Development and Comparison of Sustainability Indicators
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DECOIN – Deliverable D2.2 of WP2

Recommendations for the use of analytical frameworks for monitoring and policy making

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DECOIN – Deliverable D2.2 of WP2

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1. Target of the report

According to the DECOIN Description of Work, Workpackage 2 deals with the assessment of a given set of analytical frameworks and evaluation tools of sustainable development. The insight gained from this analysis will form the basis for the work in WP3 and WP4, where new approaches will be developed. Therefore the work in this WP deals only with the assessment of a sample of different types of frameworks and evaluation tools. This is to say that a more comprehensive overview of the frameworks found in literature for dealing with the issue of sustainable development would include a large variety of analytical methods such as statistical and econometric analyses, environmental accounting, inter-temporal optimisation as well as systems dynamics analysis. However, the terms of reference for the DECOIN project was to focus in this assessment only on new approaches in this field, aimed at applying the general philosophy of multi-criteria analysis in combination with other tools.

The content of the work to be done in WP2 was divided during the pre-contract negotiation phase of the DECOIN project between two parallel projects, DECOIN and INDI-LINK. It was agreed on that the DECOIN Consortium will concentrate only on the frameworks identified in the Description of Work, while INDI-LINK Consortium will include more comprehensive coverage of different frameworks in their work.

The following is a detailed description of the WP2 activity (from DoW):

Objectives:
The target of WP2 is to examine potential analytical frameworks for the assessment of the interlinkages between trends and to make recommendations for their use in monitoring and policy making.
Description of work: Different potential analytical frameworks for the assessment of interlinkages between trends are analysed from the point of view of: (i) their analytical soundness, (ii) their comprehensiveness (in respect of the possibilities to analyse the different dimensions of sustainability, different time scales and different spatial coverage), (iii) their reporting capability (including aspects of easiness to understand the results and the calculation procedures, visualization capability, transparency of the methodology), (iv) easiness to use (data input, flexibility of use with different quality of data, flexibility for different institutional settings). Based on the assessment of the different analytical frameworks recommendations will be made for their use in monitoring and policy making. The different analytical frameworks to be examined in this WP2 are: *DPSIR, PSR, STEEPV, MIPS, SUMMA, MSIASEM, ASA*.
Deliverables: D2.1 Report on the assessment of different analytical frameworks (Month 12) D2.2 Report of the recommendations for the use of analytical frameworks in monitoring and policy making (Month 18)
Milestones and expected result: Assessment of analytical frameworks Recommendations for the use of analytical frameworks for monitoring and policy making

2. General considerations on the criteria used for the assessment

The scientific literature dealing with assessments/analyses of sustainability issue includes different typologies of quantitative frameworks and evaluation procedures. When performing a comparative evaluation of approaches such as DPSIR, MIPS, MSIASEM, ASA, LCA we are dealing with a comparative evaluation of "apples" and "oranges". This is to say, that these different approaches are quite heterogeneous in relation to what they claim to do and in relation to what they actually do. This makes a comparison difficult since the considered tools are based on the use of different: (i) methodological approaches - e.g. heuristic methods *versus* fully formalized models; (ii) selections of attributes/indicators - e.g. referring to the characteristic of the society *versus* the characteristics/impact on the environment; and (iii) purposes - e.g. approaches looking for an appropriate mix of criteria to be used in the analysis *versus* approaches looking for protocols to be used for a given quantitative indicator. This implies that some methods deal only with semantic categories – e.g. DPSIR discussing of the various criteria to be considered in relation to different dimensions of sustainability - whereas other methods deal with numbers obtained from calculations defined by the analyst – e.g MIPS.

Therefore, before getting into an analysis of the strength and weakness of the different tools found in literature for dealing with the issue of sustainability, it is important to develop a taxonomy of analytical frameworks and evaluation procedures. In this way it becomes possible to categorize the various approaches considered in this comparative evaluation in relation to: (i) their objectives; and (ii) their ability of delivering results in relation to these objectives.

