can be as a functional type (at the level n-2), that can be expressed by structural realizations of a pulsing hearts (at the level n-3). In this example we have two different structural types mapping onto the same functional type (a natural heart and a mechanical heart).
Using the overview provided by this figure we can make a distinction when referring to the system "human heart" between: (i) functional type, (ii) structural type, and (iii) individual realizations belonging to a given equivalence class of structural types (i.e. either natural heart or mechanical heart). Let's define more in details these terms:

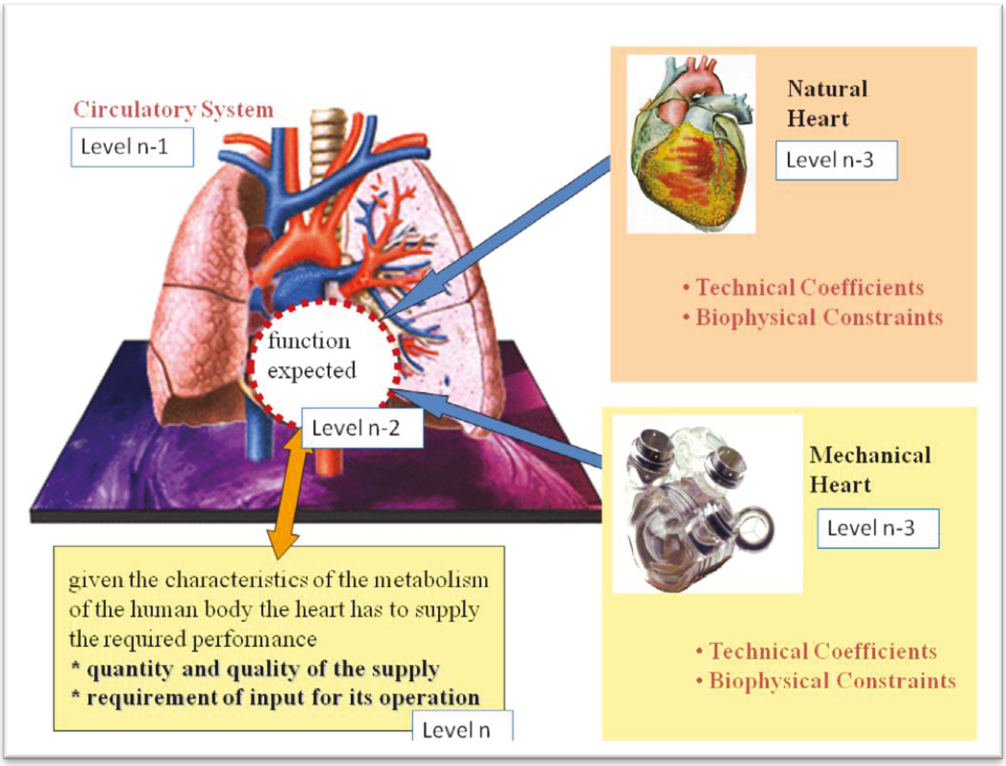


Fig. 4 A representation (abstraction) of organs within the human body

- *Functional type:* In the example of **Fig. 4** the functional type refers to the role of a pulsing heart that guarantees the circulation of blood in the human body. The definition of this functional type refers to the role played by this type (level n-2) in a structured context (the circulatory system – level n-1). The expected/expressed role must be beneficial for the larger system (the human body – at the level n) making it possible to reproduce both the functional system and the structure context. Therefore the functional type "heart" must result useful in relation to the interface "heart"/"circulatory system"/"human body". The definition of a functional type is meaningful in relation to the WHAT/WHY question (what is the function of a heart and why we need it).
- *Structural type:* In the example of **Fig. 4** there are two examples of structural types - artificial heart vs natural heart. Both structural types are mapping onto the same functional type. They both refer to specific types of organized structures making it possible to perform the role required by the functional type. The structural type defines the characteristics of an equivalence class of instances of that organized structure. That is, a structural type is defined by a TEMPLATE (which can be formalized in a blue print) both describing and making possible the combination of parts in a way that makes it possible to express the required pattern of organization. A structural type "heart" must result useful in relation to the interface "parts"/"heart"/"circulatory systems". The definition of a structural type is meaningful in relation to the WHAT/HOW question (what is the structure of a heart and how can we make it).
- *Individual realizations of a structural type:* In **Fig. 4** we can only provide representations (e.g. images) of actual entities pumping blood for real. Any given realization of either a natural or artificial heart - an organized structure fabricated according to a given blue-print which is mapping in terms of

structural organization onto the relative template – would represent an instance of this structural type. It should be noted however, that all individual realizations of structural types are special due to their specific history accumulating stochastic events. Therefore the characteristics of specific instances never coincide exactly with the expected characteristics of the type (instances of "apples" are all special!).

After introducing these examples it is possible to discuss the epistemologically tricky perception that humans have when studying complex systems organized in nested hierarchies: when observing complex self-organizing systems humans can only perceive "holon". This is the type of perception we get when studying ecological and social systems. The basic conceptualization of "Holon" has been explored by several authors. Herbert Simon (Simon, 1962) proposes that when dealing with complex systems organized in nested hierarchy one has always to use a combination of two concepts: "organized structure" and "relational function". (Bailey, 1990) proposes the same approach, but using different terms: "incumbent" and "role", for dealing with the organization of human societies. For example, the president of USA is a combination of the functional type – the US presidency – a structural type – a person born in America elected to the office – and an incumbent – Mister Obama, who is the particular realization of the structural type in office now. (Salthe, 1985) suggests a similar combination of descriptions based on yet another selection of terms: "individuals" (as equivalent of "realizations of organized structures" or "incumbents") and "types" (as equivalent of "relational functions" or "roles"). Finally, (Rosen, 2000, p. 361) proposes, within a more general theory of modeling relation, a more drastic distinction which gets back to the old Greek philosophical tradition. He suggests to make a distinction between: "individual realizations" (which are always "special" and which cannot be fully described by any scientific representation since any individual maps only imperfectly with the relative template, due to its unique history) and "essences" (associated with the semiotic characteristics of an equivalence class coupling a functional and a structural type). The logical similarity between the various couplets of terms is quite evident.

The common semantic message found in all these claims calls for the need of a simultaneous use of two complementing views for defining the elements (holons), which are making up ecological or social systems.

In relation to this predicament Arthur Koestler (Koestler, 1968, p. 365), (Koestler, 1969), (Koestler, 1978) proposed the metaphor of the holon. Holon is a term that has the double nature of "whole" and "part" of components of ecological or human systems which are able to express a valid identity both in functional and structural terms (for a discussion of the concept see also (Allen & Starr, 1982, pp. 8-16).

Holons must fit two typologies of constraints in terms of WHAT/WHY (large scale view for defining a relevant functional type) and WHAT/HOW (local scale view for defining a pertinent structural type). This is why Koestler selected the term holon, which is a combination of two Greek words: (1) the word HOLOS means the whole with constraints from the macroscopic view (external view); (2) the suffix ON means the part or particle (as in proton or neutron) with constraints from the microscopic view (internal view). Holons therefore can be considered as a sort of "*natural identities*" expressed by elements of ecological and human systems that humans must adopt in order to perceive and represent them. Holons entail two major epistemological problems:

#1 *the scale useful to perceive and represent "realizations of organized structures" is different from the scale useful to perceive and represent "functional relations"*.

An example of this impasse is illustrated in Fig. 5 showing the two different scales required to describe "why/what" of a clock (on the left) and the "what/how" of a clock (on the right).

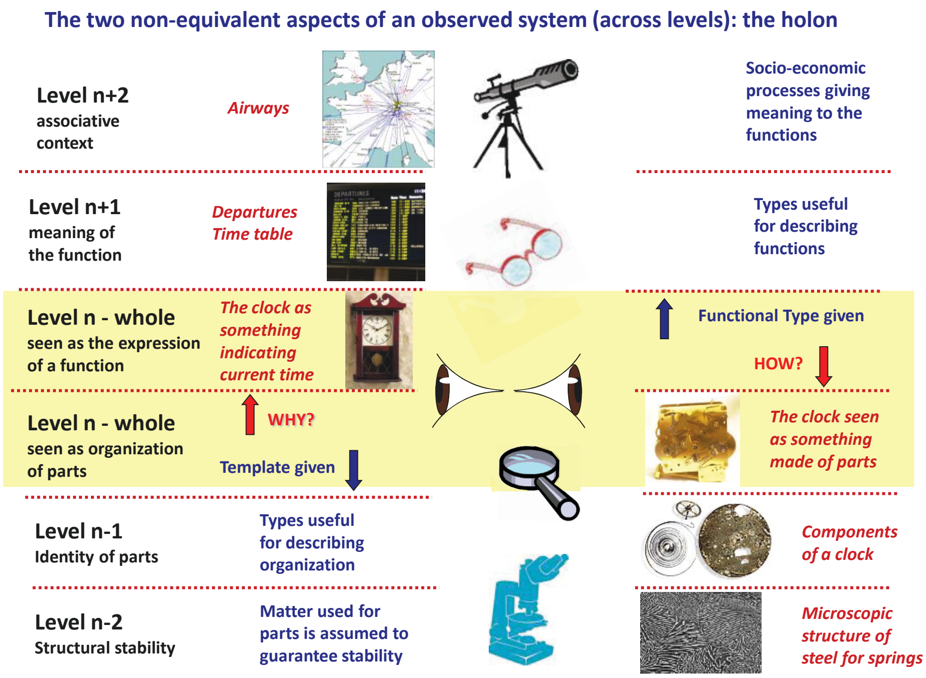


Fig. 5 The mismatch of scale when looking at the information relevant for WHAT/WHY and the WHAT/HOW in relation to a clock

#2 *When dealing with holons it is impossible to have a formal one to one mapping between "types of organized structures" and "types of functional relations". The universe of the possible coupling of structural and functional types is open and expanding*

An example of this impasse is illustrated in Fig. 6a and Fig. 6b that explore the different facets of a timepiece. The examples given in Fig. 6a illustrate having many different structural types (many HOWs) that map onto the same functional type (the same WHY). In this case, after defining the performance associated with a given role, we can learn how to increase the efficiency of structural types. That is, we example given in Fig. 6b, the structural type 'old mechanical clock' can become the structural type as 'object worth putting in a museum'. This new functional type is associated with the shared feeling of a society for the need to preserve records and a common memory of their process of learning how to keep time.

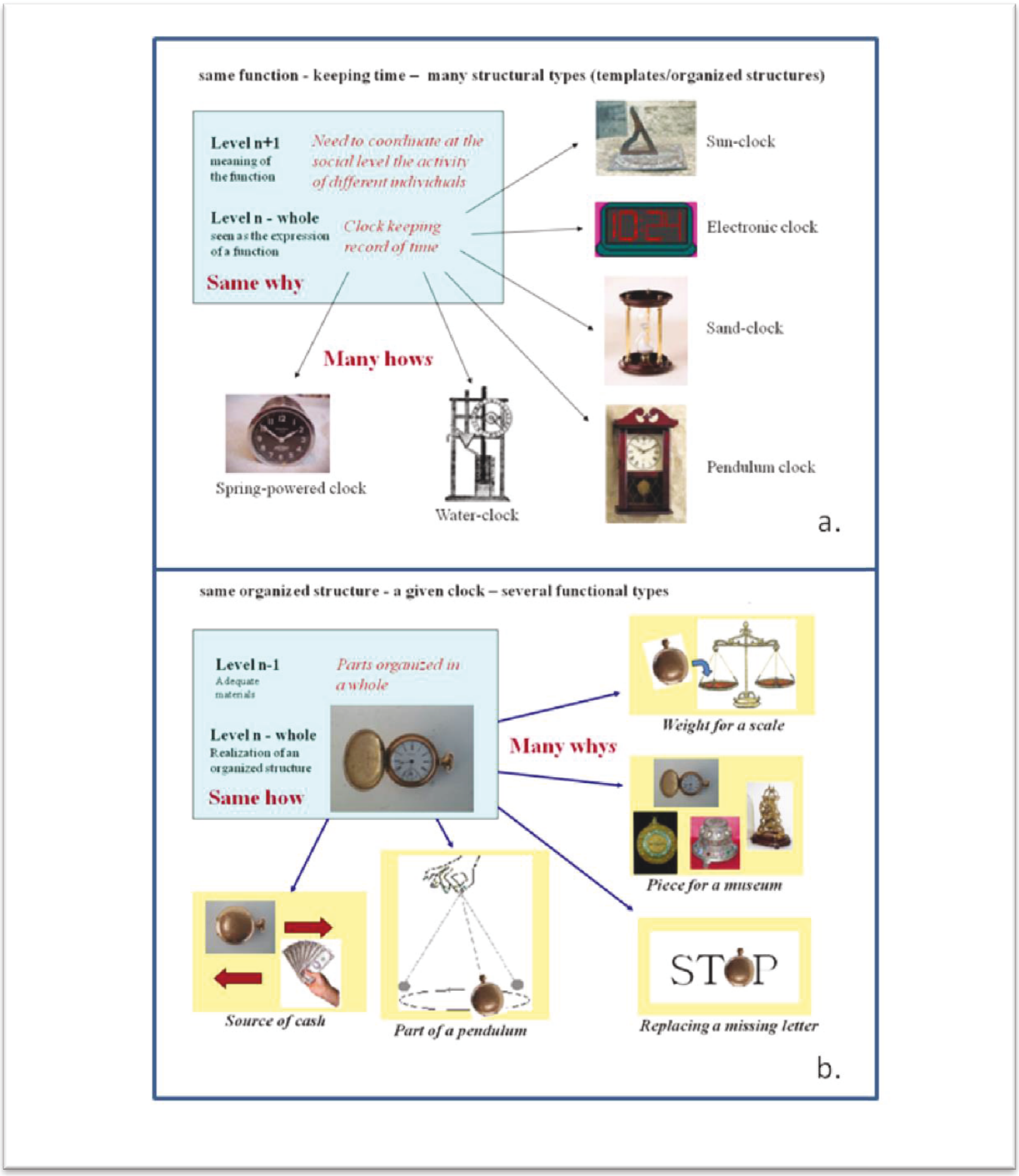


Fig. 6 Examples of multiple couplings of structural and functional types (from (Giampietro, et al., 2006))

This is an example of emergence, in which a new combination of structural organization, carried out by an individual realization, is coupled to a different associative context (a latent demand for new functions expressed by the system of knowledge in which meanings are created and preserved). In the new context a given realization of the old structural type generates new meaning, and therefore a different function for the organized structure in question.

When dealing with the evolution of Holarchies (a system made up of holons - (Koestler, 1969, p. 102)), we should expect a continuous loss of a one to one mapping between realization of structural types and functional types. More specifically:

(i) When we can assume as valid the definition of the functional type for the model, then we can have many structural types mapping onto the same functional type (many hows for the same why of a clock as in Fig. 6a). In this situation, the different performances of these different structural types can be compared. Here we are in the realm of design and efficiency.

(ii) When a sudden change in boundary conditions makes it possible, a given realization of a structural type can perform a function which is different from that for which that original structural type was originally fabricated. In this case, a new useful function can generate press for the introduction of a new natural identity (a new holon), associated with a new definition of role that has to be fulfilled. As illustrated in Fig. 6b, a virtually infinite universe of whys can be assigned to the same how, depending on the circumstances. This is the realm of emergence. ***Emergence by definition cannot be predicted from within models***. In fact it implies the assignment of a meaning to a function expressed by the modeled system that can only be perceived at a scale different from the one adopted by the model! This implies that when dealing with the analysis of the evolution of complex adaptive systems it is impossible to maintain over time a valid formalization based on the existing coupling of structural and functional types. In case of emergence, models not matter how complicated and sophisticated will become also useless (beside wrong). This is the realm of ignorance faced by modelers asked to deal with evolution and emergence.

1.2.2 Examples of terrible simplifications: the bifurcations in the accounting of food and energy consumption

In this section I present two self-explaining examples, whose implications are discussed in details in (Giampietro, et al., 2014).

- *Example #1 – the unavoidable bifurcation in the accounting of food flows within a given society.*

Let's imagine that we want to quantify the consumption of food in a given society. In order to achieve this result we have to decide first of all a proxy variable capable of characterizing quantities of food. For this reason we should use a numeraire (a basic standard expressed in a quantitative variable by which a value can be calculated) that makes it possible to measure and sum different items. For example in the case of food we can use as numeraire quantities of "food energy" to assess quantities of food. However, even if we manage to find in this way an equivalence class capable of measuring different items as belonging to the same categories (e.g. potatoes, beef and apples can all be expressed in kcal of food. To do that we have to use a combination of: (i) information referring to the internal view – $(kcal/kg)_i$ of food item *i*; and (ii) information referring to the external view – kg of food item *i*. The overall measurement in energy will be: $kcal_i = (kcal/kg)_i \times kg_i$. However, we still face the unavoidable bifurcation determined by the dual nature of holons. When measuring quantities of food we can use "food energy" in relation to two non-equivalent systems of accounting. We can refer to categories of food products (e.g. kg of potatoes), but they can also refer to categories of macronutrients (e.g. grams of carbohydrates). That is, we can measure quantities of food energy also in relation to grams of Carbohydrates, Proteins, and Fats. This bifurcation in the options for accounting can be explained easily with the double nature of the holons: (i) a food energy accounting based on potatoes, beef and apples refers to the external view (how to produce food items when interacting with the context); (ii) a food energy accounting based on carbohydrates, proteins and fats refers to the internal view (how food energy is distributed and used within the human body). The implications of this accounting are illustrated in Fig. 7. A given quantity of food energy (in this case 5.9 Peta Joules) assessing the final consumption of the people in the Mauritius Island can be measured in relation to two different types of accounting: (i) Primary Agricultural Products (in the external view) and (ii) macronutrients (in the internal view).

