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Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MUSIASEM): An Outline of Rationale and Theory[*]

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Abstract: This paper presents an outline of rationale and theory of the MuSIASEM scheme (Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism). First, three points of the rationale behind our MuSIASEM scheme are discussed: (i) endosomatic and exosomatic metabolism in relation to Georgescu-Roegen's flow-fund scheme; (2) the bioeconomic analogy of hypercycle and dissipative parts in ecosystems; (3) the dramatic reallocation of human time and land use patterns in various sectors of modern economy. Next, a flow-fund representation of the MUSIASEM scheme on three levels (the whole national level, the paid work sectors level, and the agricultural sector level) is illustrated to look at the structure of the human economy in relation to two primary factors: (i) human time - a fund; and (ii) exosomatic energy - a flow. The three levels representation uses extensive and intensive variables simultaneously. Key conceptual tools of the MuSIASEM scheme - mosaic effects and impredicative loop analysis - are explained using the three level flow-fund representation. Finally, we claim that the MuSIASEM scheme can be seen as a multi-purpose grammar useful to deal with sustainability issues.

1. Introduction: The Metabolism of Human Society and the Biophysical Analysis

The "metabolism of human society" is a notion used to characterize the processes of energy and material transformation in a society necessary for its

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continued existence. This notion became a scientific subject starting the mid-19th century because of the work of authors such as Liebig, Boussingault, Moleschott, Jevons, Podolinski, Arrhenius, Ostwald, Lotka, White, and Cottrell (for an overview, see Martinez-Alier, 1987). However, it was in the 1970s (triggered by the oil crisis) that the study of energy and material metabolism of human society became a fashionable scientific exercise. In the 1970s, energy and material metabolism of human society was widely applied to farming systems, economic systems, and in general to describe the interaction between socioeconomic systems and their environment (e.g., Georgescu-Roegen, 1971; Odum, 1971, 1983; Rappaport, 1971; Leach, 1976; Gilliland, 1978; Slesser, 1978; Pimentel and Pimentel, 1979; Morowitz, 1979; Costanza 1980; Herendeen, 1981; Hall et al, 1986; Smil, 1987; Ayres and Simonis, 1994; Fischer-Kowalski, 1998).

This paper presents the rationale and theoretical core of our scheme, Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM). Section 2 presents the rationale behind MuSIASEM scheme in comparison with other energy analyses and conventional economic analysis. Section 3 introduces a flow-fund representation on three levels in the economic process in terms of human time allocation and exosomatic energy allocation. Section 4 discusses the two key conceptual tools—mosaic effects and impredicative loops—within MuSIASEM scheme. Section 5 compares MuSIASEM scheme to a construction and evolution of multi-purpose grammar showing the strength of MuSIASEM for dealing with sustainability issues.

2. Rationale behind MuSIASEM Scheme

The methodology presented here is called Multi-Scale Integrated Analysis of Societal and Ecosystem Metabolism (MuSIASEM) - originally termed as Multi-Scale Integrated Analysis of Societal Metabolism (MSIASM) and later extended to include the interplay between the socioeconomic systems and the ecosystems. It was introduced by Giampietro and Mayumi (1997, 2000a, 2000b) and more systematically investigated by Giampietro (2003). Empirical analyses based on this approach have been conducted on several countries including Ecuador (Falconi-Benitez, 2001), Spain (Ramos-Martin, 2001), and Vietnam (Ramos-Martin and Giampietro, 2005).

The rationale behind the MuSIASEM scheme can be summarized as follows: (i) energetic and material flows can be analyzed using the concept of endosomatic and exosomatic metabolism in relation to Georgescu-Roegen's flow-fund scheme; (2) the structure of the dynamic budget of the metabolism can be analyzed using the bioeconomic analogy of hypercycle and dissipative parts in ecosystems; (3) economic development entails dramatic changes in the overall size of metabolism, the pace of metabolism and the structural typology of the dynamic budget of energy, forcing a dramatic reallocation of the profiles of human activity and land uses over the various sectors of the economy.