2.1. Proposed Taxonomy for analytical frameworks used to generate sustainability indicators

There are analytical frameworks that focus on the appropriate definition of the issue of sustainability – for example the DPSIR approach – in terms of a choice of relevant aspects to be considered in the analysis. These frameworks look for an effective procedure to be used to identify WHAT is relevant in relation to sustainability issues. By defining WHAT is relevant for sustainability, it becomes possible to focus on a set of "relevant attributes" of sustainability (semantic categories, which have to be considered in the analysis of sustainability). Then these "relevant attributes" can be quantified by selecting an appropriate set of proxy variables.

There are other analytical frameworks – for example MIPS – that already assume the identification of a relevant attribute of sustainability – in this case the material intensity of a service delivered to the economy – and focus on HOW the specific attribute is different when considering different situations or processes.

This general discussion is important since it points at two distinct "quality checks" to be performed, when assessing the usefulness and effectiveness of analytical frameworks used for generating sustainability indicators. When dealing with analytical framework proposed for generating WHAT indicators, it is the ability of selecting the right choice of semantic categories that matters, when dealing with analytical framework generating HOW indicators, it is the ability of selecting the right choice of data and protocols – in relation to the issue to be dealt with - that matters.

In conclusion, the generation of sustainability indicators entails two distinct challenges. It requires the ability to perform both:

1. a wise choice of semantic categories (criteria/attributes to be included in the analysis) for issue definition and problem structuring. Only in this way, the following quantitative analysis will be able to generate a relevant input for policy discussion; and
2. a pertinent choice of formal categories and production rules (protocols). The chosen set of proxy variables, after the gathering of the relative data, must be able to provide, within the chosen issue definition/problem structuring, a reliable quantitative output for characterizing situations, options and determining, whenever possible, causal relations.

At this point it is possible, when classifying analytical methods, to make a distinction between:

A. methods that explicitly address the need of performing a quality check on the validity of both: (1) the semantic choices behind the issue definition used for quantification - e.g. Is the criterion/attribute to which an individual indicator refers to a valid one? Is the choice of the given set of relevant attributes (criteria) used to characterize the sustainability of a system relevant? (2) the syntactic choices behind the selection of a lexicon and production rules used in the quantification - e.g. is the chosen protocol pertinent? Are the chosen proxy variables reflecting the semantic associated with the chosen attributes? Do we have access to reliable data if we decide to use this indicator?

B. methods that focus only on the specification and implementation of a given protocol. These methods assume that the quality control on both the semantic and the applicability of the relative protocol to the particular issue to be dealt with, is given by default.

2.2. Additional Approach considered in this assessment

Upstream, large-scale indicators such as Material Flow Analysis, ecological footprint and EMergy form a new approach in the assessment of environmental impacts. Compared with downstream approaches – focusing only on an analysis of emissions aimed at the individuation and characterization of pollutants - they provide a new and wider perspective for the analysis of sustainability. They have already been applied to case studies, but they still suffer from the lack of reliable databases, sufficient number of case studies, sufficient theoretical treatment and software for easy calculation. The possibilities to introduce upstream indicators in the analysis will be studied. In relation to the possibility of using the upstream approach, the geographical allocation of burdens and impacts is crucial for sustainability. For this reason we decide to add to this report a section dealing with the assessment of the potentiality of this approach.

For example, the use of aluminium in Europe affects the tropical forest clear-cut (and hence biodiversity and water cycle) where bauxite is extracted as well as the surface water cycle alteration in places where hydroelectricity is produced and offered to aluminium smelters at low cost, for bauxite processing (several cases investigated in Brazil, Canada, Europe). Furthermore, increased trade of biomass for energy among European and extra European countries for improvement of carbon balance in importing countries generates risks of overexploitation and environmental degradation (soil erosion) in countries where biomass is cropped. Importing meat from livestock rich countries implicitly means an import of feedstock corn and hidden land, diverted from feeding local population. The list could continue. These "much needed" indicators should be analysed. It is very important to explore the geographical allocation of environmental burden, because they will provide a significant tool for future policy.

The geographic allocation of burdens based on an expanded LCA framework can be used to generate - by integrating large scale and socio-economic upstream indicators to the usual local scale -

mass-based indicators of LCA impact categories. Therefore, it might provide significant insight and comprehensiveness. Such an evaluation framework would yield complementary indicators addressing socio-economic and environmental aspects at different spatial and time scales calculated by means of consistent procedures. For this reason in Appendix 1 of this document we present an additional assessment of this tool.