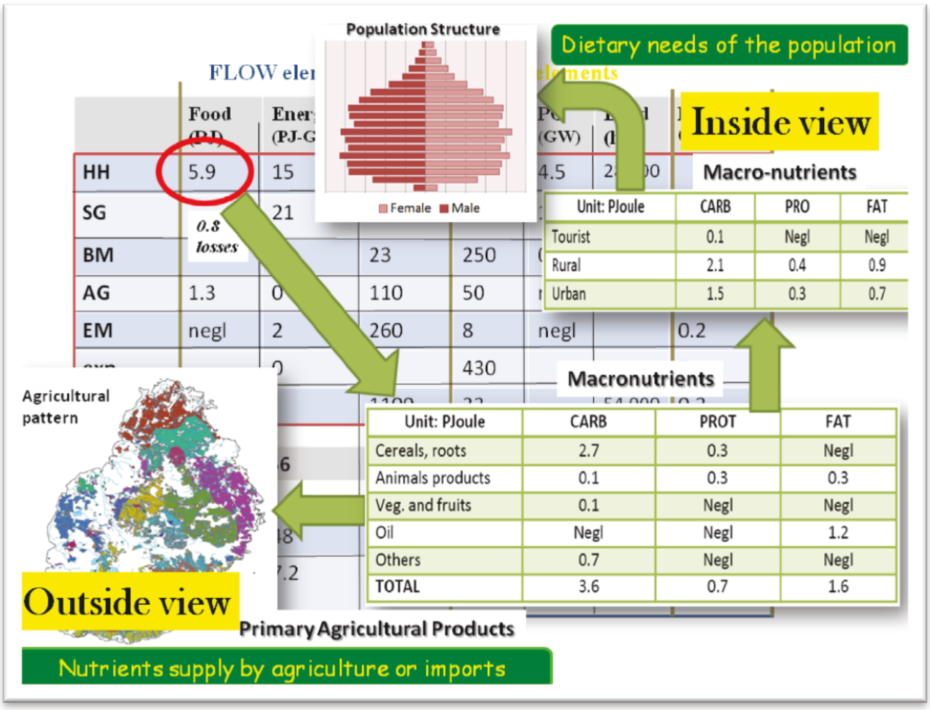


Fig. 7 The two possible quantifications of energy food flows within a society (from (Giampietro, et al., 2014))

Clearly both type of information is required. The external view is needed when looking for environmental constraints and socio-economic factors, studying the process of production of food. The internal view is needed when looking at the matching of dietary requirements and the actual supply of nutrients in the diet. A single number cannot provide the two non-equivalent types of information. It should be noted that the problem of a bifurcation in the quantitative analysis is not determined by the use of non-equivalent formal categories of accounting (e.g. kg of primary agricultural products vs grams of macronutrients), but it refers to the choice of semantic categories used in the accounting. To clarify this point, let us imagine to compare the consumption of food in China and in the USA using for this task a single proxy variable: "kg of grain" in the diet. That is, in this case we are using only a single formal category of accounting. If we do such an analysis we will find the same logical bifurcation as illustrated in Tab. 1.

Country	gross supply (food system)	net supply (final consumption)	ratio gross/net
USA	1,100	110	10
PR China	300	150	2

Data refer to the year 2009 and are expressed in kg per capita per year

Table 1 The bifurcation in the assessment of grain consumption in China and USA

In 2009 in the USA the per capita gross grain consumption (1,100kg of grain per capita) was almost three times that of China (300kg of grain per capita), but this relation is no longer found when comparing the final domestic consumption. Then, per capita net grain consumption is higher in China (150kg of grain per capita) than in the USA (100kg of grain per capita). The difference between the direct consumption at the household level (internal view) and the gross domestic supply of grain from the agricultural sector (external view) is "eaten" by the huge internal loop of the US food system using grain mainly to feed animal and to make alcoholic beverages.
Obviously, if one is not aware of the different meaning of the different assessments it is easy to make contrasting statements all based on sound scientific information. In fact, using this data set we can say that Chinese people consume more grain p.c. than US citizens (in their direct diet), but also that US citizens consumed much more grain p.c. than Chinese (when including the indirect consumption associated with their diet).

- *Example #2 – the unavoidable bifurcation in the accounting of energy flows within a society*

The same conceptual problem is found when looking at energy flows in a country. What is illustrated in Fig.8 is the accounting of energy flows in Spain (2007) showing the flow of energy from Primary Energy Sources (on the left of the figure) to the End Uses in the various compartments of the society (on the right of the figure). In the middle of the figure we have the interface between the two views represented by the flows of Energy Carriers (fuels, electricity and process heat) used by the society. Due to the bifurcation discussed early we can look at a quantification of the flows of Energy Carriers from the two sides: (i) the external view sees the energy carriers from the outside (as in the case of agricultural products in food accounting), the Primary Energy Sources getting in their production. This is the interface that the society has with its context; (ii) the internal view sees energy carriers from the inside (as in the case of macronutrients in food accounting). How much energy is given by the carriers.

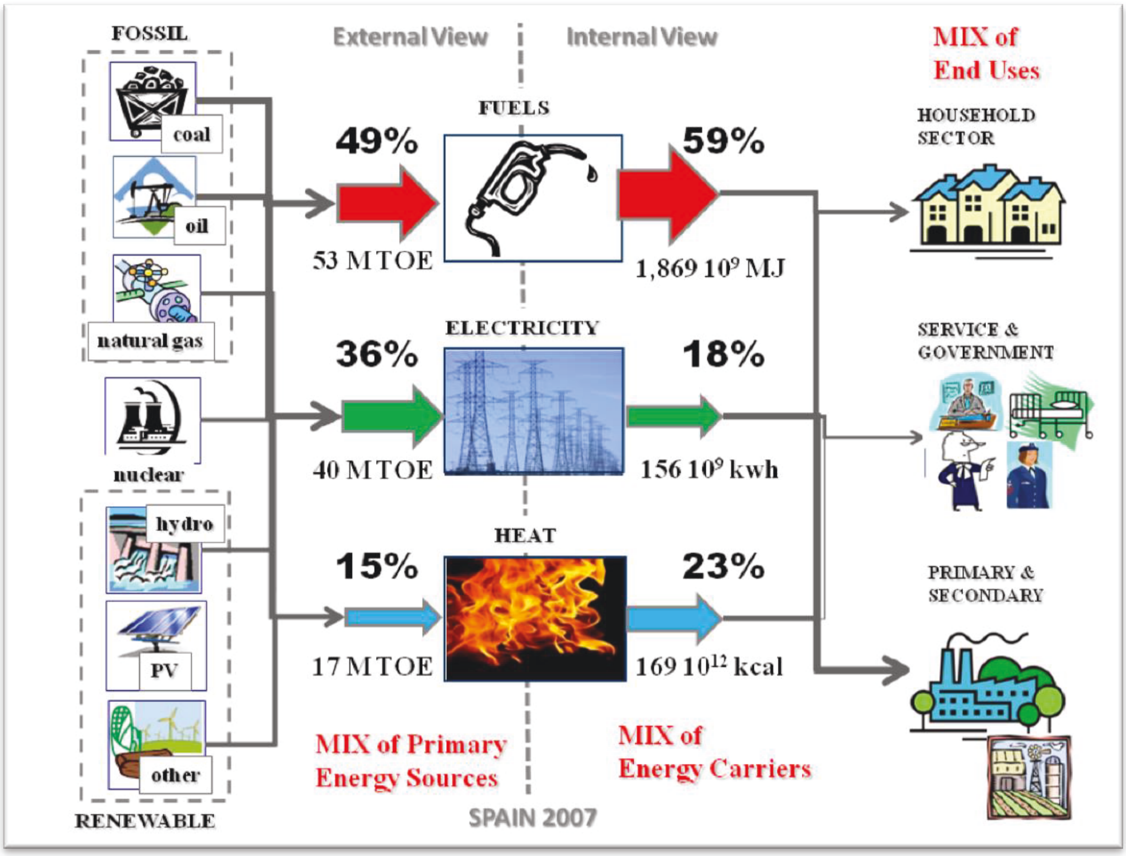


Fig. 8 Example of the bifurcation of energy accounting within a country (from (Giampietro & Sorman, 2012))

For this reason, the accounting of electricity results different in the two views: in the external view it refers to "how much energy is required to make one unit of electricity", in the internal view it refers to "how much electricity is consumed in the final use". This explains the bifurcation in the quantitative assessment shown in Fig. 8: when measuring flows in quantities of energy referring to primary energy sources (e.g. Joules of Tons of Oil Equivalent) we have that electricity uses 36% of the total flow of energy. When measuring flows in quantities of energy referring to energy carriers (how much energy is actually getting into my refrigerator) the flow of kWh of electricity compared with the flow of Joules in the fuels and the flow of process heat used by society is only 18% of the quantity of energy (measured in Joules) provided in the form of energy carriers. According to this fact, we should conclude that it is impossible to characterize the energy consumption of a country using a single system of accounting. On the other hand, statistical offices seem not to be aware of this problem since they generate overviews of the type indicated in Fig. 8 but using only a single set of quantitative assessment across the whole graph. This choice has serious negative consequences on the usefulness of the assessment. Not only a single number characterization is conceptually wrong, but it is also useless. In fact, the possible solutions to the epistemological dilemma are: (i) calculate everything in terms of Primary Energy Source equivalent (as done by the Energy Information Administration and the BP statistics). However, with this choice, we cannot know the actual flows of electricity getting into the final "end uses"; (ii) calculate an overall index based on a set of equivalence factors for electricity produced in different ways (as done by Eurostat and the International Energy Agency). In this case, we do not get information neither on the

amount of primary energy source required by society or the amount of energy carriers used for "end uses". In fact, the quantitative assessment obtained in this way will depend on the mix of Primary Energy Sources, the mix of use of energy carriers and the choices made by the analysts when choosing arbitrary accounting factors ((Giampietro & Sorman, 2012)).
The consequences of such a terrible simplification used by statistical offices can be appreciated by looking at the resulting bifurcation of the quantitative assessments referring to a given country with a given set of energy flows determined by a given mix of Primary Energy Sources and a given mix of Energy Carriers.

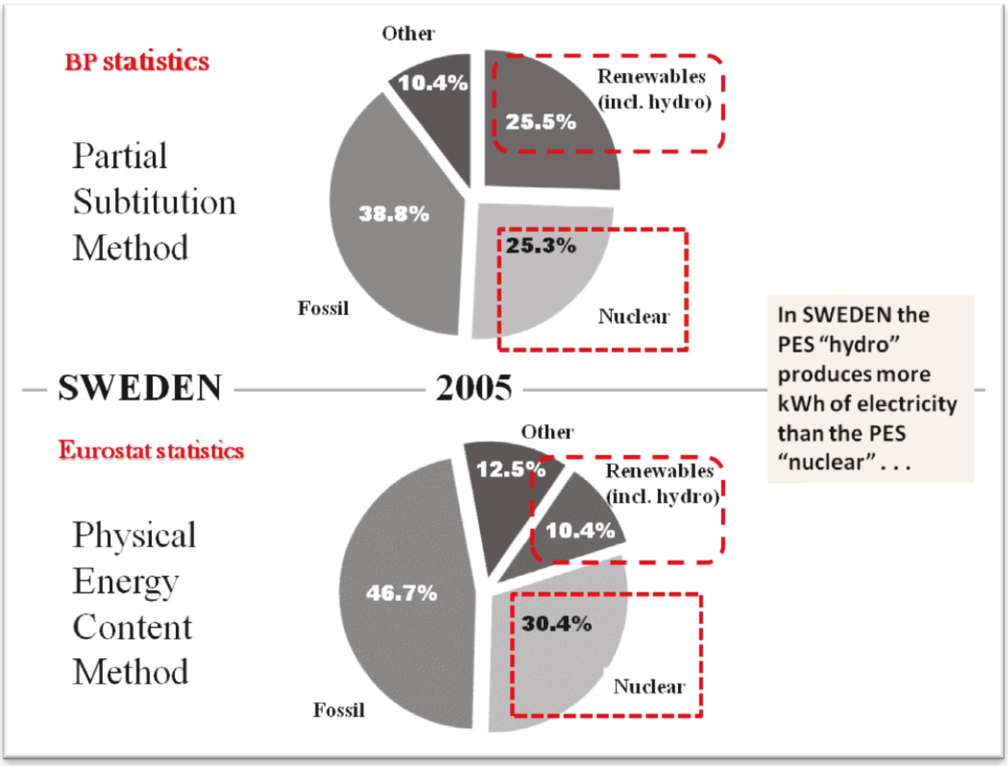


Fig. 9 Examples of two different assessments of energy use given by two different sources of energy statistics for the same country (from (Giampietro & Sorman, 2012))

The example given in Fig.9 shows the co-existence of non-equivalent assessments obtained when adopting the two different methods of accounting to the energy analysis of Sweden. In Sweden, in 2005 the two Primary Energy Sources: "Hydroelectric power" and "Nuclear Power" produced more or less the same amount of electricity. However, in the accounting of BP statistics the assessment is done in terms of Joules of Primary Energy equivalent (even though the quantity of electricity actually used in Sweden is much less than the 25% - see the explanation in Fig. 8). In the accounting of Eurostat for the same country in the same year, Nuclear Power is described as producing 3 times more electricity than Hydroelectric (because of a generous conversion factor assigned to Nuclear Power). In this case, this assessment does not coincide neither with the actual flow of electricity consumed in Sweden or an estimate of Primary Energy Source requirement. Looking at this example one can only wonder whether it would be more sensitive to develop a method of accounting keeping separated the two non-equivalent categories – "primary energy sources" on one side and "energy carriers" on the other! This accounting is possible (Giampietro, et al., 2013), (Giampietro, et al., 2014) and it would provide a much more effective quantitative representation of energy flows in modern societies.

Section 1.3 The limits of mono-dimensional accounting (2): The need of always using an integrated set of assessments referring to multiple scales

1.3.1 Intensive and extensive variables: addressing the heterogeneity of systems across scales

Let's start this section with an example taken from (Giampietro, et al., 2012). Nobody would believe that Leo Messi – one of the most famous professional soccer players - could maintain his top performance, if he would start eating consistently only half the usual amount of food, inhaling consistently only half the amount of oxygen, and/or producing consistently only half the usual amount of urine, faeces and CO_2 exhaled. This scepticism derives from our solid or sometimes intuitive knowledge of the energy metabolism of the human body. Indeed, scientists have established the expected (i.e., typical) size and metabolic rate for various organs making up a human being. For instance, an average adult liver weights 1.8 kg (size) and consumes 9.7 W/kg of energy (metabolic rate per unit of size), an average adult brain weights 1.4 kg (size) and consumes 11.6 W/kg of energy (metabolic rate per unit of size), and an average heart weights 0.3 kg (size) and consumes 21.3 W/kg (metabolic rate per unit of size). Therefore, whenever the size of the various organs considered (such as skin, bones, and skeletal muscles) equals the total body size we can establish a relation between what is consumed by the whole human body and the combination of: (i) characteristics of the typology of organ (metabolic rate per unit of size); and (ii) relative size of the various organs – Fig. 10. We have sufficient information about the relation between the organized structures and relative functions within the human body to assess pretty accurately the food energy requirement (and associated material flows) for carrying out a specified set of physical activities while maintaining the original body weight and composition. Thanks to this knowledge, we know that nobody would even think about consistently cutting the food energy intake of Leo Messi or other professional soccer players by half.

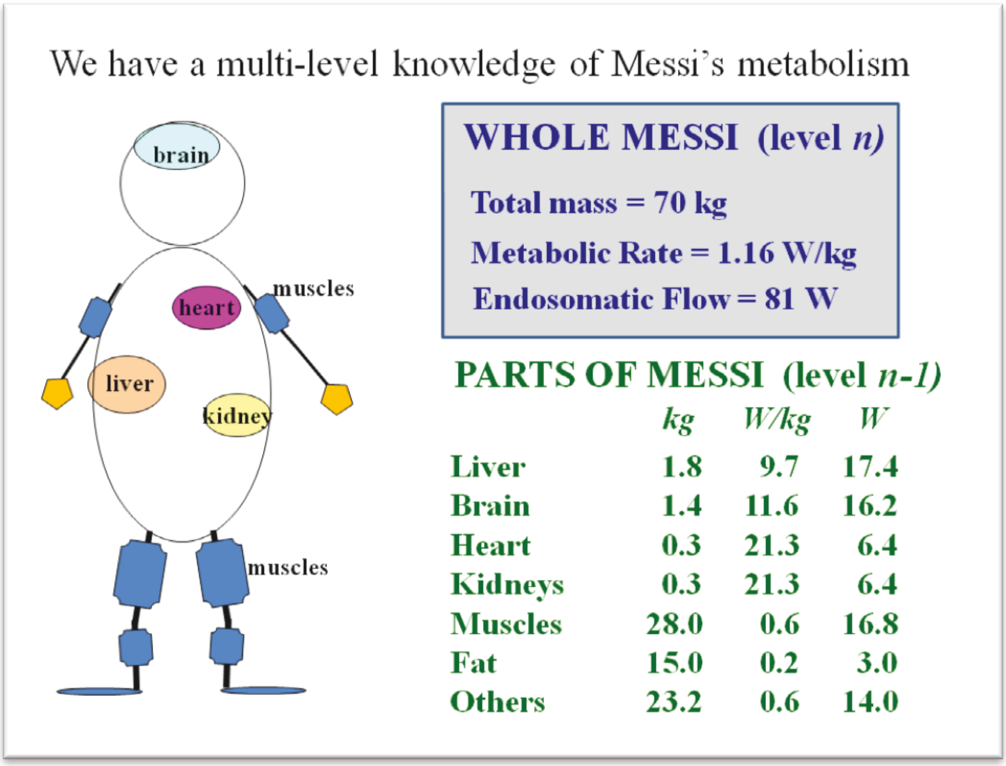


Fig. 10 The multi-level analysis of the metabolism of Messi

However, strangely enough, nobody seems to object to the ambitious targets for reductions in CO_2 emission launched at international conferences on Climate Change. In the 2009 Copenhagen Climate Summit, proposals have been put forward to reduce the CO_2 emissions of industrialized countries by 50 per cent, 70 per cent, and even 80 per cent within a time frame of only a few decades. By the serious worldwide attention that this conference drew, we have to conclude that at present there exists generalized consensus on the idea that altering the metabolic pattern of complex socio-economic systems is far easier than changing the metabolic pattern of professional soccer players. This fact clearly indicates the relevance of this discussion for a sound generation of indicators of environmental impact that can be integrated with indicators of the proper functioning of socio-economic systems. This is particularly important if we want to study possible options of reduction of CO_2 emission and viable path to a low carbon economy. Using the metaphor of the metabolism of Messi an informed discussion about de-carbonization of modern society should be organized over the following questions: What are the organs of the society that are consuming more? What is determining the consumption of input or emissions of the various organs: their size or rather their throughput per unit of size? Can we guarantee the same functions expressed right now for the society if we either reduce the size of the organ or reduce the throughput of energy (and other materials) per unit of size? Without generating analytical models and indicators capable of making it possible to study separately these different factors it is very unlikely to obtain a good problem structuring, let alone the selection of appropriate policies. The same predicament applies to the comparison made across different countries. Again using the metaphor of the metabolic pattern of the human body we can illustrate the problem of a comparison of the biophysical functioning of different typologies of socio-economic systems just at the level of the whole society – at just one level of analysis. This illustration is given in Fig. 11.