Lotka (1956) introduced the notion of human society consisting of a double metabolism: (i) one related to *endosomatic* organs part to the human body; and (ii) another related to *exosomatic* organs fabricated by humans such as tools and mechanical devices. This idea was further elaborated by Georgescu-Roegen (1971) in his efforts to integrate economic and biophysical processes in view of sustainability. To effectively address this double-metabolism and to indicate the need for an integrated approach to sustainability issues, Georgescu-Roegen

introduced the term *Bioeconomics* and the flow-fund scheme. Flow coordinates are elements that enter but do not exit the production process or, conversely elements that exit without having entered the process (e.g., a new product). Flow coordinates include matter and energy *in situ*, controlled matter and energy, and dissipated matter and energy. Fund coordinates (capital, labor, and Ricardian land) are agents that enter and exit the process, transforming input flows into output flows. Fund coordinates can only be used at a specified rate and must be periodically renewed. Georgescu-Roegen's scheme can account for scale and time duration and address the question of whether or not a given technology is *viable*. A technology is viable if and only if the economic system it represents can operate steadily, with environmental flows of available energy and matter forthcoming in necessary amounts in relation to the constraints determined by the fund elements. Georgescu-Roegen's scheme is based on an explicit acknowledgment of both multi-scale integrated analysis and the existence of biophysical constraints on the process of economic development (Georgescu-Roegen, 1977).

Another crucial idea associated with the MuSIASEM scheme is Zipf's characterization of socioeconomic development as bio-social forms of organization (Zipf, 1941). Zipf proposed a basic principle of socioeconomic development: in order to be able to consume more, a socioeconomic system has to invest more in the consumption sectors both in terms of capital formation and human time. In his analysis of ecosystem structure, Ulanowicz (1986) introduced a similar idea based on Eigen's pioneering work (Eigen, 1971). According to Ulanowicz, the network of matter and energy flows making up an ecosystem can be divided into two parts: one part is a hypercycle and the other is a purely dissipative part. The hypercycle part is a net energy supplier for the rest of the ecosystem. Since dissipation is always "necessary to build and maintain structures at [the] sub-compartment level" (Ulanowicz 1986: 119), the part producing a net supply of energy for the rest must comprise activities that generate a positive feedback by taking advantage of gradient of free energy outside the system (e.g. solar energy). The role of the hypercyclic part is to drive and keep the whole ecosystem away from thermodynamic equilibrium. The dissipative part comprises activities that are net energy degraders. However, this part is not useless for the whole system. The dissipative part provides a control mechanism over the entire process of energy transformations, explores innovations (guaranteeing adaptability) and stabilizes the evolutionary sustainability of the whole system. In fact, an ecosystem made of a hypercyclic part alone cannot be stable over time. Without the stabilizing effect of the dissipative part, a positive feedback "will be reflected upon itself without attenuation, and eventually the upward spiral will exceed any conceivable bounds" (Ulanowicz, 1986: 57). In the analogy with human societies the hypercyclic part of the society is made up by the economic sectors generating profit and goods and services and the purely dissipative part the final consumption sector.

One of the theoretical pillars of MuSIASEM is that the technological development of a society can be described in terms of *an acceleration of energy and material consumption together with the dramatic reallocation of distribution of age classes, human time profile of activities and land use patterns in various sectors of modern economy, resulting in time and land saving in the energy and agricultural sectors* (Mayumi, 1991). Within the MuSIASEM scheme qualitative differences in energy forms are not addressed using thermodynamic concepts such as exergy or enthalpy. Rather, the time dimension of energy transformation in the

energy sector and its relation to other economic sectors is used to focus on crucial qualitative factors, which are neglected in the traditional biophysical and thermodynamic analysis. MuSIASEM is an attempt to incorporate these qualitative differences in the intensity of flows into a simple scheme that can be used to analyze the societal metabolism of an economy for sustainability issues.

3. A Flow-Fund Representation of MUSIASEM on Three Levels

The MuSIASEM scheme is an operationalization of Georgescu-Roegen's bioeconomic approach to the economic process that explicitly addresses biophysical feasibility and constraints. Biophysical feasibility and constraints are analyzed in relation to: (i) socioeconomic factors within production and consumption, (ii) energy and material transformation processes, (iii) demographic changes, (iv) the profiles of human time allocation and land uses in various economic sectors, and (v) the impact on ecosystem health resulting from the compatibility of the flows of energy and matter metabolized by society and the supply and sink capacity of the ecosystems embedding the society. It is also possible to introduce GDP (or food production in the case of agroecosystem analysis) as additional flows to be considered and land as another fund to be used in the MuSIASEM scheme. However, in this paper the MuSIASEM scheme is presented to look only at two primary factors: (i) human time as a fund in terms of hours; and (2) exosomatic energy as a flow in terms of Joules.