3. Assessment of the selected analytical frameworks

3.1. DPSIR

3.1.1. General Description

Driving forces, Pressures, State, Impacts and Responses (DPSIR) framework has become popular among researchers and policy makers as a conceptual framework for structuring and communicating policy relevant research about the environment.

The roots of the DPSIR framework can be traced back to the Stress–Response framework developed by Statistics Canada in the late 1970s (Rapport and Friend, 1979). In the 1990s, this approach faced further development by, among others, OECD (1991, 1993) and United Nations (1996, 1999, 2001). The DPSIR framework was first elaborated in its present form in two studies by the European Environmental Agency (EEA, 1995; Holten-Andersen et al., 1995). The DPSIR is a relevant tool for structuring communication between scientists and end-users of environmental information, while it is not equally appropriate as analytical tool. Within the resulting conceptual framework, each of the five D, P, S, I and R concepts are specified, for application in integrative analysis of relationships between policy, society, economy and biodiversity (L. Maxim, et al., 2007). DPSIR approach is adopted for the assessment of four alternative management strategies for a forest enterprise in Austria at the management unit level (H. Vacik, et al., 2007). The DPSIR framework is viewed through the 'lenses' of four major types of discourses on biodiversity: Preservationist, Win–win, Traditionalist and Promethean (Svarstad H., 2008). Based upon this examination, the DPSIR framework does not provide a tool generating neutral knowledge. The DPSIR approach was also adopted as basis to develop a policy tool aimed to describe the Catchment-Coastal Zone Continuum and identify policy and management options (Trombino G., et al., 2003).

3.1.2. Analytical soundness

DPSIR is not a real analytical framework in strict sense, but it provides an overall mechanism for analysing environmental problems, with regards to sustainable development. The DPSIR Framework is exclusively used to value environmental quality and it provides guidelines to policy makers in to respect principles of sustainability. In fact, DPSIR does not focus on the analytical procedure (formal protocol), but instead aims at selecting the right set of relations in issue definition and problem structuring. If properly used, DPSIR helps choosing an effective integrated set of indicators.

Figure 1 illustrates the DPSIR framework in its most basic scheme. Driving forces, in the form of social, economic or environmental developments, exert Pressures on the environment and, as a consequence, the State of the environment changes. This leads to Impacts that may elicit societal Responses that feed back to the Driving forces, Pressures, State, or Impacts (EEA, 2001).

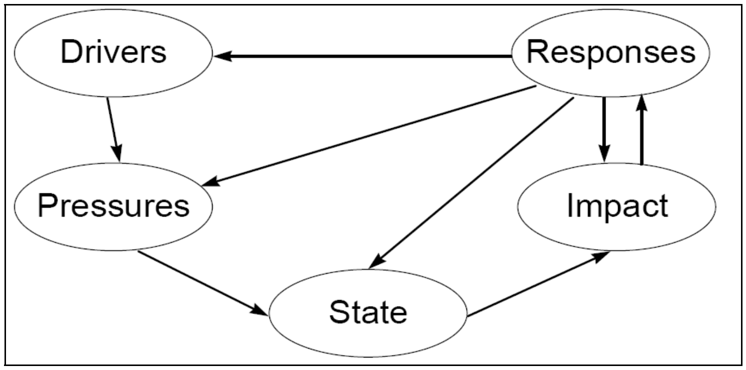

Fig. 1 The Driving forces, Pressures, State, Impacts, Responses framework.

Hence, 'Driving Forces' are considered normally to be the economic and social policies of governments, and economic and social goals of those involved in industry. 'Pressures' are the ways that these drivers are actually expressed, and the specific ways that ecosystems and their components are perturbed, i.e. for the ecosystem effects of fishing, the central pressure would be fishing effort. These pressures degrade the 'State' of the environment, which then 'Impacts' upon human health and ecosystems. Environmental impacts refer to the effects that variations in environmental and conditions can have on society, causing society to 'Respond' with various policy measures, such as regulations, information and taxes.

A presumed strength of the DPSIR framework is that it captures, in a simple manner, the key relationships between factors in society and the environment, and, therefore, can be used as a communication tool between researchers from different disciplines as well as between researchers, on the one hand, and policy makers and stakeholders on the other.