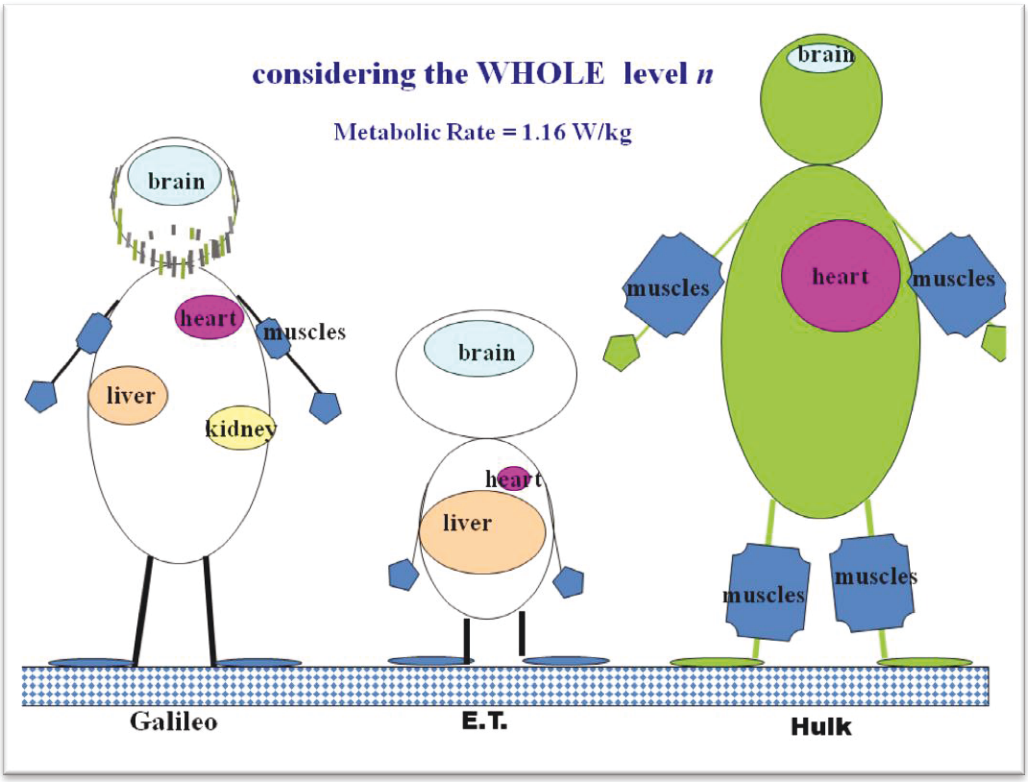


Fig. 11 Same characteristics of the whole, different characteristics of the parts

In this figure it is clear that if we use just a single indicator – the level of energy throughput per kg of body mass (but this could also be an indicator of CO_2 emissions per capita per year) – applied to a given hierarchical level – the whole body, or the whole country – we risk to miss important differences – and end up by mixing "apples" and "oranges". In our hypothetical example, a different combination of relative size of muscles, heart, brain and liver can generate the same overall Metabolic Rate for typologies of human bodies completely different!

Before closing this section I would like to add another example of the importance of developing indicators across different levels of analysis and scales, this time referring to a spatial analysis. Let's imagine that we want to compare national characteristics of Canada with the characteristics of the USA in terms of density of population, for studying the impact of domestic sewage. In order to calculate a measure of density of population should we divide the population by the total area of Canada? By doing so we would get a value that again does not have an external referent in relation to the issue of domestic sewage, since the vast majority of Canadian land is not inhabited! In this case it would be better to study the density of metropolitan areas (less than 4% of the total area of Canada hosting more than 85% of the population). By doing so, not only we discover that the residential density in Canada is not very different from the value found in residential areas in USA but also that the environmental load due to residential sewage is affecting only specific areas of the country.

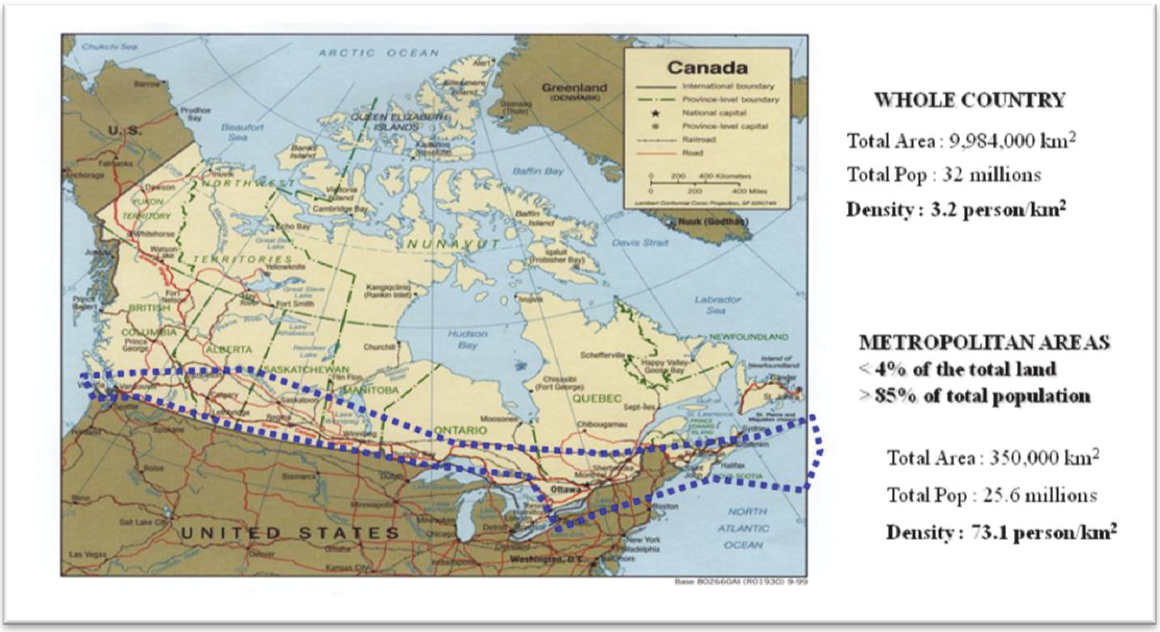


Fig. 12 Deciding the hierarchical level of analysis for an indicator of the density of residential population in Canada

1.3.2 Intensive and extensive variables: a theoretical definition

The distinction between intensive and extensive properties (variables) was introduced by Richard Tolman in the field of thermodynamics and materials science. This distinction is exactly related to the difference of the two types of information about observed systems discussed in Section 1.1.

- ***An extensive property*** refers to a quantitative assessment of an observed system useful to quantify the size of a system in relation to its context (e.g. the mass, the volume, the length). A variable used to measure an extensive property - an ***Extensive variable*** - is additive. More specifically, in natural science, a variable is said to be extensive if its values depend on the "quantity" of the property under study.
- ***An intensive property*** refers to a quantitative assessment of an observed system useful to quantify a relevant quality of the system in relation to its internal nature. This assessment if per unit of size (e.g. the temperature, the pressure). A variable used to measure an intensive property - an ***Intensive variable*** is non-additive. The variable can be used to characterize a qualitative aspect of the system only if the property is homogeneously expressed over the whole system. More specifically, in natural science, an intensive variable is independent of the quantity of material present.

When coming to the discussion of indicators to be used to describe environmental pressure and environmental impact determined by the interaction of human societies and ecological systems, it is possible to operationalize the concept of intensive and extensive variables using the flow-fund model developed by (Georgescu-Roegen, 1971) – for a detailed explanation see (Giampietro, et al., 2014).

In the conceptualization provided by Georgescu-Roegen both socio-economic systems and ecosystems can be seen as self-organizing systems reproducing themselves. That is, according to Georgescu-Roegen ***the economy does not produce goods and services (flows) but rather "reproduce the fund elements required to both produce and consume goods and services"*** (happy people, technical capital, managed land). In his view the epistemological problem of scaling described in Section 1.1 can be solved by introducing a distinction between "fund elements" – what the socio-economic system is made of – and "flow elements" – the flows required for reproducing the fund elements. In this framework we can consider *People* (human activity), *Technology* (technical converters), *Land Uses* (managed land) as the set of funds that can be used to characterize the size of a socio-economic system. Flows are those elements that either appear or disappear in the duration of the analysis – e.g. food, energy, water, other materials plus monetary flows. The stabilization of these flows is required for the reproduction and maintenance of the fund elements. Therefore, fund-elements describe "what the society is" and can be considered as extensive properties of the society. The flow-elements describe "what the society does" when interacting with its environment.

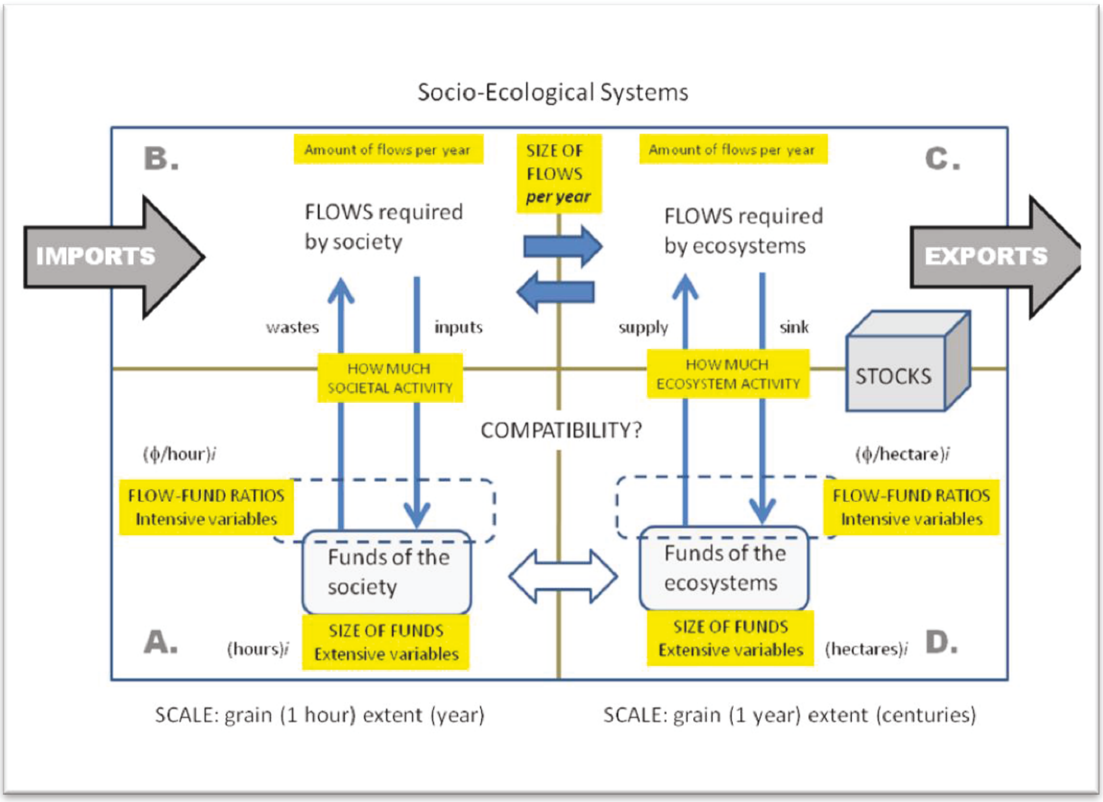


Fig. 13 An overview of the different types of information required to study the impact of human activity on the environment (after (Madrid & Giampietro, 2014))

The flow-fund model can be used to measure the pressure that the society exerts on the environment, but also to study the external constraints that the environment place on societal activity (when addressing the issue of sustainability). When adopting this framework we can define qualitative characteristics of the various compartments of the societies as intensive properties that can be measured by typical flow-fund ratios (the required amount of drinking water per day, the rate of energy consumption per capita per year, the GDP per capita).
Within this framework it becomes evident that an integrated use of intensive and extensive variables is required in order to describe the interaction of socio-economic

systems and ecological systems (what have been called Socio-Ecological Systems – (Berkes & Folke, 1998)). An overview of the relevant information required to characterize these systems is given in Fig. 13.

❖ Quadrant (A.) deals with the metabolic pattern of societies, it shows the flows of matter and energy required by a society (when considering both inputs to be supplied and wastes to be absorbed). These flows should be expressed as given quantities per year – throughputs – in relation to a supply side (inputs) and a sink side (outputs). The size of these throughputs is determined by a combination of two pieces of information: (i) intensive properties of the relevant typology of society (the metabolic characteristics of the society such as "output/input of flows" and "flow/fund ratios" such as flow rate (per hour) – e.g. a developed country; (ii) extensive properties referring to the size of fund elements of the specific instance – e.g. the size of the USA and the size of its lower level components (the parts making up the whole). Therefore the throughput associated with any given *fund element i* (either the parts or the whole) can be written as:

$$Throughput_i = (fund\ size)_i \times (metabolic\ characteristics\ of\ the\ fund)_i$$

This method of accounting has been already presented when discussing the bifurcation of accounting for food energy in Section 1.2.2:

* *Food flow* ($kcal_i$)*= food product size* (kg_i) *x food product characteristics* $(kcal/kg)_i$

and in the example of the metabolic pattern of Messi (Fig. 10, in Section 1.3.1):

* *Liver throughput (17.4 W) = liver size (1.8 kg) x metabolic characteristics (9.7 W/kg)*

In this way, when dealing with systems organized in holarchies (nested hierarchical levels) it becomes possible to use triplets of quantitative assessments – (i) $throughput_i$; (ii) fund*i* size; and (iii) fund*i* metabolic characteristics – to characterize a given component at a given level – e.g. level n – and to link this information to the information referring to lower level metabolic elements – e.g. at level n-1 – described using the same triplet of quantitative assessments.

❖ Quadrant (B.) deals with the metabolic pattern of ecosystems, it shows the flows of matter and energy required by an ecosystem (when considering both inputs to be supplied and wastes to be absorbed). These flows should be expressed as given quantities per year – throughputs – in relation to a supply side (inputs) and a sink side (outputs). Theoretical ecology has clearly shown that it is possible to define expected metabolic patterns for typologies of ecosystems (Lomas & Giampietro, 2014). A quantitative characterization can be obtained by combining two pieces of information: (i) intensive properties of the relevant typology of ecosystem. That is the metabolic characteristics of functional compartments – e.g. autotrophs, herbivores, carnivores, detritus feeders – "output/input of flows" and "flow/fund ratios" such as flow rate (per kg of biomass) or flow density (per hectare) – e.g. a tropical forest; (ii) extensive properties referring to the size of the specific instance – e.g. the size of the forest under investigation, the amount of biomass available in a given area.

The overview given in Fig. 13 makes it possible to detect a glaring issue of scale to be addressed in this type of integrated analysis: the scale used to generate the quantitative information in the quadrant (A) – with a dt of a hour and a duration T of a year – is different from the scale used to generate the quantitative information in the quadrant (D) – with a dτ of a year and a duration Θ of centuries (at least) – more on this in (Madrid, et al., 2013), (Giampietro, et al., 2014).

Two additional complications have to be added to this analysis (for more on this point see (Giampietro, et al., 2014)):

(1) when considering the flows metabolized by a given socio-economic system it is important to make a distinction between: (i) domestic metabolic flows - those flows used by funds that are produced and dumped in the local ecosystems; (ii) externalized metabolic flows – those flows used by funds that are imported or exported to distant societies or distant ecosystems;

(2) in case of mismatch between the throughput associated with societal metabolism and the throughput associated with ecosystem metabolism society stabilize its throughputs by depleting stocks (e.g. use of non renewable resources) or filling of stocks (e.g. accumulation of pollutant in the environment).

This theoretical discussion over set of relations described in Fig. 13 is important to explain the logic and the difficulties in the quantitative implementation of the DPSIR framework (discussed in the next section) and it will be used in Part 2 to structure the comments on the two documents revised in this study.

1.3.3 The DPSIR framework

The DPSIR framework is a conceptual approach that individuates causal relations in the interactions between society and the environment in time. This framework developed in the 90s (OECD) is now used by many organizations dealing with environmental protection (e.g. UNEP, EEA). A reference to the DPSIR framework is found in the theoretical introduction of both documents considered in my study [the Environmental Pressure Index, developed with Yale and Columbia University, and composite indicator for monitoring Environmental Pressure in the EU at the national level (G03 collaboration with Environment Directorate-General)]. However, the implications of this conceptual framework are not addressed, later on, when explaining the methodological choices made for the generation of the composite indicator. In this section I want to briefly illustrate the implications of the set of relations described in Fig. 13 for those willing to use the DPSIR framework for the development of an integrated set of indicators. The acronym o DPSIR stands for: (i) Driving Forces; (ii) Pressures; (iii) State; (iv) Impacts; (v) Response.

(i) Driving Forces – are factors determining changes in the set of arrows described in Fig. 13. In general these drivers are referring to changes taking place in the quadrant (A) – in the terms of the size of fund elements – e.g. demographic increase (increase in the size of the population); and in terms of changes in the flow/fund ratios – e.g. economic development determining changes in life styles (increase in the metabolic rate). In current applications only the drivers referring to human metabolism are considered (probably the scale of the drivers affecting ecosystem metabolism is too large . . .);

(ii) Pressures - changes determined by drivers result in an increase in the level of societal activity - Fig. 13 quadrants (A) and (B) – that is a larger throughput of material and energy flows taken from and dumped into the environment. When the arrow indicating the quantity of flows consumed by society is larger than the arrow of supply generated by ecological processes this mismatch will generate a pressure on the supply side. When the arrow indicating the quantity of flows discharged by society is larger than the arrow of sink capacity generated by ecological processes this mismatch will generate a pressure on the sink side. This pressure can be assessed looking at the arrows in the two quadrants (B) and (C). In fact: (i) the information found in the quadrant (B) defines the boundary conditions required by the society expressing a given metabolic pattern (the amount of required inputs and the amount of sink capacity to absorb the wastes); (ii) the information found in the quadrant (C) defines the boundary conditions required by the ecosystem expressing a given metabolic pattern. The net effect of trade (imports and exports) certainly complicates this assessment.

(iii) States - in order to be able to define the *Impacts* that the *Pressures* are generating on the ecosystem it is important to know what is the State (or better the "expected state") of the ecosystem. This information "depends on" and "refers to" the given typology of ecosystem considered. This information can be obtained from the two quadrants (C) and (D). In relation to this task, theoretical ecology has developed a robust theory making it possible to predict and to characterize in quantitative terms "expected states" of different typologies of ecosystems (marine and terrestrial) – e.g. (Allen & Hoekstra, 1992); (Margalef, 1968); (Odum, 1969); (Odum, 1971); (Odum, 1971); (Ulanowicz, 1986); (Ulanowicz, 1997). An example of expected patterns associated with states of ecosystem is given in Fig. 14.