Figure 1. A Flow-Fund Representation of MSIASM Scheme on Three Levels
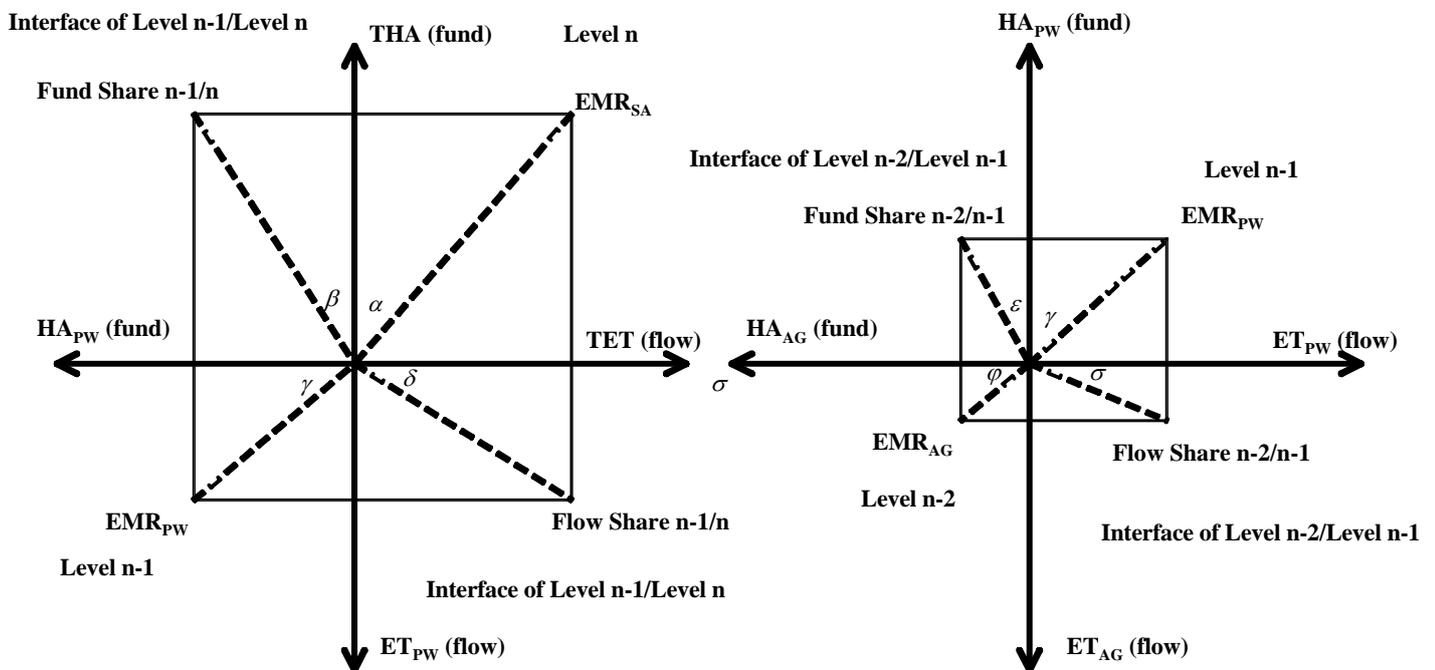
A flow-fund representation of MuSIASEM on three levels (the whole national level, the paid work sectors level, and the agricultural sector level) is illustrated in Figure 1 using extensive and intensive variables. Here variables that are additive, like volume, are called *extensive variables*. They depend on the size or the extent of the system. Variables that cannot be added, but represent a ratio such as

pressure or potential are called *intensive variables*. They are intrinsic to the system and can vary from point to point and in components of the metabolic system operating at different levels and scales.

There are four extensive variables and four intensive variables referring to level n and level n-1 on the left in Figure. 1.