It should be noted that when adopting a characterization of the interaction "human societies – ecosystems" based on the analysis of their metabolic pattern (as shown in Fig. 13), it becomes possible not only to define "states" for ecosystems, but also for socio-economic systems. Examples of analysis of metabolic patterns of societies are given in Fig. 20 and Fig. 2. These expected patterns should be considered as representations of the integrated set of flow/fund ratios and fund sizes described in the quadrant (D) in Fig. 13.

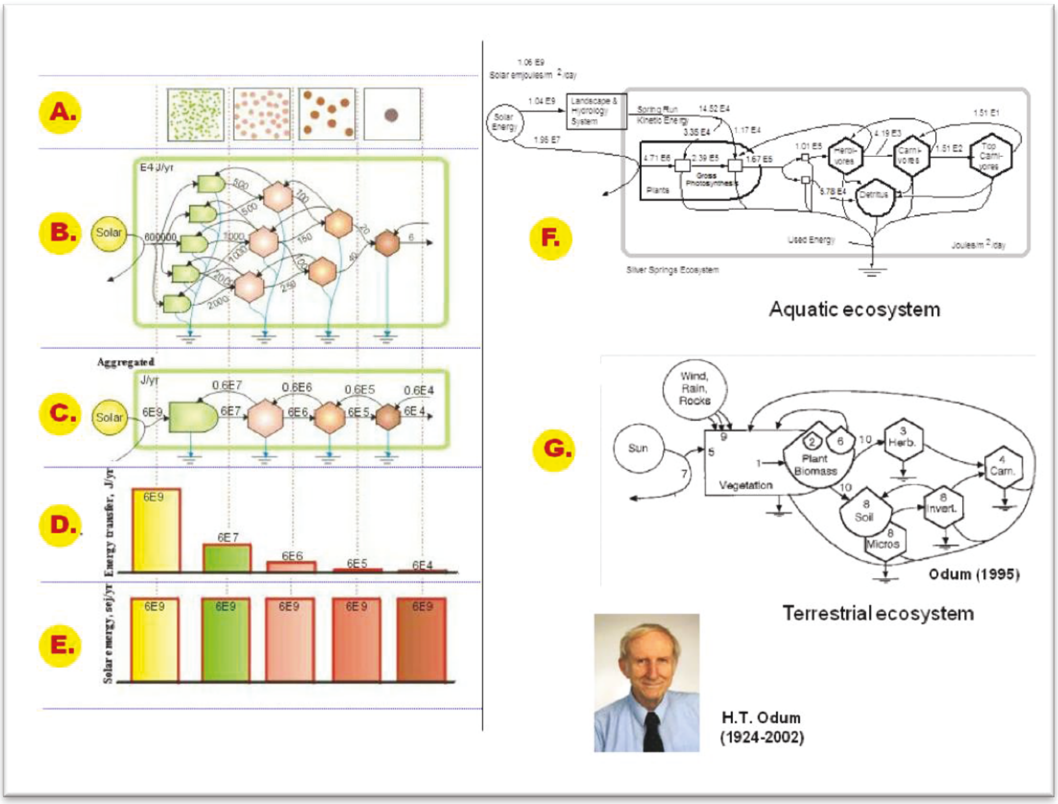


Fig. 14 Examples of expected pattern associated with the metabolic pattern of ecosystems.

In conclusion, when analyzing a Socio-Ecological complex it is possible to define: (i) states for a societal metabolic patterns looking at the information in the two quadrants (A) and (B) – (Giampietro, et al., 2012), (Giampietro, et al., 2013), (Giampietro, et al., 2014); and (ii) states for a ecological metabolic patterns looking at the information in the two quadrants (C) and (D).

(iv) Impacts – the definition of expected states for known typologies of ecosystems, that can be quantified using expected values of flow/fund ratios calculated for specific elements (nitrogen flow per hectare in a given type of agro-ecosystem, concentration of substances in a given stream of water, standing biomass per hectare in a given typology of terrestrial ecosystem) makes it possible to study the impact that human activity has on the embedding ecosystems. An analysis of impact can be obtained by looking at the level of alteration of an ecosystem (its actual state) compared with the original state referring to the known typology. This alteration is reflected in changes in: (i) the value of flow/fund ratios compared against expected benchmarks (pollution for an excessive inflow, or depletion for an excessive extraction); or (ii) the relative size of funds (deforestation, elimination of wetland, overdraft from water bodies). An example of this type of analysis is shown in Fig. 15.

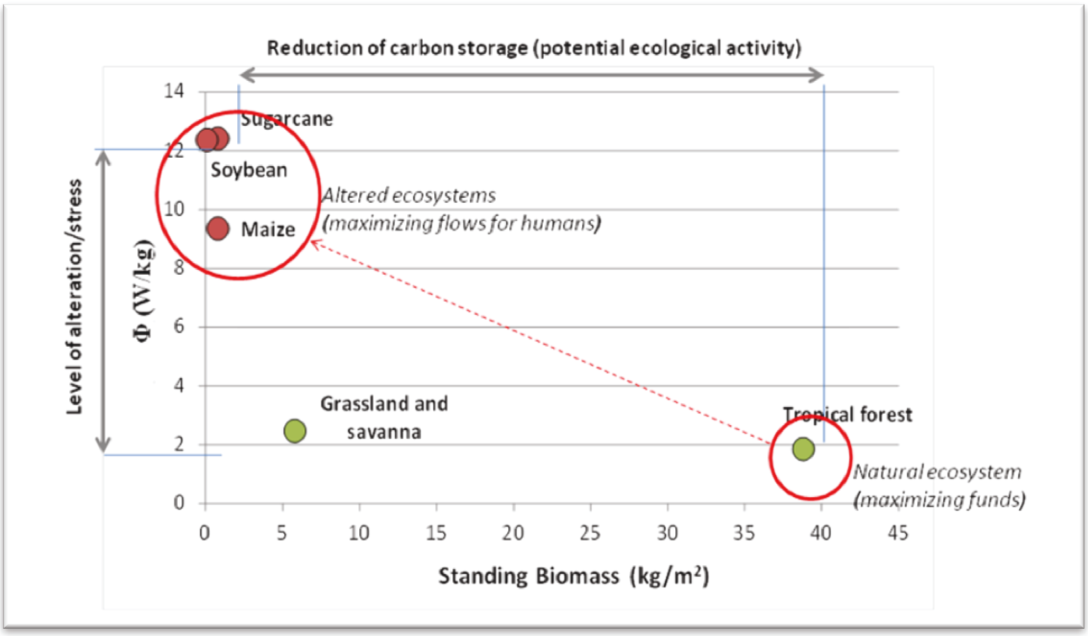


Fig. 15 Examples of analysis of the impact due to the alteration of the original state for terrestrial ecosystem (Lomas & Giampietro, 2014).

(v) Response – the concept of response introduce a semantic attribute quite different from the previous ones. An analysis of response is not about a description of either a state or a pressure or an impact. Rather it is a description of the results of an action (considering the different pieces of information given in Fig. 13) that is obtained by comparing a given situation at two different points in time. That is, an analysis of "response" can only be obtained by looking at a given situation described using the scheme illustrated in Fig. 13: (i) at time "t", when a given undesirable situation is detected; and (ii) at time "t+1", after an action has been taken to fix the problem to check the results. In the case of the Environmental Pressure Index, developed with Yale and Columbia University, indicators of response are included in the composite indicator. However, including this attribute of performance in the integrated set of indicators introduces in the logic of the assessment a different criterion. The assessment is no longer limited to environmental pressure (an analysis of the situation of the socio-ecological system described in Fig. 13), but it refers to the "quality" of the action taken by human agents. What is observed is not in the information space illustrated in Fig. 13. For this reason its inclusion in the composite indicator generates a clear logical problem of aggregation in relation to the pre-analytical decisions in both normative and descriptive terms. This issue will be discussed in Section 1.4

Before closing this section it is important to illustrate the relevance of the theoretical discussion carried out so far for the implementation of the DPSIR framework in practical applications. In fact, the DPSIR framework is generally proposed as a conceptual procedure useful to structure and organize information in practical projects. However, so far, a coherent quantitative framework to be adopted for this task is still lacking.

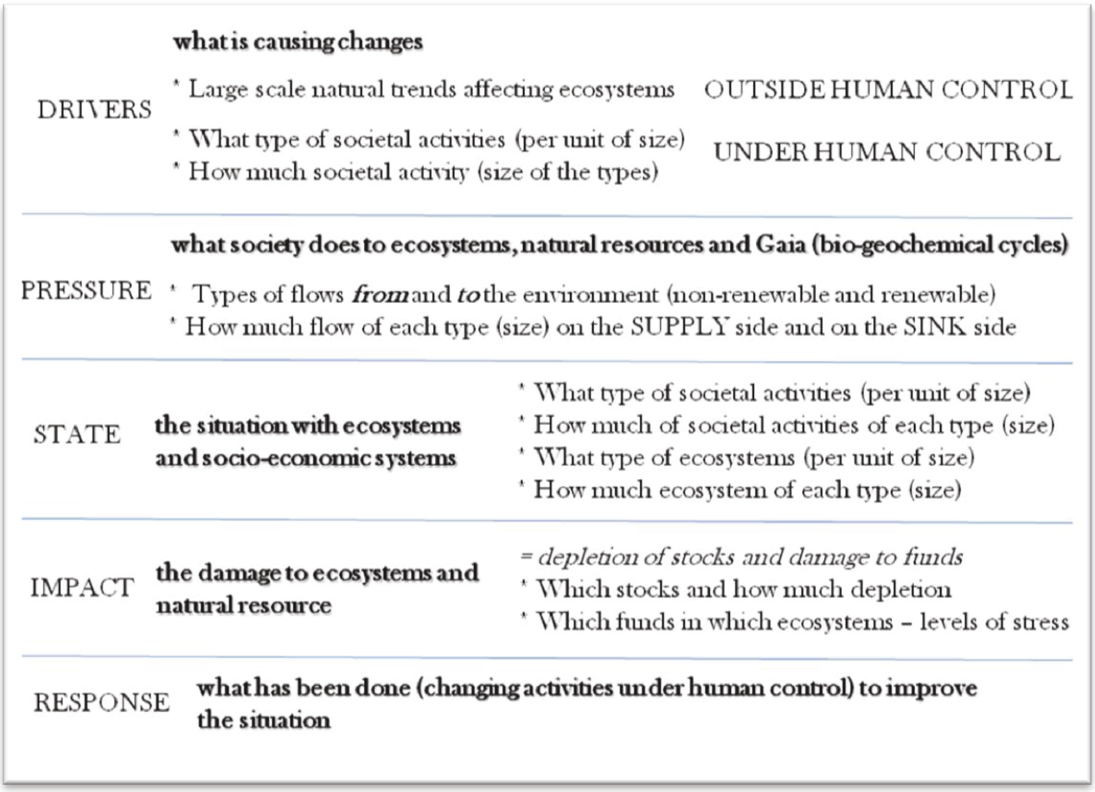


Fig. 16 The DPSIR framework interpreted in relation to an analysis of the metabolic pattern of society and ecosystem

The epistemological problems discussed in this document easily explain the problematic implementation in quantitative analysis of the DPSIR framework. In fact, in order to develop a coherent quantitative framework capable of characterizing the interaction between human societies and ecosystems according to the overview given in Fig. 13 we need a method of quantitative accounting capable of:

(i) addressing the obvious fact that the characterization of the information in Quadrant (A) and Quadrant (B) require the simultaneous adoption of two different space-time scales: (A) dt = 1 hour and T = 1 year; (B) $d\tau$ = year Θ = centuries;

(ii) establishing a bridge between the quantitative information defining states for the metabolic pattern of societies (internal view) and the metabolic pattern of ecosystems (external view) – when dealing with information in quadrant (B) and (C);

(iii) describing the characteristics of the metabolic patterns across different levels of organization – e.g. sub-parts/parts/whole (within quadrant A and quadrant D);

(iv) making a distinction between flows that come from stock depletion and stock filling (non-renewable) and flows that come from fund-flow processes (renewable);

(v) defining the degree of openness of the interaction addressing the effect of externalization due to imports and exports.

Finally, it should be noted that not only the DPSIR framework but also the Millennium Ecosystem Assessment framework can be explained using the same set of relations within socio-ecological systems described in Fig. 13. This is illustrated in Fig. 17.

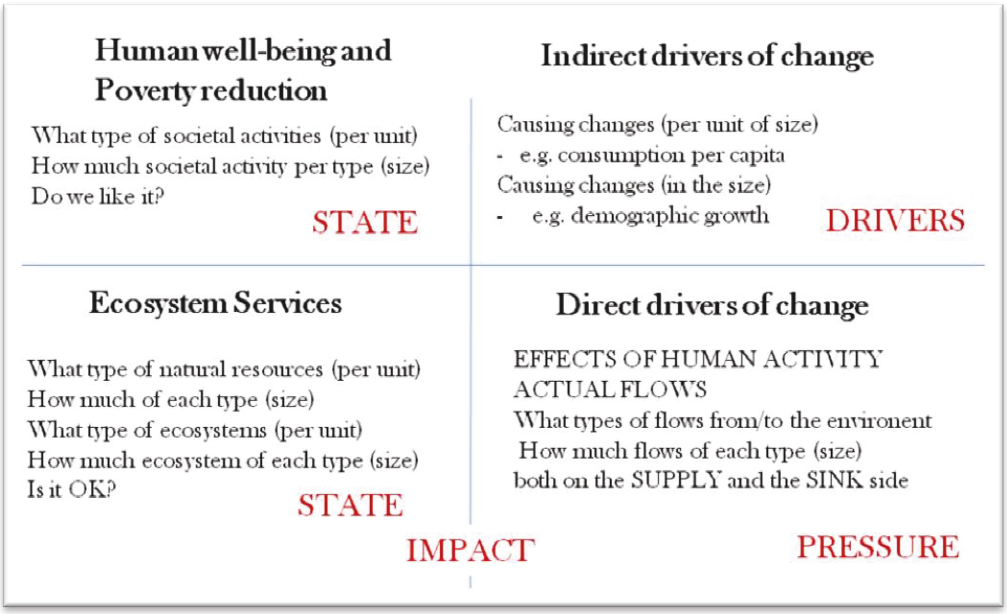


Fig. 17 The Millennium Ecosystem Assessment framework interpreted in relation to an analysis of the metabolic pattern of society and ecosystem

1.3.4 Examples of terrible simplifications: the fairy tale of "Kuznet curves" and the problem of defining environmental impact with just a number

Going back to the example of the metabolism of Messi (Fig. 10) the examples presented so far have proved that it is possible to use simultaneously:

A. *two types of quantitative information* to be used to describe the metabolic pattern: (i) the pace of metabolic pattern per unit of mass; (ii) the size of the mass of the metabolic system;
B. *two categories of accounting for food energy* – external view (e.g. agricultural products/primary energy sources/water funds) - vs internal view (e.g. macronutrients/energy carriers/typologies of water use) – e.g. Fig. 7;
C. *two hierarchical levels for the analysis of the metabolic pattern*: (i) the whole Messi (at the level n); and (ii) the organs of Messi (at the level n-1).

In this section we use practical examples to show the key importance of considering these three points in order to generate an effective system of indicators for the study of the internal factors determining the level of consumption of resources (on the input side) and the level of emissions (on the output side). We do this analysis by looking at the narrative of the "dematerialization" of developed economies. This narrative is based on the analysis of the reduction of the EEI (Economic Energy Intensity) - measured by the indicator "US$ of GDP per MJ of energy". The figures of this example are taken from (Giampietro, et al., 2012).
The historic series of EEI (measured in BTU/US$) and GDP per capita ($GDP_{PC}$) of the US economy - between 1950 and 2005 - reported in Fig. 18a - gives many analysts the illusion that economic growth (a persistently increasing GDP_{PC}) and technological progress have been associated with a steady dematerialization (EEI) of the economy. Therefore the narrative of dematerialization associates economic growth to a decreasing dependence of modern economies on energy.

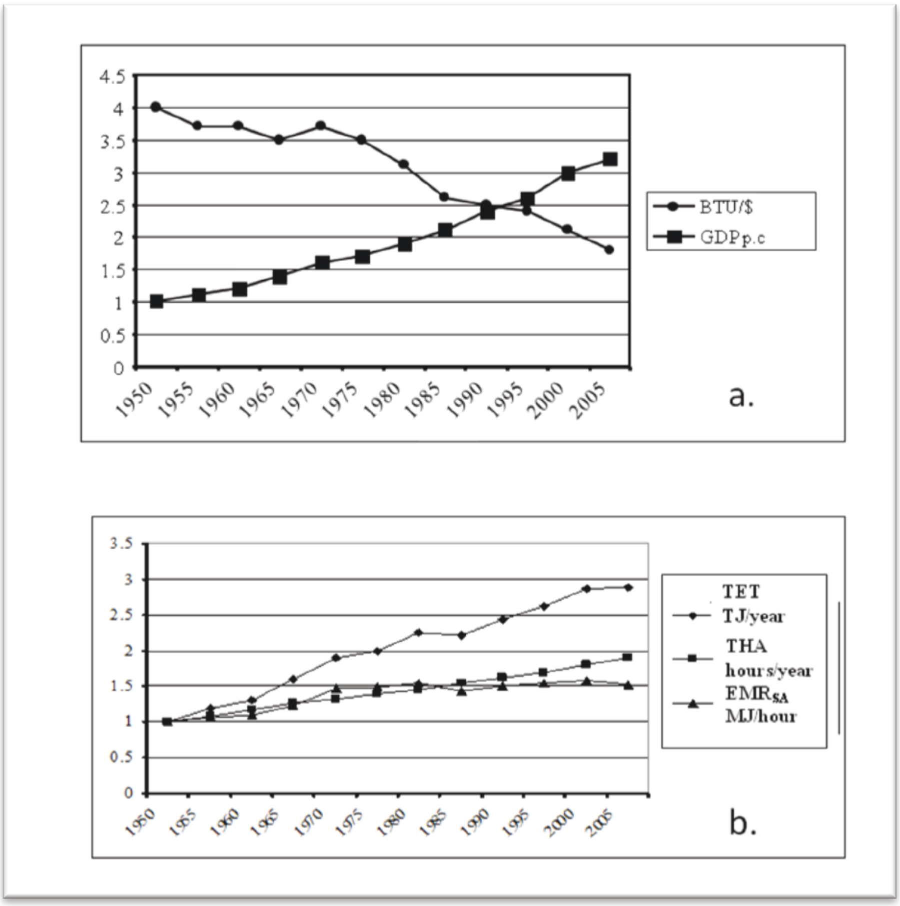


Fig.18 Changes in EEI of USA using both intensive and extensive variables

However, this neoclassical interpretation simply reflects the choice of using data that only refer to intensive variables: (i) the value of EEI; as noted in section 1.1, is a ratio of two ratios (“GDP/THA”/“TET/THA”); and (ii) GDP_{PC}; is also a ratio GDP/THA referring to a value per capita per year. The choice of using these two intensive variables is simply not useful for checking the compatibility of the socio-economic process with ecological processes, i.e., for checking sustainability and the environmental impact associated with human activity. Economists’ belief that what they call “dematerialization” – a reduction of the value taken by an intensive variable - measures an improvement in sustainability is simply wrong. In fact, in order to check the external constraints determining the sustainability of the economic process – the compatibility of the environmental pressure on the ecological processes - we need to compare ***the relative size*** of the flows generated by the society - quadrant A of Fig. 13 - to the size of the available environmental services (supply of inputs and sink capacity for outputs) – quadrant B of Fig. 13. To clarify this point let’s consider the relative changes taking place in the USA in the same historic period (1950 and 2005) for two *extensive* variables: (i) total energy throughput (TET) – a flow in the quadrant B of Fig. 3 - and (ii) population size – the fund size in quadrant A in Fig. 13.
These changes are illustrated in Fig. 18.b. The ratio of these two variables (TET/population – flow per capita year) is also represented in this figure. When considering the two extensive variables the size of the population and the consequent aggregate size of the metabolized flow, the picture of what happened in US economy between 1950 and 2005 becomes dramatically different. The extensive variable

population has been steadily increasing over this period. The intensive variable energy use per capita increased up till about the year 1970 and then leveled off. Then, when looking at the overall movements of TET – the actual quantity of primary energy consumed by the USA - there is no evidence of dematerialization of the economy. On the contrary, the consumption of primary energy in USA has been experiencing steady increases due to the combination of changes in the two variables: (i) population (the size of the system); and (ii) energy use per capita (metabolic pace per unit of size). When considering simultaneously these two non-equivalent pieces of information – one referring to a typology out of scale (the metabolic rate per capita of a developed country) and one referring to the instance of a developed country (the population size of the USA) we may conclude that over the historic period considered, more than doubling the energy efficiency of the US had the effect to increase the aggregate use of commercial energy (TET) in the US economy by almost three times! Obviously, an increased aggregate use of energy entails more human activity disturbing natural ecological processes, a faster depletion of fossil energy stocks and more greenhouse gas emissions.

A second example - also taken from (Giampietro, et al., 2012) - refers to the possibility of externalizing the production of goods to other economies via favorable terms of trade. In fact, as shown in Fig. 13, externalization of some functions to other economies can alter the requirement of energy and other material flows for the operation of a given economy. Going back to the example of the metabolism of Messi illustrated in Fig. 10 we can notice that the activity of the Liver, Heart and Muscles accounts for 50% of the energy consumption of the human body. At this point one can imagine a strategy in which we: (i) import into Messi body or export outside the body all the chemical substances processed by the liver; (ii) transplant a mechanical heart operating with electricity imported from the outside (of the type illustrated in Fig. 4); (iii) associate to the body a mechanical exo-skeleton made of iron and operated by electric engines, that is totally replacing the functions of muscles. After all these changes could we say that "Messi" is now *much more efficient* since it is operating using only half of the metabolic energy that he was using before? Can we compare the metabolic rate of "the whole Messi" in the two cases: (i) case #1 – when Messi is expressing all his physiological functions; and (ii) case #2 – when Messi is externalizing a lot of his body functions to other external agents? If when comparing different countries we are not able to make this distinction we will generate sloppy quantitative analysis. We cannot compare the metabolic pattern of human bodies at different levels of externalization! This is exactly the error that many analysts do when analyzing the degree of dematerialization of modern economies. If one looks at the functional and structural changes taking place in modern societies across different scales (looking at the characteristics of internal organs) one can immediately recognize the existence of a clear pattern that is illustrated in Fig. 19. After the industrial (oil) revolution, the modernization of economies has implied a progressive reduction of the role of agriculture, a temporary increase in the role of the industrial sector followed by a situation called "post-industrialization" or service economy where the larger share of the GDP is coming from the service sector.

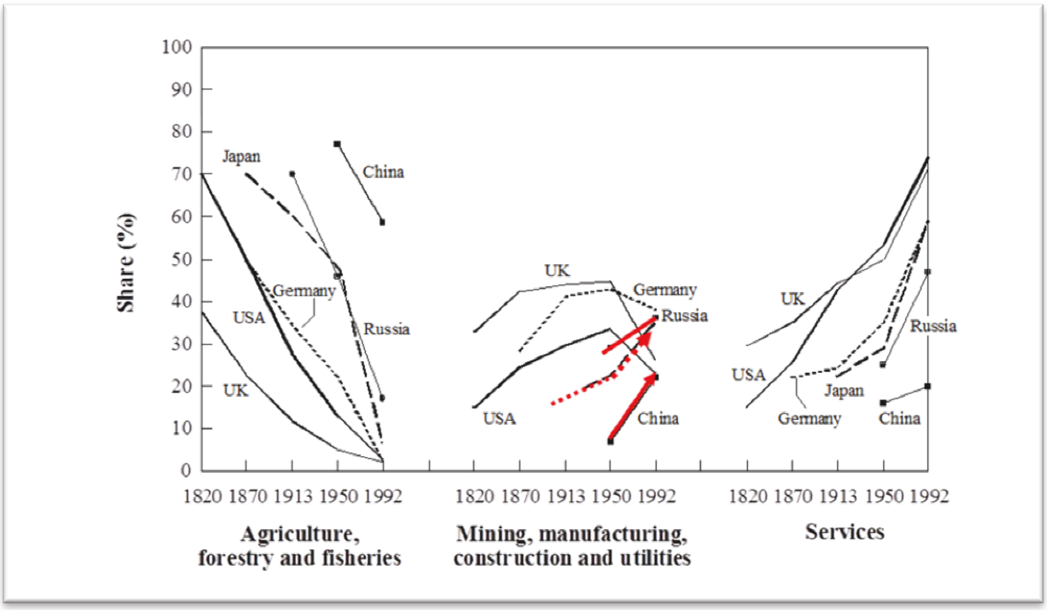


Fig. 19 The classic trend of functional/structural changes in countries at different level of economic development (Source: (Millennium Ecosystem Assessment, 2005))

Therefore, in order to understand the factors determining a change in the metabolic pattern of modern societies it is important to study the relative changes of activity across the various "organs" (economic compartments) of a society in charge for different functions and defined at different levels. An example of this analysis (illustrated in details in (Giampietro, et al., 2012)) is illustrated in Fig. 20 using the same plane introduced in Fig. 2 and Fig. 3.

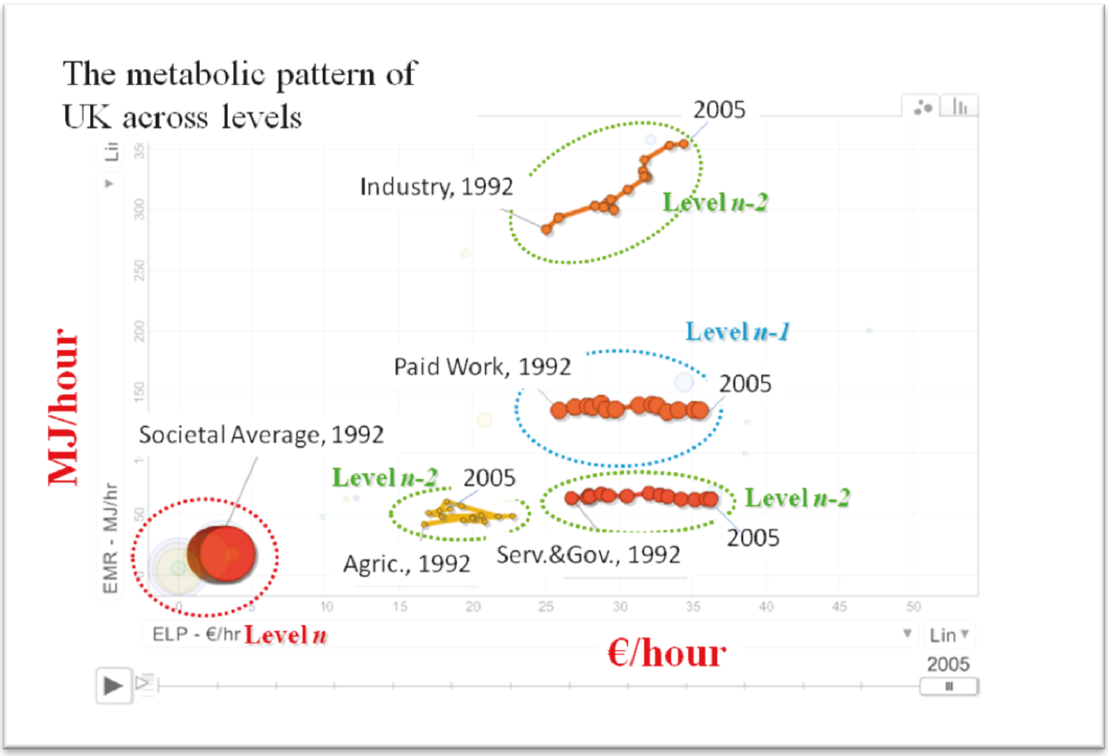


Fig. 20 The metabolic pattern of UK (1992-2005) across hierarchical levels

This plane describes the characteristics (the two ratios "MJ/hour" and "€/hour") of the metabolic pattern of UK across multi-scales. That is the characteristic flow/fund ratios of the whole society (level n), the Paid work (level n-1), the Service Sector (level n-2), etc. By doing this analysis it becomes clear that in UK during the period 1992-2005 the industrial sector has been increasing its energy use per hour of labor (EMR). Therefore, the overall effect of reduction of energy intensity for the economy has been generated by a progressive reduction of the size of the industrial sector (indicated in figure by the progressive reduction of the size of the disk moving in time).
Therefore, the reduction of the energy intensity of UK economy is not due to the adoption of more efficient technologies in the industrial sector, but rather it should be explained by a policy of externalization of the production of those goods that require more energy for their production and a progressive expansion of the financial sector.
Coming to the framework of analysis given in Fig. 13, the reduction has not relation with changes in the set of characteristics describing the functioning of the economy in the quadrant A. Rather the reduction is determined by a dramatic increase in the flow of imports in the quadrant B! Put in another way, the economy of UK reduced dramatically those functions requiring a large throughput of energy and learned how to import those goods, paying with added value generated in the financial sector. Lately developed society have developed another very effective strategy for reducing their energy intensity: they can rely on imports and then increase the level of debts in the economy to pay for them. It should be noted that the changes that took place in the metabolic pattern of UK are very similar to the changes found when looking at the other economies of the EU. This fact is illustrated in Fig. 21.

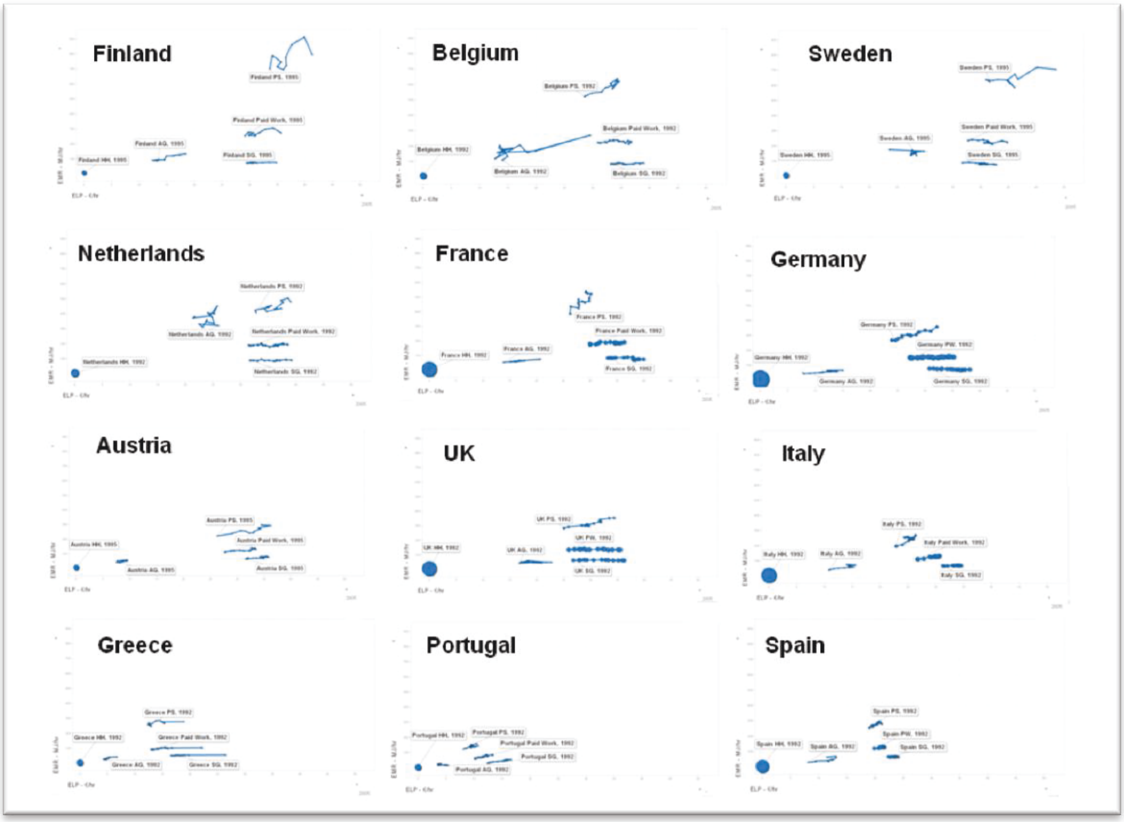


Fig. 21 The common metabolic pattern of European countries

For this reason it is essential when comparing the environmental impact of developed countries to control the level of externalization of their economy. When relying massively on imports of goods (especially agricultural commodities and industrial products) and when generating a large part of the GDP with the financial sector (or even worse, when sustaining the economy by increasing the public and private debt), it becomes possible for developed society to enjoy a quite high material standard of living, by externalization the resulting environmental pressure to other countries.
Because of this fact, when adopting dangerous simplification at the moment of assessing indicators of environmental pressure we can risk to obtain as result that the countries that most externalize their environmental impact to others will result the most virtuous countries if we assess only their local environmental impact (referring to the two quadrant C and D in Fig. 13).

1.4 Aggregation of different indicators: when is it possible?

1.4.1 The entanglement between descriptive and normative side

In this section I analyze the predicament of purposive quantitative analysis (e.g. the generation of indicators) in relation to the unavoidable entanglement with normative aspects. Applied research is about solving problems. But after accepting this definition we have to answer the following question "whose problems" have to be addressed by applied research? In applied research scientists are asked to frame a given issue in order to help the finding of political solutions. However, in order to carry out such a task they need to be given a definition of a specific problem to be studied. On the other hand, the society may not be aware of having a problem if scientists do not flag the existence of hidden critical situations. There is an unavoidable and impredicative entanglement between the descriptive and normative side in the process of production and use of scientific indicators for governance – see Fig. 22.

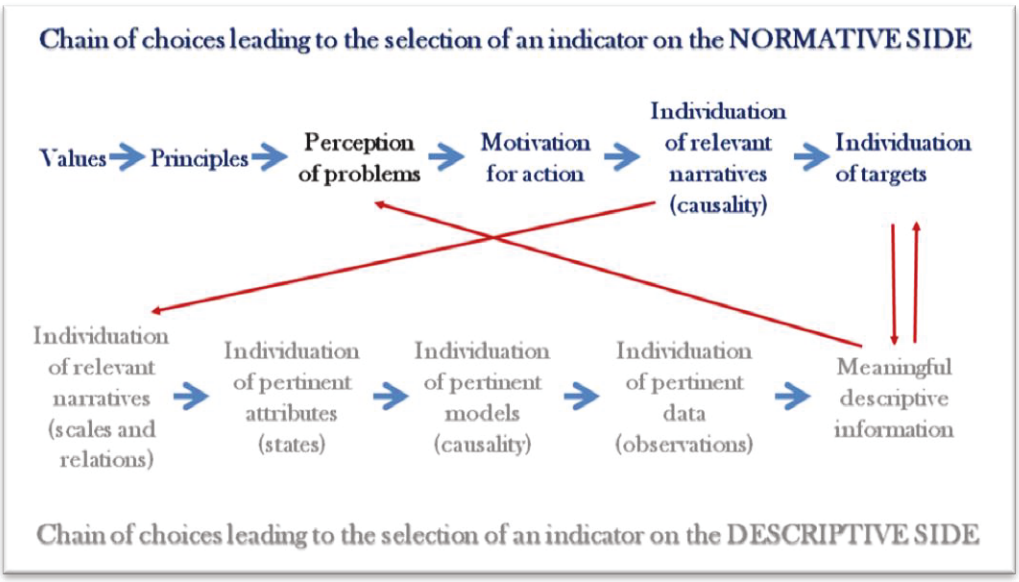


Fig. 22 The unavoidable entanglement between Normative and Descriptive inputs

In fact we can see that even the "purest" of the normative choices – individuating the priority to be given to problems to be tackled – in reality it is always affected by an input coming from the descriptive side (how bad is the situation in relation to different issues). The perception of a problem is determined by a discrepancy between: (i) a desired state (what is expected) defined in normative terms; and (ii) a perceived state (what is experienced) determined by the assessment of a given state defined in descriptive terms. In relation to this point we can conclude that an indicator must result: (i) relevant in relation to the normative input it provides; and (ii) useful in relation to the descriptive input it provides.