The four extensive variables are:

* THA is a fund element - the total human time available for the whole economy for one year, i.e., 24 hours × 365 days × population. THA consists of two parts, the total labor hours (HA_{PW}) and the rest allocated in household sector (HA_{HH}) where THA= HA_{PW}＋HA_{HH}.

* HA_{PW} is a fund element - the total labor hours in paid work sectors for one year.

* TET is a flow element - the total exosomatic energy consumption in terms of Joule for the whole economy for one year.

* ET_{PW} is a flow element - the exosomatic energy consumption for the paid work sectors for one year. TET = ET_{PW} + ET_{HH} where ET_{HH} is the exosomatic energy consumption for the household sector.

The four intensive variables are:

*EMR_{SA} ($\tan\alpha$) is a flow-fund ratio - the biophysical energy intensity for the whole economy where EMR_{SA}= TET/THA. EMR_{SA} indicates how much exosomatic energy is consumed per hour of human time at the level of the whole economy.

* Fund Share n-1/n ($\tan\beta$) is the fund ratio between HA_{PW} at level n-1 and THA at level n. This ratio indicates how much human labor is used in the paid work sectors compared with the total human activity. The combined effect of demographic structure over age class, social rules and habits, level of education, and workload for paid workers all determines the Fund Share n-1/n.

* EMR_{PW} ($\tan\gamma$) is a flow-fund ratio and the biophysical energy intensity in the paid work sectors where EMR_{PW}= ET_{PW}/HA_{PW}. EMR_{PW} indicates how much exosomatic energy is used per hour of labor in the paid work sectors as a whole.

* Flow Share n-1/n ($\tan\delta$) is the flow ratio between ET_{PW} at level n-1 and TET at level n. This ratio indicates how much energy is used in the paid work sectors compared with the total exosomatic energy consumption for the whole economy.

The paid work sector (HA_{PW}) is divided into three sectors: (i) agricultural sector (AG for short); (ii) energy and mining sector together with other productive sectors (PS for short); (iii) service and government sector (SG for short).

There are two additional extensive variables and three intensive variables referring to level n-1 and level n-2 as illustrated on the right of Figure.1.

On the right in Figure.1 we illustrate only one of the three sub-sectors considered at the level n-1 – the agricultural sector just for illustrating the approach across different levels. The two extensive variables referring to the agricultural sector are HA_{AG} and ET_{AG}:

*HA_{AG} is the total labor hours in the agricultural sector for one year.

*ET_{AG} is the exosomatic energy consumption in the agricultural sector for one year.

Three intensive variables:

* Fund Share n-2/n-1 ($\tan\varepsilon$) is the fund ratio between HA_{AG} at level n-2 and HA_{PW} at level n-1. This ratio indicates how much human labor is used in the agricultural sector compared with that in the paid work sectors as a whole.

* EMR_{AG} ($\tan\varphi$) is a flow-fund ratio and the biophysical energy intensity for the agricultural sector where EMR_{AG}=ET_{AG}/HA_{AG}. EMR_{AG} indicates how much exosomatic energy is used per hour of labor in the agricultural sector as a whole.

* Flow Share n-2/n-1 ($\tan\sigma$) is the flow ratio between ET_{AG} at level n-2 and ET_{PW} at level n-1. This ratio indicates how much exosomatice energy is used in the agricultural sector compared with the exosomatic energy in the paid work sectors as a whole.

Obviously, a similar system of accounting can be applied to the PS sector and the SG sector.