This entanglement generates an important problem at the moment of generating composite indicators. In fact, in order to be able to aggregate different indicators into a single quantitative assessment it is necessary to have a common perception of the problem to be tackled that makes it possible to establish a semantic relation over the various indicators considered. A simple mental experiment can be used to prove this fact. Let's imagine that two persons are looking for indicators to assess and rank 200 Universities operating in 20 different countries. At the moment of deciding which indicators should be included in the composite indicator we must know the "perception of problems" and "motivation for action" of the person that will use the composite indicator. Let's assume that the first person is Kevin Smith (a EU citizen getting out of high school) that is trying to choose wisely an undergraduate education; whereas the second person is a rich banker with fundamentalist radical visions willing to donate 200 million € of funds to these University for pushing his own view. In this situation it is unthinkable to imagine a selection of indicators (to cover a set of relevant issue) and a set of weighting factors (to give a relative importance to the different criteria of performance) that can be used to generate a composite indicator ranking universities in a way that will result useful to both the future freshman and the rich banker.

A composite indicator assessing the performance of Universities can work only if the selected narratives about the performance of the University (reflected in the choice of the set of indicators) are shared by those that will use them.

This problem is faced when mixing of indicators referring to the effect of environmental pressure (impacts) and indicators referring to the efficacy of the action given by the government or other social actors (response). In this case we can certainly generate an analysis of the situation at a point in time "t" and then the situation at a point in time "t+1" to assess the effect of the response. But it is not clear how this quantitative indicator can be later on aggregated and weighted with the others in a composite indicator (as proposed in the Environmental Performance Index originally developed by Yale). A simple illustration of this fact is illustrated in Fig. 23: we can have two situations (case A and case B) in which the Response given to a bad situation has generated exactly the same result in terms of what has been achieved in relation to the original target. However, due to a difference in the states and impacts found in the ecosystem in one case (case A) the Response can be considered as acceptable, whereas in the other (case B) the Response should be considered as inadequate.

Fig. 23 Two different situations in which the same RESPONSE can be assessed

It should be noted that when using a quantitative index for measuring the distance from the starting point and the target it would have been impossible to make such a distinction. Rather we should combine the indicator of response to an indicator of pressure (or state) to be able to properly assess the weight to be given to the response. We are again in a situation in which a single quantitative assessment cannot be enough for dealing with a complex problem.

1.4.2 The "relevance" of indicators depends on the relevance of the chosen narratives

Before getting into the practical comments to the two documents (Part 2) it is important to provide a last warning about the key importance of the choices made in the pre-analytical phase of any form of quantitative analysis. The importance of the pre-analytical choices becomes crucial when generating numbers to be used for guiding the governance of sustainability. Two simple examples are used below to make this point (both examples are taken by (Giampietro, 2003, p. 472)).

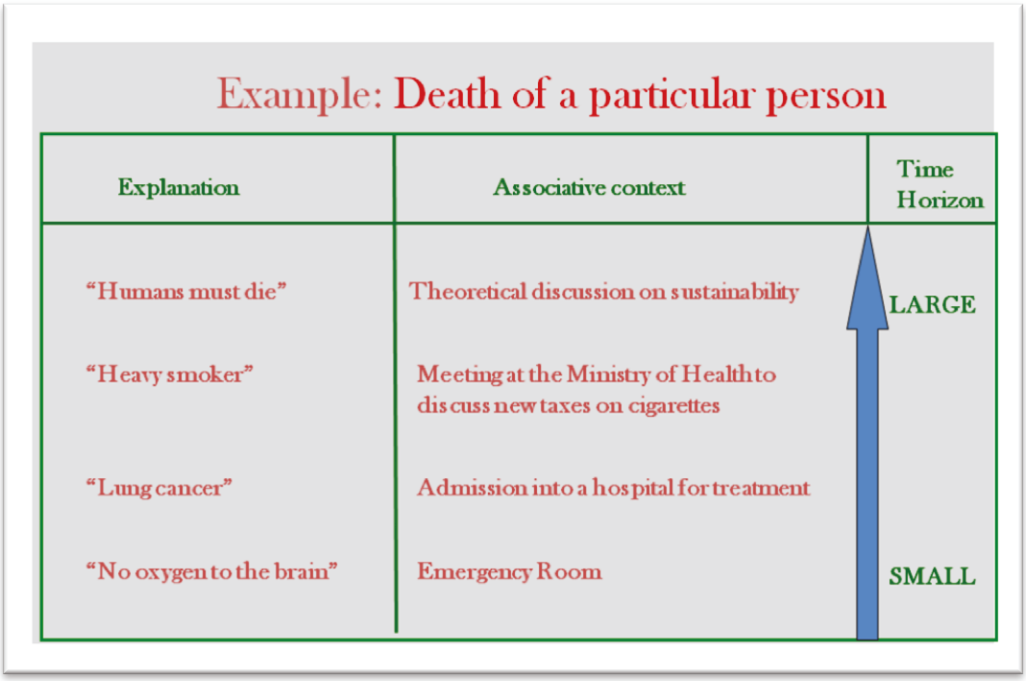


Fig. 24 Non-equivalent explanations whose relevance is context dependent

It is possible to obtain several non-equivalent scientific explanations for a given event – e.g the death of a given person – as shown in Fig. 24. All the explanations listed in Fig. 24 are perfectly legitimate and can be used in discussions about actions to be taken. However, in this situation it is essential to be able to identify the right narrative for the right occasion. If we want to prevent the death of a given person in the emergency room the explanation of the "heavy smoker" is totally useless. In the same way, the explanation of the lack of oxygen to the brain will result of not use in a discussion in the parliament about taxing tobacco. Again, as noted by Box, the real quality criterion for a model, a data set, an indicator or a given narrative about an issue is not whether they are "right" but rather whether they are "useful".

The second example deals with four non-equivalent views of the East Coast of the USA, observed at different scales and it is shown in Fig. 25.

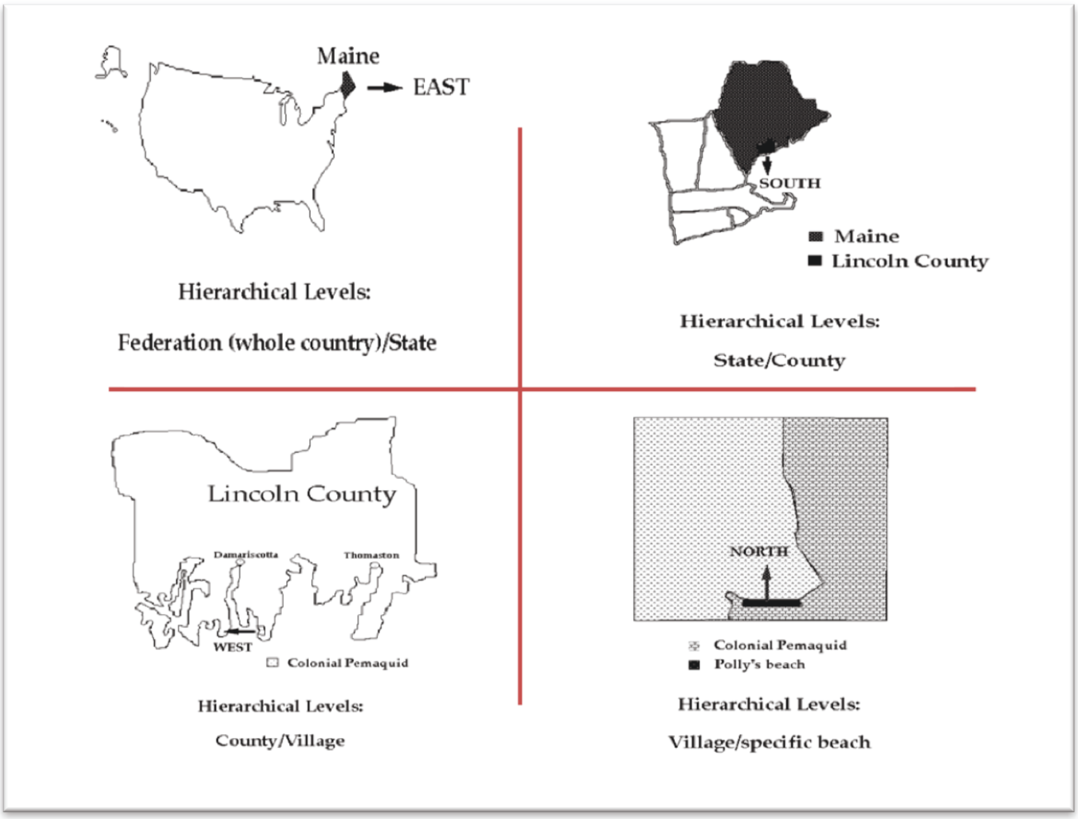


Fig. 25 Non-equivalent narratives about the orientation of the Coast of USA when is observed at different scales

In this case, depending on the scale at which the scientific information has been gathered we can get different "scientific assessments" of the orientation of the coastal line. Also in this case, the chosen narrative will result useful (relevant) or useless (non-relevant) depending on the nature of the problem to be tackled by the person deciding "what is the problem" that has to be solved with the scientific information:

1. a person interested in getting a porch looking at the sunset (orientation toward N) – will find useful the narrative referring to the local small scale;
2. a person interested in making a phone call to London to know the time difference (orientation toward E) – will find useful the narrative referring to the large scale;
3. a company willing to build a wind farm on the cost (orientation toward W) – will find useful the narrative referring to the local medium scale;

4. an astronaut trying to recognize large geographic features from the distance (orientation toward S) – will find useful the narrative referring to the large medium scale.

1.5 Conclusion: even admitting that for quantitative analysis reductionism is the only game in town, we should understand pros and cons of it

The modern scientific approach leading to quantitative description is aptly described by the term reductionism. Reductionism can be defined as a process that allows us to simplify the complexity associated with any real situation, by focusing only on few relevant aspects of a portion of the external world at the time. Indeed, it is only after having carried out such a simplification that the magic power of numbers can be unleashed. Abstraction and simplifications are very powerful epistemic tools making possible human knowledge. However, abstraction and simplifications entail the unavoidable side effect of missing relevant information about the external world every time we chose a given perception of it. So every time we adopt a given set of perceptions and representations about the external world for a given purpose we risk neglecting some other relevant pieces of information due to the pre-analytical step of abstraction and simplification. This risk is especially important when dealing with large doses of uncertainty in relation to our purpose. This is an unavoidable predicament when dealing with the analysis of complex adaptive systems that are:

(1) evolving in time - this implies emergence of unpredictable novelties; and
(2) operating simultaneously across several scales because of their organization in nested hierarchical levels- this implies the requirement of an information space that is virtually infinite in its size (information about the whole, the parts, the sub-parts, etc.).

The only possible way for dealing with this epistemological predicament is to avoid putting all "our epistemological eggs" in the same basket. That is we have to learn how to integrate different perceptions (abstractions/simplifications) of the external world referring to different dimensions and scales of analysis by using integrated sets of representations. In this document I have introduced a few concepts taken from hierarchy theory that can be used to increase the reliability of quantitative information to be generated and used for the study of the sustainability of the interaction of human societies with their environment.

In general terms, we can say that it is wise to rely on an integrated set of useful information referring to different aspects relevant for different functions, rather than rely on a single composite indicator compressing a wealth of information into a single numerical index. A self-explanatory example of this fact is illustrated in Fig. 26.

However, there are cases in which a composite indicator can result useful. For example, when exploring new possible ways of characterizing an emerging issue, about which there is not an available and robust set of semantic categorizations.

Fig. 26 Implications of the diversity in the information space used by a pilot

Part 2 - Ideas on how to monitor Environmental Pressure in the EU based on the experience of the *Environmental Performance Index* and the *Composite Index of Environmental Pressure*

2.1 A technical analysis of the Environmental Performance Index

In this section I discuss specific features of the Environmental Performance Index (developed by Yale) leaving out the discussion of the basic problem of how to deal with the different concepts of "pressure", "state" and "impact". This discussion is presented in Section 2.2 commenting the Composite Index of Environmental Pressure. The report presenting the 2012 EPI (and pilot trend EPI) was downloaded in November 2013 from www.epi.yale.edu.

2.1.1 The construction of the indicator is affected by a problem of "lamposting[1]"

Reading the introductory part of the report explaining the construction of the EPI one has the impression that the availability of data (and not the identification of the relevant external referents) has been the most important factor driving the construction of the indicators. Put in another way, it seems that the most important quality criterion considered for defining the protocol of quantitative assessment was the concern for obtaining formal rigor in the selection and handling of data. As explained in Part 1, I happen not to agree with this logic. In an integrated assessment of a complex issue it is better to go, first of all, for the big picture of the information that would be required (e.g. starting from a conceptual overview of the type illustrated in Fig. 13). In fact, looking at the "big picture" one can have a better understanding of what data are needed, available, or missing, and what type of missing information could be gathered with an extra effort or not. Only after having had this holistic analysis one should decide how to proceed in defining a protocol. However, without having provided such an overview, a short introduction told us that this index: (i) covers ten categories providing a rigorous data-driven environmental performance measurement; (ii) makes it possible to rank different countries; (iii) improves continuously in time because of the adoption of more rigorous data standards, that are assumed to translate automatically into a better quality of the product. At the same time, the short introduction provides also an impressive list of environmental issues not included in the index (in Box 2.1). The list includes: toxic chemical exposure, heavy metals, municipal waste management, toxic waste management, nuclear safety, pesticide safety, wetland loss, species loss, freshwater ecosystem health, water quality, recycling, agricultural soil quality and soil erosion, desertification, comprehensive greenhouse emissions, climate adaptation. Yet no comment is given about the implications of this missing information on the quality of the rigorous data-driven environmental performance index. When comparing the goals of the index with the various items included in this list one gets the impression of a sort of "elephant in the room" that has been ignored in the discussion of the methodology. It seems that at the moment of selecting a protocol the concern for getting data for which

---

[1] *this term refers to the joke of the drunk person looking for the lost keys of his car at night under a lamp post. Even though he knows that he lost the keys elsewhere, he looks there because it is only under the lamp that he can see something . . .*

time series were available overwhelmed the concern for getting an integrated information space useful for the task.

2.1.2 *The implications of the DPSIR framework are not properly addressed in the development of the protocol of accounting*

The system of indicators of EPI is hierarchically organized in two main categories of performance. That is the various indicators are aggregated into two main headings:

(1) "Environmental Health" – that I assume must refer to the "state" or "the pressure" referring to human society (e.g. indoor air pollution, access to sanitation, drinking water). Recalling the theoretical discussion made in Part 1, this would represent information referring to the quadrant A and/or B. in Fig. 13 (Part 1); and

(2) "Ecosystem Vitality" – that I assume must refer to the "state" or the "pressure" referring to ecosystems (e.g. indicators about forests, soils, fisheries) – again information referring to the quadrant D and/or C in Fig. 13.

However, at the moment of choosing specific indicators to be included in these categories there is no effort in individuating the proper external referent that should be used to gather the required information. For example, when looking for indicators about Ecosystem Vitality in agriculture, "subsidies" is proposed as an indicator supposed to be a proxy for agricultural intensification – the explanation is that subsidies are associated with fertilizers and pesticides use (but also with set-aside in many developed countries! So why not using directly data on fertilizer and pesticide use?). According to this assumption subsidies should be considered as an indicator of *pressure* on agro-ecosystems (e.g. affecting soil vitality?), but not an indicator of *state* since from this indicator we cannot know whether the agricultural soil is stressed or not. On the other hand, subsidies can also be associated with a better "environmental health" for the farmers. However, in relation to this goal they are not included on the Environmental Health heading. In other cases, when dealing with fisheries, the selected indicator is "Fish Stock Overexploited or Collapsed (FISOC)". This indicator deals clearly with *impact*. Looking at these examples, it is not clear to me how it is possible to aggregate together indicators that refer to different criteria (about the pressure, about the state, about the impact). Moreover, as discussed in Section 2.2, it is not clear to me whether it is possible to use a given number associated with an environmental pressure without a system of benchmarking as an indicator. A technical discussion about the impossibility of reducing into a single numerical assessment the indicators that necessarily have to deal with the differences between "state", "pressure" and "impact" is done in the analysis of the Composite Indicator of Environmental Pressure (Section 2.2). Here I want to discuss the consequences of the problem flagged in Fig. 23 (Part 1) when dealing with the assessment of the effect of a policy. In order to be able to weight different indicators referring to different motivations for action – e.g. improving the conditions of humans versus improving the conditions of ecosystems - one has to know not only the *pressure* but also the *state* of both the society and the ecosystem under observation. Moreover, one has also to understand the possible *impact* that the given pressure can generate. Without this integrated understanding it is very difficult to define priorities or judge the importance of the results. However, in the case of the EPI the various assessments provided by the two packages of indicators grouped in

“Environmental Health” and “Ecosystem Vitality” do not refer to any specific external referent, they are not contextualized in relation to the state or the impact. This implies that these indicators cannot be interpreted against (they do not have meaning in relation to) expected states or impact to be avoided. Without such a contextualization the weighting of indicators coming from two categories referring to two independent motivations for action cannot be done.
An evident sign of lack of logical discussion is clearly indicated by the chosen treatment of data in order to make them comparable across countries. Raw data in the form of extensive variable are divided by “something” either population or hectares or “some other denominator” (sic) in order to make the data comparable over the considered sample. The description of this step, which should be considered as capital epistemological sin in this context, is the only reference made in the text to the problem of how to handle the issue of external and internal view, extensive and intensive properties when constructing a quantitative accounting! This issue is discussed more in detail in Section 2.2

2.1.3 The neglecting of the implications of the openness of the socio-ecological systems

In Fig. 13 (Part 1) the analysis of the flows required for reproducing and maintaining a socio-ecological system shows clearly that in modern societies external flows (imports and exports) play a crucial role in determining the relation between “the state” of the socio-economic system (“Environmental Health”) and “the state” of the environment (“Ecosystem Vitality”). Therefore, one would expect that in the EPI, that explicitly focuses on the analysis of both states as relevant pieces of information, the level of openness of the system should be considered as a key information. This is not the case. Looking at the ranking generated by the EPI we find that Switzerland results on the top of the ranking. However, probably Switzerland could not keep its record of Environmental Health for humans and Ecosystem Vitality if Swiss economy had to produce all the imported goods using resources produced and consumed in its own territory. In the same way, the good environmental scoring of Egypt (discussed on p. 28) is probably due to the fact that right now the vast majority of the population is urban and it is living on imported food mainly provided by international aid (Egypt does not even have to produce enough added value to pay for the imports). When looking at the resulting ranking of countries, one wonders whether it would be wiser to include also the effect that imports have on the Environmental Health an Environmental Vitality in other countries.