4. Key Conceptual Tools of MuSIASEM Scheme: Mosaic Effects and Impredicative Loop Analysis

Since the MuSIASEM approach explicitly deals with population structure in terms of the distribution of hours of human activity across compartments, it is possible to analyze the relation between human time allocation and exosomatic energy flows. Therefore, the combination of extensive variables and intensive variables gives us redundant but useful information to increase the robustness of the analysis. Such characteristic can be termed as *mosaic effects across levels*. A good metaphor for the mosaic effect is the process of solving a crossword puzzle. Due to the particular organizational structure of the puzzle, we can guess a lot of missing information about individual words or double check given information by taking advantage of the internal rules of coherence of the system at different places. The right word can be easily identified if some other crucial words are already identified in the puzzle. There are situations in which one can retrieve a horizontal word totally unknown, just by solving all the vertical words crossing it. In the case of hierarchically organized metabolic systems, individual elements express a predictable behavior due to the intrinsic organizational structure. They define for themselves what is metabolized and at what pace in parallel on different levels. This peculiar characteristic makes it possible to obtain a mosaic effect when looking simultaneously at their metabolism on various levels. For example, in Figure.1, Flow Share n-2/n can be inferred when Flow Share n-1/n and Flow Share n-2/n-1 are already identified. In the same way, Fund Share n-2/n can be inferred when Fund Share n-2/n-1 and Fund Share n-1/n are already known. In fact, any of the three Flow Shares (or Fund Shares) is identified/determined by the other two Flow Shares (or Fund Shares). The metabolic characteristic at a focal level is derived from another set of characteristics referring to the higher and lower levels and vice versa. That is, the generation of redundant information makes it possible to reasonably infer plausible values for certain variables from the information coming from different hierarchical levels. The generation of redundant information is also useful to see whether or not the data set coming from various sources are compatible with each other, or whether or not the assumptions about future scenarios are plausible, enhancing in this way the robustness of the MuSIASEM scheme.

The term, 'impredicative', might sound strange to readers of this paper. However, without grasping the meaning of this term, any scientific activity in the field of sustainability issues could be muddled. So, let us begin with the definition introduced in mathematical logic:

"When a set M and a particular object m are so defined that on the one hand m is a member of M, and on the other hand the definition of m depends on M, we say that the procedure (or the definition of m, or the definition of M) is impredicative. Similarly when a property P is possessed by an object m whose definition depends on P (here M is the set of objects which possess the property

P). An impredicative definition is circular, at least on its face, as what is defined participates in its own definition" (Kleene, 1952, p. 42).

In fact, impredicativity is considered as a nuisance in scientific reductionism, since it makes it impossible to establish a linear causation, which is a typical goal of any traditional scientific activity. Thus, in order to avoid impredicativity, the usual procedure adopted by scientific analysis is to choose a particular linear causation (a narrative explaining the facts of interest, resulting from a choice of a single scale) and resort to empirical validation to see whether or not this particular causation is acceptable, whenever controlled and repeated experiments are possible. However, when dealing with a metabolic system operating on different hierarchical levels it becomes difficult to obtain a robust identification of just a linear causal relation. This is especially true when considering a set of 'attributes' referring to different processes occurring simultaneously at different levels. In this case, what can we do most?

Figure 2. Impredicative loop relationships among various categories (variables or parameters) belonging to three levels

$$TET(n) = ET_{PW}(n-1) + ET_{HH}(n-1) = ET_{AG}(n-2) + ET_{PS}(n-2) + ET_{SG}(n-2) + ET_{HH}(n-1)$$

$$THA(n) = HA_{PW}(n-1) + HA_{HH}(n-1) = HA_{AG}(n-2) + HA_{PS}(n-2) + HA_{SG}(n-2) + HA_{HH}(n-1)$$

$$Flow - Share(n-1/n) = \frac{ET_{PW}(n-1)}{TET(n)} \qquad Fund - Share(n-1/n) = \frac{HA_{PW}(n-1)}{THA(n)}$$

$$Flow - Share(n-2/n-1) = \frac{ET_{AG}(n-2)}{ET_{PW}(n-1)} \qquad Fund - Share(n-2/n-1) = \frac{HA_{AG}(n-2)}{HA_{PW}(n-1)}$$

$$EMR_{SA}(n) = \frac{TET(n)}{THA(n)} = \frac{ET_{PW}(n-1) + ET_{HH}(n-1)}{HA_{PW}(n-1) + HA_{HH}(n-1)} = \frac{ET_{AG}(n-2) + ET_{PS}(n-2) + ET_{SG}(n-2) + ET_{HH}(n-1)}{HA_{AG}(n-2) + HA_{PS}(n-2) + HA_{SG}(n-2) + HA_{HH}(n-1)}$$

$$EMR_{AG}(n-2) = \frac{ET_{AG}(n-2)}{HA_{AG}(n-2)} = \frac{TET(n) - ET_{HH}(n-1) - ET_{PS}(n-2) - ET_{SG}(n-2)}{THA(n) - HA_{HH}(n-1) - HA_{PS}(n-2) - HA_{SG}(n-2)}$$

Impredicative loop analysis (Giampietro, 2003) is an attempt to deal with this problem within the MUSIASEM scheme. It works by: (i) deriving a set of ex-post (or accounting) impredicative relations among a selected set of categories (the definition of flows, funds and compartments) to which the division between variables and parameters are assigned later; (ii) trying to identify a set of plausible causal relations among these categories based on available data; (iii) identifying crucial constraints on variables belonging to different hierarchical levels in response to changes in some of the selected parameters. Figure 2 shows such a set of impredicative relations among categories (variables or parameters) on three levels introduced in Figure. 1. Numbers indicated in parenthesis (n, n-1, and n-2), show the hierarchical level to which the respective category (variable or parameter) belongs. Any change in any variable (or parameter) belonging to a particular level can/must be associated with (is affecting/is affected by) changes in other variables (or parameters) belonging to other levels. So, any change in any variable (or parameter) will result in an overall change in configuration among

various variables (or parameters). It should be noticed that any a priori choice of division between variables and parameters cannot be made by default, contrary to the case of linear causation typical in optimization procedures in neoclassical economics. This distinction depends on the task of the analysis: what could happen if this parameter is changed? Or what should be changed to get this result? Or what would represent the bottleneck if we try to change the overall result of these integrated set of relations? On the contrary, the usual procedure in neoclassical economics is conducted to look for an optimal set of values of a set of objective functions subject to a set of constraints. This requires, however, that the set of causal relations, based on a clear division between variables and parameters, must be already chosen in the pre-analytical stage. Due to this particular nature of linear causation, dynamic systems in conventional economics cannot deal with real structural changes that are intrinsic to evolving systems (Giampietro, 2003; Mayumi, 2005; Giampietro et al. 2006). In fact, dynamical systems within themselves cannot deal with identification of both structural causality and functional causality for evolving systems *endogenously*. By structural causality we mean which part of a system affects other parts of the system. By functional causality we mean how a part of a system affects other parts of the system. Impredicative loop analysis allows us to visualize the existence of a set of reciprocal constraints affecting the forced equilibrium of the dynamic budget in societal metabolism. A plausible configuration of human time allocation and exosomatic energy distribution among various variables (or parameters) using two four angle representations can only be obtained by coordinated changes of the characteristics of parts in relation to the characteristics of the whole, and changes in the characteristics of the whole in relation to the characteristics of the parts. In this way the MuSIASEM approach is used to make comparisons between the values of variables referring to different hierarchical levels or the same hierarchical level but belonging to different places. MuSIASEM has the explicit goal of addressing the existence of chicken-egg patterns in the perception and representation of hierarchically organized systems operating on multiple levels. Whenever we deal with any metabolic system, the identity of the whole defines the identity of the parts and vice versa. MuSIASEM is an attempt to deal with this fact, rather than pretending that this is not a crucial issue.

5. Conclusion: MuSIASEM as a Construction and Evolution of a Multi-Purpose Grammar for Dealing with the Sustainability Issues

Within the narrative adopted by western science the sustainability issues have always been framed as "the preservation of the status quo" for as long as possible. In this narrative the perceived threats against the "status quo" come from the finiteness of natural resources and the fragility of ecological processes, which are required to have life on this planet in the first place. This narrative or "story telling" entails by default that when dealing with sustainability the identity of the "story-teller" has never been questioned, let alone changed. It is the "external world" which has to be fixed and submitted to "human wants". This naïve "story-telling about sustainability" is behind the ideological assumptions of "full substitutability of production factors" in neo classical economics. In this "story-telling", at the basis of the standard economics, humans will never run out of resources or never be constrained by ecological processes. In fact, as soon as the price will be enough "high" to generate investments for substitution, the scarce

"resources" - no matter what type of resources we are talking about - will be then miraculously made available by technological development.

In response to this story-telling a drastically different "story-telling" about sustainability has been proposed by Silvio Funtowicz and Jerry Ravetz (1990; 1993). This "story-telling" has been developed in relation to the new challenges faced by Science for Governance, and it is based on the concept of "the tragedy of change". In this alternative view, sustainability is not about fixing the external world anytime we perceive a problem here and now, but it is about learning how to co-evolve with our context consisting of other learning systems. This alternative take on sustainability entails learning how to become "something else" collectively by moving to different feasible and desirable identities of the set of story-tellers.