2.1.4 The focus on outcome-oriented indicators - needed to measure the effect of policies (measuring RESPONSE) - makes the whole assessment shaky

The EPI wants to represent a tool for decision makers giving rigorous information about the effect of policies in relation to several goals at the same time: (i) reducing environmental stresses on human health; (ii) promoting ecosystem vitality; (iii) promoting sound natural resource management. According to what discussed in Part 1 it seems that the idea of aggregating all this information in a single number is too ambitious. To make things even more difficult the focus on the analysis of “response” is determining a move of the EPI from a tool analyzing pressures and states to a tool analyzing trends and responses. This implies that necessarily the quantitative protocol

deals only with the analysis of changes and as a result of this, it has to ignore the states. That is, when carrying out an analysis of trend in a given country on the time window 2000-2010 we may observe a major improvement in Environmental Vitality in relation to the reference year 2000. But this analysis could miss the fact the majority of ecosystems originally present in that country were already destroyed before the year 2000! In this case the measured "improvements" would refer only to a negligible area populated by ecological relicts. Without considering the state of the system (in quantitative and qualitative terms) we are not able to define how important or urgent is the response. Looking at the examples shown in Fig. 23 (Part 1) we cannot even define whether the starting point or the result achieved should be considered bad (a state described as red), acceptable (a state described as yellow) or very good (a state described as green).
Clearly, this does not imply that trend analysis is not relevant or important, but simply that when dealing with complex issues it is always better to develop an integrated analysis based on different sets of indicators capable of handling different relevant characteristics (pressures, states, impacts, trends/drivers, and response).

2.2 A technical analysis of the Composite Index of Environmental Pressure

The Reference Report on "*Further development of the composite index of environmental pressure with the full documentation of indicator selection and methodological choices*" (21 December 2012) focuses on the task of monitoring Environmental Pressure. Compared with the EPI document its introductory section discusses much more in detail the theoretical framework and the process leading to the chosen protocol. In fact, it provides an elaborated discussion of possible theoretical framework to be used for this task (the DPSIR and the Millennium Ecosystem Assessment framework are not only mentioned but also illustrated and discussed in details). It should be noted that, however, the final decision has been to focus only on indicators of *pressure*. In the rest of this section I claim that both this decision and the consequent implementation generates an excessive simplification in the resulting quantitative assessment preventing the achievement of the stated goals of this composite indicator.
In the rest of this section I present only a discussion of the protocol of accounting. A technical discussion of the pros and cons of each one of the indicators included in the indicators has been done in the three day meeting in Ispra in March, 2014.

2.2.1 The conceptual issue about the comparability of data across countries has not be properly addressed (what is compared when using only intensive variables?)

In Part 1 I made the point that those willing to characterize systems belonging to the same typology ("apple") but having different sizes ("big and small apples") have to learn how to use two different types of information. A type of information used to characterize "*apples*" (intensive properties) and a type of information used to characterize the size of the apple (extensive properties). The former type of information refers to the internal characteristics of the typology (the internal view) and the latter refers those characteristics of the system that are relevant for studying its interaction with the context (the external view).
The issue of how to make comparable environmental data across countries (only briefly mentioned in the EPI report) is addressed more in details in this report (p.49-52). However, the existence of the unavoidable bifurcation between the internal and

external view has not be addressed in the 4-page discussion. Therefore, also in this report, the problem of comparability of the selected indicators is framed in terms of a simplistic recipe: the need of eliminating *extensive variables*. The reasoning is simple: since extensive properties determine the impossibility of comparing countries of different size, we have to transform them into *intensive variables* "by dividing them by a denominator" (sic p.49). However, this division does imply possible complications depending on the external referent to which the number of the denominator refers to!

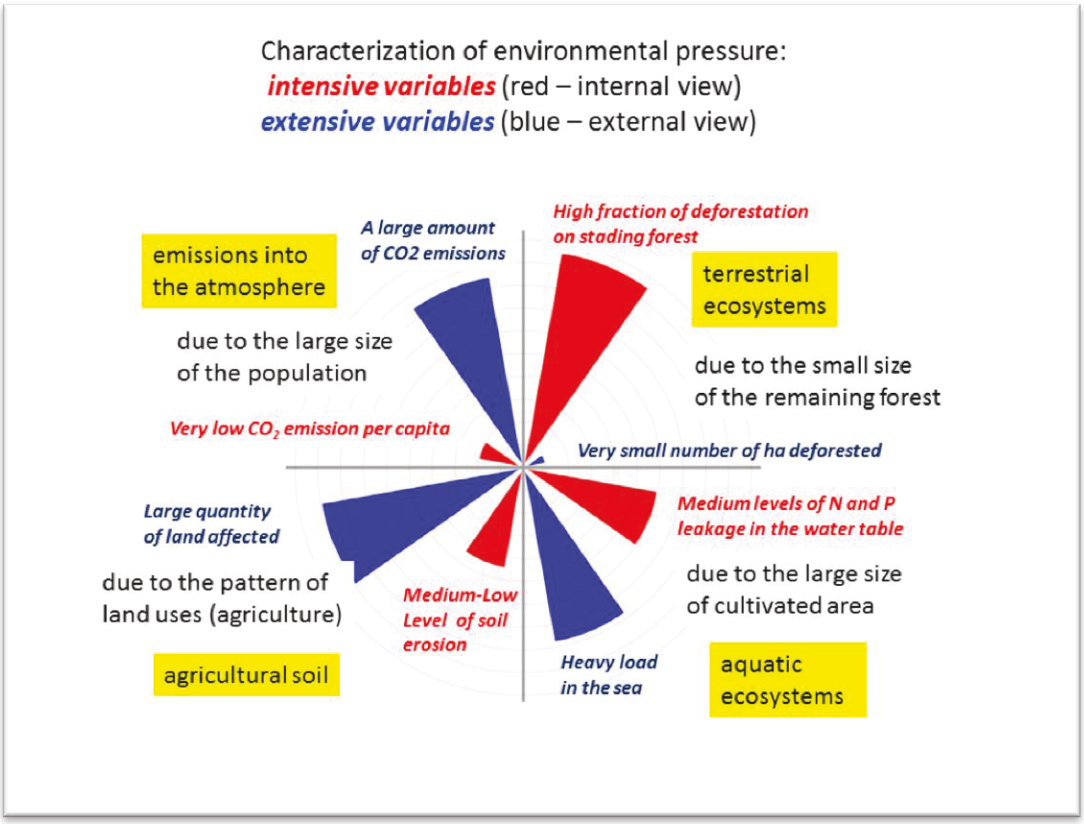


Fig. 2.1 The difference in the type of information given by intensive and extensive variables

Before getting into a discussion of this fact, let's use an example of assessment of environmental pressure based on a combination of extensive and intensive variables to clarify this point. This example is illustrated in Fig. 2.1.

Let's start from the upper left quadrant of Fig. 2.1:
∗ Emission in the air – the intensive variable "CO_2 emission per capita" gives us information about the characteristics of the typology of country (a developing country in this example). In this example, the emission per capita are lower than the world average. This intensive property is an information about the *state* of the socio-economic system (it refers to the quadrant A in Fig.13). The extensive variable – "total CO_2 emission of the country" refers to the amount of waste that is dumped into the atmosphere. This is extensive property is an information about the *pressure* on the environment (it refers to the quadrant B in Fig. 13). If we want to know about the impact of this pressure we should compare this quantity of flow with the sink capacity (the capacity of absorbing this CO_2 of the atmosphere) – the information in quadrant C

and D in Fig.13. Therefore, it should be noted that the value of the intensive variable "CO_2 emission per capita" does not represent an indicator of pressure but rather an indicator of state (of the society). China with 1.2 billion of person can have a relative low level of emission per capita (a state describing it as a typology of country with low emissions per capita) but still it generates a quite large pressure of CO_2 emission (a large pressure in terms of emissions in the atmosphere).

∗ Terrestrial Ecosystems – in this example the chosen intensive variable "fraction of deforestation of the standing forest" refers to a percentage. In this example the intensive variable indicates a very bad situation (e.g. 80% of the total). However, if the country has already eliminated all the original forests, this very high impact would not translate into a large quantity of hectares deforested. The lesson here is that "percentages" need additional information in order to be useful indicators;

∗ Aquatic Ecosystem – also in this case the intensive variable "use of fertilizer per hectare" describes an internal characteristics of the system (a *state* of the agricultural sector). In order to have an indicator of *pressure* we have to scale up this information by multiplying this value by the number of hectares under production (quadrant C in Fig. 13). Then we can assess the potential *impact* of this *pressure* by comparing this pressure with the sink capacity of the water body where this pressure is applied (quadrant D in Fig. 13).

∗ Soil – the case of the soil is similar to the ones discussed so far, so we can skip it.

From these examples it is clear that it is simply not true that whatever denominator we use for standardizing the original indicators (expressed in terms of extensive variables) we solve the problem of comparability after generating in this way intensive variables. As a matter of fact, depending on the denominator that we use we will generate different typologies of indicators. If we use a denominator referring to the internal view (e.g. a flow per capita), then we are measuring the characteristics of a typology of society – this should be considered a description of the *state* of the socio-economic system. Flows per capita do not describe pressure unless they are complemented by an extensive assessment. That is, we cannot compare the pressure of GHG emission of China and Malta using an indicator referring to their level of emission per capita. If we are measuring a flow per hectare, then this can be considered an indicator belonging to the category *pressure*, assuming that we are dividing the flow by the right category of land use. We can recall here the example of the right assessment of the density of sewage associated with residential areas in Canada in Fig. 12 (Part 1).

Different is the case of percentage such as: "people without sewage" – this indicator refers to characteristics of the society (quadrant A of Fig. 13) and has to be scaled to become an indicator of pressure (quadrant B); or "milligrams of phosphorous in water" – this is indicator of state of the ecosystem (quadrant D of Fig. 13) that in order to be related to a pressure has to be scaled as well (quadrant C of Fig. 13).

2.2.2 Can we define indicators of environmental "Pressure" without making any reference to information referring to State and Impact?

In order to explain why it is important to integrate different types of information into the construction of an integrated assessment of environmental impact, let's start from a trivial example of comparison across different countries of a simple indicator: the price of bread. Then we can repeat the same reasoning applied to any indicator of environmental impact. Let's imagine that we want to compare the price of 1 kg of bread across a sample of 100 countries quite different in their levels of economic development. In order to be able to carry out an effective comparison we have to contextualize the quantitative assessment we use. In fact, a single number – e.g. the price of 1 US$/kg - is certainly not useful for this task. What can be compared across countries is the "meaning" of the number within a given contextualization. For example, across our sample of countries we can characterize the bread as "cheap" – e.g. if its price is less than 1/3rd of the minimum hourly wage – or "expensive" – e.g. if its price is equal to the minimum hourly wage. The contextualization requires referring to the state of the society. In general terms we can say that in this case what can be compared ***is the meaning of the quantitative assessment not the number itself***.

In order to provide to the numbers a given contextualization it is important to get an external referent (a state) in relation to which the "pressure" can be evaluated as something that will generate an Impact. To understand better this point we should always remember that an indicator needs three pieces of information: (i) a relevant attribute to be measured; (ii) a framework of reference for its benchmarking; and (iii) a reliable source of data (an effective measurement scheme). What is missing at the moment in the discussion of the various indicators to be included in the index is the analysis of the framework of reference that should be used for benchmarking. An indicator used for governance should always be able to answer the question: "is 1 US$ per kg of bread a cheap price or rather is it an expensive one?" in the same way our indicator of pressure should always be able to tell us whether the pressure is high or low.

For this reason, when developing a set of indicators of environmental pressure we should be able to provide a tailoring of the meaning of the quantitative assessment in relation to the situation experienced in the different countries.

Let's discuss this point using again another practical example of analysis of environmental pressure based on the combination of intensive and extensive variables. In this example the assessment is not related to the pressure exerted on local ecosystems (because of the production and consumption of goods and services within the boundary of the country) but to the pressure externalized to other ecosystems because of the imports of a given country.

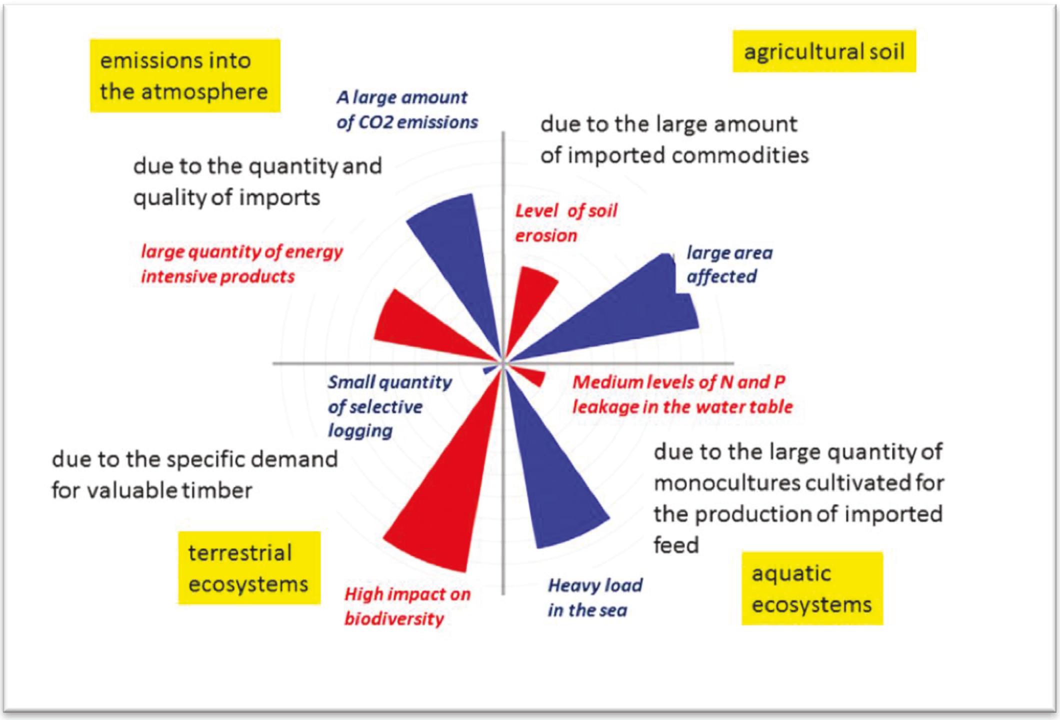


Fig. 2.2 The difference between pressure and impact (in an assessment of an Externalized Environmental Pressure)

∗ Emissions into the atmosphere – in this case the pressure (the flow of CO_2 emissions) generated by the import of a large quantity of energy intensive products goes into the atmosphere and therefore we cannot define a specific threshold of impact or a state specific for any country. For emissions into the atmosphere both the state, the pressure and the impact are referring to the characteristics of the atmosphere that it is in common across the sample of countries (and not to "climate").
∗ Agricultural soil – in this case we have a situation in which the level of soil erosion can be used as an indicator of impact that can be tailored on the different typologies of soil present in different countries – e.g. some soils are more fragile than others (in tropical countries);
∗ Aquatic ecosystems – in this case large amount of imported feed can results in heavy loads of fertilizers into water bodies – the black spots in the sea or eutrophication of lagoons;
∗ Terrestrial ecosystems – in this case depending on the nature of the ecosystems we can have important impacts on biodiversity generated by small quantities of imported products (e.g. elephant tusks, valuable timber).

With these examples I want to make the point that the required contextualization of the indicator of pressure can only be obtained if we establish a link between the quantitative assessment of pressure (quadrant C in Fig. 13) with the ecological funds that are affected by such a pressure (quadrant D in Fig. 13). In relation to this task the choice of the 5 themes used to aggregate indicators "Land, Water, Air, Climate and Chemical and waste" seems to be not appropriates. Rather indicators should be grouped after having individuated external referents making it possible to contextualize the quantitative information about pressure with additional information about the state and the possible impact. For this reason the aggregation of indicators in themes and sub-themes should be done in relation to a taxonomy based on ecological fund elements. Put in another way, it is necessary to establish a correspondence between the various types of information illustrated in Fig. 13: (i) information referring to quadrant A (intensive variables about characteristics of the state of a country – e.g. emission per capita); (ii) information referring to quadrant B (extensive variables about the pressure generated by a country – e.g. total emissions of CO_2); (iii) information referring to quadrant C (intensive variable about the pressure perceived by the ecological fund – e.g. emission per hectare); and (iv) information referring to quadrant D (intensive variables about the level of health or stress of the ecosystem).

For this reason I would suggest to replace the actual five themes used to define in semantic term the nature of the indicator (it is an indicator characterizing the pressure on "air", "water", "land") with semantic definitions about the nature of the indicators measuring a pressure on specific fund elements. That is, this group of indicators characterizes the pressure on aquatic ecosystems - that can be further split into marine and fresh water. This group of indicators measures the pressure on soils, on terrestrial ecosystems, etc. This categorization of indicators of pressure on a specific fund element identifies an external referent makes it possible to apply a more holistic framework of analysis (the overview given by Fig. 13). In fact, ecological funds are the elements to be reproduced in order to guarantee the environmental functions needed by the society. Ecological funds do have their own identity that implies the possibility of defining expected characteristics. When dealing with ecological funds we can define for them states and impact combining extensive and intensive properties (see examples of Fig. 14 and Fig 15 in Part 1). Categories of accounting such as "air", "water", "land" are too generic to represent a useful external referent. In conclusion enriching the analysis with the concept of ecological funds is important since they make it possible to contextualize the quantitative assessments referring to an indicator of pressure.

For example the five themes could be replaced by:

(1) TERRESTRIAL ECOSYSTEMS – the indicators characterizing a pressure on ecological terrestrial funds can be divided in sub-categories reflecting different typologies of terrestrial ecosystems;

(2) AQUATIC FUNDS – these ecological funds include aquatic ecosystems (as a sub-themes) but also other types of funds such as Aquifers whose reproduction is required to preserve the regular supply of water to society (see (Madrid, et al., 2013));

(3) SOIL FUNDS – also in this case the indicators can be contextualized acknowledging the existence of different type of soils and a profile of distribution of the agricultural are across these different soils;

(4) the ATMOSPHERE – in this case we can use a common ecological fund for the various country. However it should be noted that what define "state", "pressure" and "impact" is the process of self-organization of the atmosphere (an ecological fund defined at the global scale) and not the concept of "air";

(5) INHABITED AREAS – this category represents a special case for the indicator included in the index under the theme "chemical and wastes". In fact, the indicators of environmental impact included in this theme do not refer to a type of pressure and potential impact to ecological systems, but rather to pressure and impact on humans. Therefore this category of indicators reminds the heading "Environmental Health" of the EPI composite indicator of Yale. In this case, the state to be considered to assess the consequence of the pressure are flows generated by humans that do affect humans

(information referring to the quadrants A and B in Fig. 13). Also in this case, these indicators should be aggregated using this criterion, since they are logically distinct from the others (the impact is on humans and not on ecosystems).