Unfortunately, scientific tools used so far to deal with the concept of "sustainability" tend to reflect the original "story-telling" of the enlightenment typical in the western culture. The selection of analytical tools is based on "heroic simplifications" and models based mainly on differential equations and other formal systems of inference which are *semantically closed*. They can represent only specific events isolated in the pre-analytical framing of the relevant issues, by using a finite set of attributes (parameters and variables) and adopting a single scale at the time, according to *the chosen narrative* (Giampietro et al. 2006a; 2006b). When using these analytical tools the "formalized identity" of the modeled system has to be decided in advance and it will remain the same "by default" through whatever analysis and simulation one decides to perform.

The MuSIASEM scheme outlined in this paper can be a flexible meta-framework useful to describe a set of expected relations among a set of formal categories (variable and parameters) derived from a set of semantic categories. By a semantic category we mean "an expression" whose meaning could be understandable (or shared) among users of the expression, and in many occasions could be represented in terms of a set of formal categories following a set of definite rules. For example, in Section 2, we state that the technological development of a society can be described in terms of an acceleration of energy and material consumption together with the dramatic reallocation of distribution of age classes, human time profile of activities and land use patterns in various sectors of modern economy, resulting in time and land saving in the energy and agricultural sectors. The expressions such as "acceleration of energy consumption", or "time saving in the energy" and "time saving in the agricultural sector" are examples of semantic categories. These semantic categories are then expressed in terms of formal categories such as EMR_{SA} or Fund-Share n-1/n or Fund-Share n-2/n (Figure. 1) and represented in terms of internal relations among these formal categories (variables or parameters) belonging to various levels (Figure. 2). The different selections of categories used in the MuSIASEM scheme can be divided into: (i) semantic categories – the categories used by the analyst to make sense of the analysis (e.g., indicators of performance); and (ii) formal categories - the categories used to provide a formal quantification. Then the formal categories are divided into tokens (data) and names (numbers derived from the data after the application of production rules). The given selection must make it possible to use external referents (sources of empirical information) referring to the elements represented on the different hierarchical levels over the impredicative loop (Figure 1 and Figure 2).

Under this circumstance the MuSIASEM scheme can be regarded as a meta-system of accounting based on a flexible network of expected relations between

semantic categories (e.g. relevant attributes of sustainability) and formal categories (names – indicators) generated by production rules applied to gathered data (tokens) – Giampietro et al. 2008. This framework can also be expressed as Multi-Purpose Grammar that is associated with the jargon used in software development. A Multi-Purpose Grammar entails a preliminary definition of:
(1) A taxonomy – the set of semantic categories and formal categories used in the grammar. This set consists of the types of types that are used in the grammar;
(2) The vocabularies for the various categories included in the taxonomy – the set of attributes used to identify/characterize the various elements of the different sets. This set consists of relevant meanings and information formalized using names and tokens;
(3) The production rules to be applied to formal categories using the distinction between "tokens" (or "an instance of a linguistic expression") and "names". Tokens are associated with a data set which must be assigned to the grammar for its operation (data input). Then, the production rules are associated with the formal system of inference determining the values of "names" starting from the data input.

As emphasized in the first part of this section, negotiating "how to become something else" while "preserving a shared set of values" requires an informed and fair process of deliberation. Humankind as a whole (and not only its hegemonic part) has to decide how to deal with the semantics of sustainability, which entails answering a set of questions such as: "sustainability of what?", "sustainability for whom?", "sustainability for how long?", "sustainability at which cost?" (Tainter, 2008). Scientific analysis cannot and should not be used to answer these questions, but can and should be used to help the society in learning how to deliberate about them. However, for this task a new type of science is required that is able to deal with the complexity associated with the issue of sustainability. We believe that by adopting the MuSIASEM scheme it is possible to generate more elaborated and flexible analysis based on an integrated definition of several dynamic budgets referring to different categories of flows (food energy, exosomatic energy, added value, key material flows) which can be represented against different definitions of a multi-level matrix of funds – e.g. human activity and land uses - to address also other type of constraints, including economic and demographic aspects.

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