2.2.3 The distinction between "local environmental pressure" and "externalized environmental pressure"

The theoretical analysis of Fig 13 (in Part 1) shows the importance of making a distinction between the assessment of a "local environmental pressure" (described using information referring to the quadrants C and D of Fig. 13) and an "externalized environmental pressure" (that can be associated with the flows of imports in the quadrant B of Fig. 13).

This distinction, neglected in the EPI of Yale is neglected also in the Composite Index of Environmental Pressure. An example of a dual assessment referring to different categories of indicators is give in Fig. 2.3. The analysis of the local environmental pressure (on the left) is based on indicators reflecting the activities of domestic production and consumption. The analysis of the externalized environmental pressure (on the right) is based on indicators reflecting the activities required to produce and transport the imported goods consumed in the country.

There are many methods available to assess the environmental impact that can be assigned to the imports and they have been discussed with the team of EC-JRC-G03 (Econometric and Applied Statistical Unit) in the three day meeting at Ispra in March, 2014. In relation to this issue it is possible to find available datasets (e.g. "satellite accounting", "virtual water") from which one can calculate the environmental pressure to be associated with imports – e.g. considering changes in land use and use of inputs of typologies of agricultural production or the typical levels of resource consumption per typology of imported product.

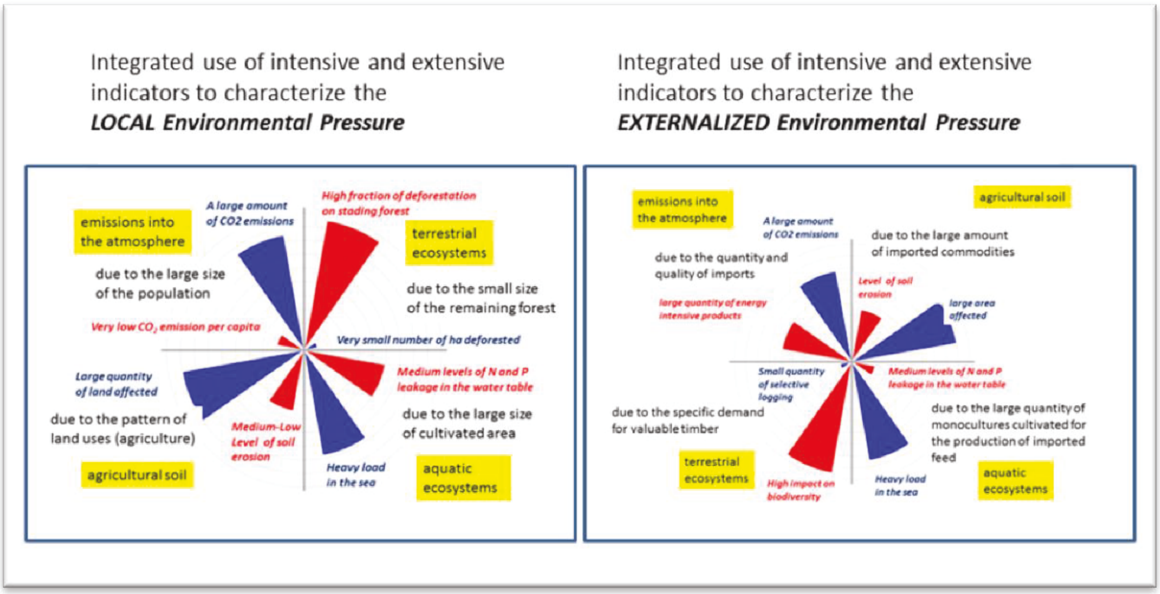


Fig. 2.3 The difference between an assessment of a LOCAL Environmental Pressure and an EXTERNALIZED Environmental Pressure

2.3 Suggestions for continuation and refinement of this line of investigation

The goal of the "*composite index of environmental pressures*" is to provide an effective characterization of the different types of pressures that a country exerts on the environment based on an integrated set of indicators. This composite index should be used to compare these pressure across different countries. This very ambitious goal requires a careful discussion of the pre-analytical choices leading to the formulation of an accounting protocol.

According to what discussed in Part 1 and to the comments on the two documents presented here (Part 2) I claim that this integrated assessment is possible, but it requires a more articulated method of accounting. More specifically the discussion of the pre-analytical choices should start from an overview of the conceptualization of the external referents (information to be gathered) required in the relation to the role of the various data, to be used either as a measure of pressure (the value of the attribute) or as an information used for contextualization (benchmarking) – an example is given in Fig. 2.4.

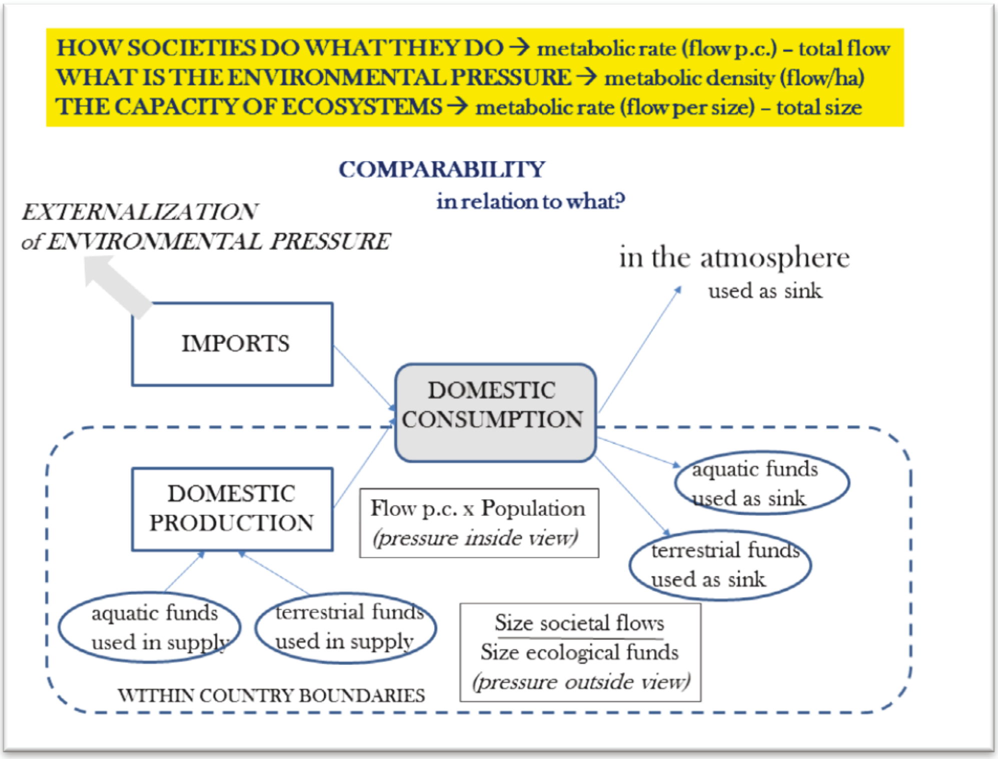


Fig. 2.4 An overview of the conceptualization of the external referents of the different indicators used to describe the environmental pressures of a society

Within this general framework of analysis:

(1) the quantitative integrated assessment should be based on a combination of intensive and extensive indicators providing: (i) an assessment relevant in relation to the internal view - the characterization of the investigated system in relation to the typology to which it belongs (how the instance of society is doing in relation the category to which it belongs); and (ii) an assessment referring to the external view – the

characterization of the size of the investigated system in relation to its interaction with the context (see Fig. 2.1);

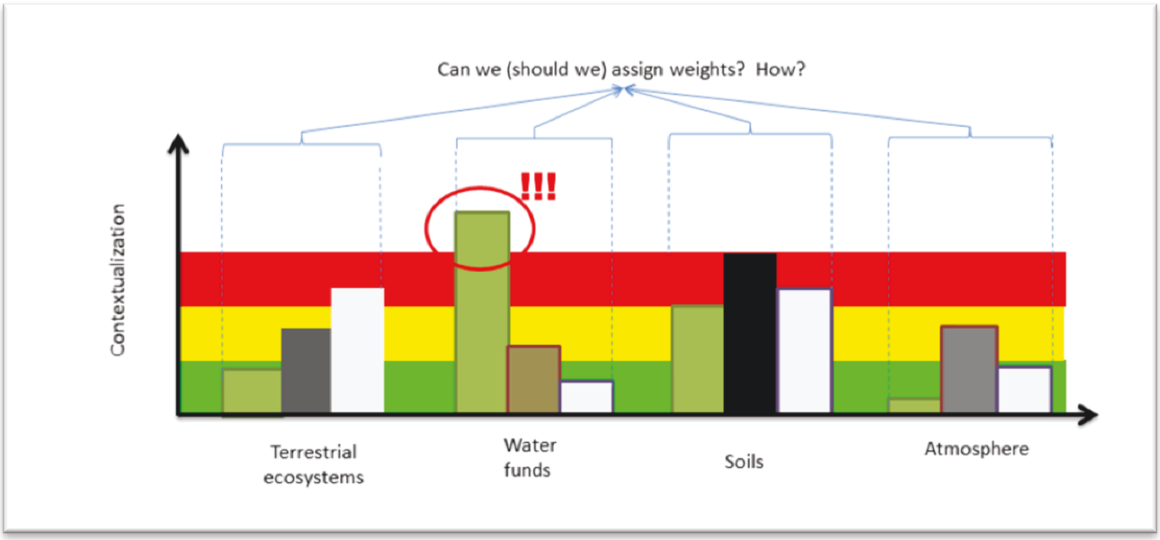


Fig. 2.5 Examples of contextualization of the value taken by indicators of pressure in relation to the states of the relative ecological funds (green, yellow and red)

(2) the indicators of impact referring to the activity of the society should be interpreted according to the characteristics of the ecosystem typologies (or the natural funds) that are impacted – e.g. those affecting the water funds, those affecting the soil, those affecting aquatic ecosystems. This division in groups makes it possible to associate the assessment of pressure to the concept of impact using a system of benchmarking. An example of this fact is provided in Fig. 2.5.
(3) the assessment should be based on a dual system of accounting for assessing both the Local Environmental Pressure (referring to states, pressure and impact observed within the boundaries of the Socio-ecological system); and the Externalized Environmental Pressure (referring to states, pressure and impact generated elsewhere because of the activities embodied in the imported goods and services) – see Fig. 2.3

In conclusion this integrated analysis should be based on a standardized characterization of the socio-ecological system considered, capable of illustrating the main features of the metabolic pattern of the society (the typology of society) in terms of benchmarks. In particular, the benchmarking should provide information referring to;

* Structure of the socioeconomic system - size and characteristics of the whole, plus the relative size and specific characteristics of the main parts (the state of the society) – Fig. 20 and Fig. 21 (Part 1);
* Imports/Exports (degree of openness) – Fig. 13 (Part 1);
* Stock-flows versus Fund-flows (non-renewable vs renewable resources use)

Then the metabolic pattern of the society has then be related to the metabolic pattern of the embedding ecosystems (the typology of ecosystem) across scales, hierarchical levels of organizations and dimensions. For this integration one should characterize:

* Structure of the ecological systems directly embedding the societies - size and characteristics of the ecological funds used to stabilize the flows (matter and energy) making possible the reproduction of the society (the state of ecosystems) – Fig. 14 and Fig. 15 (Part 1);
* Environmental Impact Matrix (the impact of ecosystems)

An integrated assessment making it possible to compare the environmental pressure in different countries comparing the situation in semantic terms, while assessing the specific pressure in quantitative terms in each country can be done. But it requires acknowledging that the required method of accounting cannot be based on the simplifications typical of reductionism.

Acknowledgement

This report has been prepared by Mario Giampietro for a study commissioned by the EC-JRC-G03 (Econometric and Applied Statistical Unit) – appointment letter No. 258573 (October 25th, 2013) – and it represents the final deliverable of that contract. During the preparation of this report Mario Giampietro spent three days at the EC JRC-GO3 (March 3rd-5th, 2014) to discuss preliminary results with Andrea Saltelli and his team. These three days of interaction have proven extremely useful and Mario Giampietro gladly acknowledges the input received by the entire team, especially by Michaela Saisana and Pawel Stano. Additional thanks are due to Pedro Lomas, Tiziano Gomiero and Cristina Madrid who have provided useful inputs during the preparation of the report.

Bibliography

Ahl, V. & Allen, T. F. H., 1996. *Hierarchy Theory.* s.l.:Columbia University Press.

Allen, T. & Hoekstra, T., 1992. *Toward a Unified Ecology.* New York: Columbia University Press.

Allen, T. & Starr, T., 1982. *Hierarchy: Perspectives for Ecological Complexity.* Chicago: University of Chicago Press.

Ashby, W., 1956. *An Introduction to Cybernetics.* s.l.:Chapman & Hall.

Bailey, K. D., 1990. *Social Entropy Theory.* Albany, NY: State University of New York Press.

Berkes, F. & Folke, C., 1998. *Linking Social and Ecological Systems: Management Practices and Social Mechanisms for Building Resilience.* Cambridge: Cambridge University Press.

Box, G., 1979. Robustness is the strategy of scientific model building. In: R. Launer & G. Wilkinson, eds. *Robustness in Statistics.* s.l.:Academic Press N.Y., pp. 201-236.

Chaitin, G. C., 1987. Algorithmic Information Theory. In: *Cambridge Tracts in Theoretical Computer Science Vol. 1.* Cambridge ed. Cambridge: Cambridge University Press.

Fiorito, G., 2013. Can we use the energy intensity indicator to study "decoupling" and "dematerialization" in modern economies?. *Journal of Cleaner Production,* Volume 47, pp. 465-473.

Georgescu-Roegen, N., 1971. *The Entropy Law and the Economic Process.* Cambridge, MA: Harvard University Press.

Giampietro, M., 2003. *Multi-Scale Integrated Analysis of Agro-ecosystems.* Boca Raton: CRC Press.

Giampietro, M., Allen, T. & Mayumi, K., 2006. The epistemological predicament associated with purposive quantitative analysis. *Ecological Complexity,* 3(4), pp. 307-327.

Giampietro, M., Mayumi, K. & A.H., S., 2013. *Energy Analysis for a Sustainable Future: The Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism.* s.l.:Routledge.

Giampietro, M., Mayumi, K. & Sorman, A., 2012. *The Metabolic Pattern of Society: Where Economists Fall Short.* s.l.: Routledge .

Giampietro, M., R., A., J., R.-M. & Bukkens, S., 2014. *Resource Accounting for Sustainability: the nexus between Energy, Food, Water and Land use.* s.l.:Routledge.

Giampietro, M. & Sorman, A., 2012. Are energy statistics useful for making energy scenarios?. *Energy,* 37(1), pp. 5-17.

Koestler, A., 1968. *The Ghost in the Machine.* New York: The MacMillan Co..

Koestler, A., 1969. Beyond Atomism and Holism - the concept of the Holon. In: A. Koestler & J. Smythies, eds. *Beyond reductionism.* London: Hutchinson, pp. 192-232.

Koestler, A., 1978. *Janus: a summing up.* London ed. s.l.: Hutchinson.

Lomas, P. & Giampietro, M., 2014. Environmental Accounting for Sustainability: Linking Societal and Ecosystem Metabolisms. *BioScience,* Volume submitted.

Madrid, C., Cabello, V. & Giampietro, M., 2013. Water-use sustainability in Socio-ecological systems. *BioScience,* 63(1), pp. 14-24.

Madrid, C. & Giampietro, M., 2014. Re-hydrating social metabolism: key issues and a proposal. *Journal of Industrial Ecology,* Volume submitted.

Mandelbrot, B., 1967. How Long is the Coast of Britain? Statistical Self-Similarity and fractal dimensions. *Science,* Volume 155, pp. 636-638.
Margalef, R., 1968. *Perspectives in Ecological Theory.* Chicago: The University of Chicago Press.
Millennium Ecosystem Assessment, 2005. *http://www.maweb.org/en/index.aspx,* s.l.: s.n.
O' Neill, R., 1989. Perspectives in hierarchy and scale. In: J. Roughgarden, R. May & S. Levin, eds. *Perspectives in Ecological Theory.* Princeton: Princeton University Press, pp. 140-156.
Odum, E., 1969. The strategy of ecosystem development. *Science,* Volume 164, pp. 262-270.
Odum, E. P., 1971. *Fundamentals of ecology.* 3rd ed. Philadelphia: Saunders.
Odum, H., 1971. *Environment, Power, and Society.* New York: Wiley-Interscience.
Prigogine, I., 1978. *From Being to Becoming.* San Francisco: W.H. Freeman and company.
Prigogine, I. & Stengers, I., 1984. *Order Out of Chaos.* New York: Bantam Books.
Reinert, E., 2011. The terrible simplifiers: common origins of financial crisis and persistent poverty in economic theory and the New 1848 moment. In: A. Chowdhury & J. K. Sundaram, eds. *Poor Poverty: The Impoverishment of Analysis, Measurement and Policies.* s.l.:Bloomsbury Academic.
Rosen, R., 1977. Complexity as a System Property. *Int. J. General Systems,* Volume 3, pp. 227 -232.
Rosen, R., 1985. *Anticipatory Systems: Philosophical, Mathematical and Methodological Foundations.* New York: Pergamon Press.
Rosen, R., 1991. *Life Itself: A Comprehensive Inquiry Into the Nature, Origin and fabrication of Life.* New York : Columbia University Press.
Rosen, R., 2000. *Essays on Life Itself.* New York: Columbia University Press.
Salthe, S. N., 1985. *Evolving Hierarchical Systems: Their Structure and Representation.* New York: Columbia University Press.
Simon, H. A., 1962. The architecture of complexity. *Proc. Amer. Philos. Soc.,* Volume 106, pp. 467-482.
Ulanowicz, R., 1986. *Growth and Development: Ecosystem Phenomenology.* New York, NY: Springer-Verlag.
Ulanowicz, R., 1997. *Ecology, The Ascendent Perspective.* New York: Columbia University Press.
Whyte, L. L., Wilson, A. G. & Wilson, D., 1969. *Hierarchical Structures.* New York: American Elsevier Publishing Company, Inc.,.

European Commission
EUR 26917 EN – Joint Research Centre – Econometrics and Applied Statistics
(DDG.01)
Title: Mono-dimensional accounting and multidimensional measures of sustainable growth

Author: Mario Giampietro

Luxembourg: Publications Office of the European Union

2014 – 66 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series –ISSN 1831-9424 (online)

ISBN 978-92-79-44003-8 (PDF)

doi:10.2788/244356

LB-NA-26917-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

doi:10.2788/244356

ISBN 978-92-79-44003-8

Publications Office