3.1.3. Comprehensiveness

The *comprehensiveness* of DPSIR is warranted if the used indicators are selected according to specific criteria. In particular, indicators need to:

1. be measurable in an easily and reliable manner;
2. offer the possibility to detect changes in time and space;
3. have the capacity for the provision of an evaluation stress and non-stress conditions;
4. have the capacity to forecast changes in the ecosystems;
5. have a reference level defined according to a variance whenever this is possible;
6. have a significant signal/noise ratio.

This approach is used to indicate different dimensions of sustainability, different scales and different spatial coverage. However, DPSIR does not say anything on how to handle the epistemological predicament of orchestrating models, data and indicators in quantitative analysis referring to different descriptive domains and different dimensions of sustainability.

Therefore, the perception and representation of *Driving forces, Pressure, State, Impact* and *Response* factors and resulting indicators in the form of a linear causal relation is determined by the semantic choices of a spatio-temporal scale performed by those using the framework. However, on a different scale and a different narrative (in the long term, when considering evolutionary changes), one gets the opposite perception: an increase in efficiency boosts the pace of becoming of the system and the more efficient system will do more and consume more. In many applications of this framework, for instance, *State* and *Impact* indicators mainly focus on environmental issues (the environmental impact), and *Driving forces* are mostly limited to socio-economic activities. This is due to the difference in the scale of relevant processes taking place in socio-economic systems and ecological systems. Quicker changes in socio-economic systems are easily perceived as causes of changes in ecological systems. However, on a different scale - e.g. when looking for long term biophysical constraints - a different direction of causality should also be considered.

3.1.4. Reporting capabilities

Concerning *reporting capability,* the DPSIR framework seems highly capable of showing information in an analytical, causal way when differentiating between causes and effects as well as human measures and responses to control the amount of impacts to end users. The DPSIR helps the communication and interpretation of results, by making evident the relations between causes of problems, indicator of problems and possible remedies. However, the DPSIR method does not provide the required protocols for integrating across different scales and different dimensions sustainability issues. It does not help in providing a representation of these relations in quantitative terms. Without the adoption of an adequate set of grammars able to guarantee this required orchestration, this method does not "guarantee" any sound quantitative analysis.

3.1.5. Easiness to use

This methodological approach offers only general guidelines, in assessing impacts and risks. Therefore, the method is *easy to use,* because it explicitly acknowledges the need for addressing the different dimensions of sustainability, but it does not address the need for integrating the resulting changes in the different dimensions of sustainability in each of the elements of the cause-effect chain. Therefore those using DPSIR should have clear in mind that it is very effective in the selection of relevant attributes of performance, in the phase of issue definition and problem structuring, but it does not help for the successive phase of formalization (choosing the right models and the right datasets). Missing this point can give the false impression that the causality suggested by the acronym (Pressure-State-Impact-Response) is a type of causality to be used in specific models and quantifications. This causality goes only in one direction, only "one scale at the time", that is, within the particular mode and scale selected by the analyst. Therefore, an attempt to translate the semantic associated with DPSIR directly into the syntax of a mono-scale and mono-dimensional model is not only difficult but also provides misleading results.

3.2. PSR

3.2.1. Description

Pressure-State-Response (PSR) scheme, was introduced in the seventies by OECD (OECD, 1993) and its development in Driving-Pressure-State-Impact-Response (DPSIR) was realised by European Environmental Agency (EEA).

The PSR refers to the first version of DPSIR; a sort of initial and more generic definition of this heuristic approach. The DPSIR model develops the PSR model adding the *driving* to the pressure component that is all activities and individual behaviours that cause pressures on the environment.

3.2.2. Analytical soundness

The original idea of PSR was to force the analysts to focus on relevant relations in the analysis of the relation between environmental processes and socio-economic processes. Starting from a relevant way of studying this relation boosts the usefulness of the resulting issue definition and problem structuring. This approach is based on the concept that human activities exert pressures on the environment, changing the quality and quantity of natural resources. The human responses to changes of the environment include organised behaviour, which aims to reduce, prevent or mitigate effects on the environment.

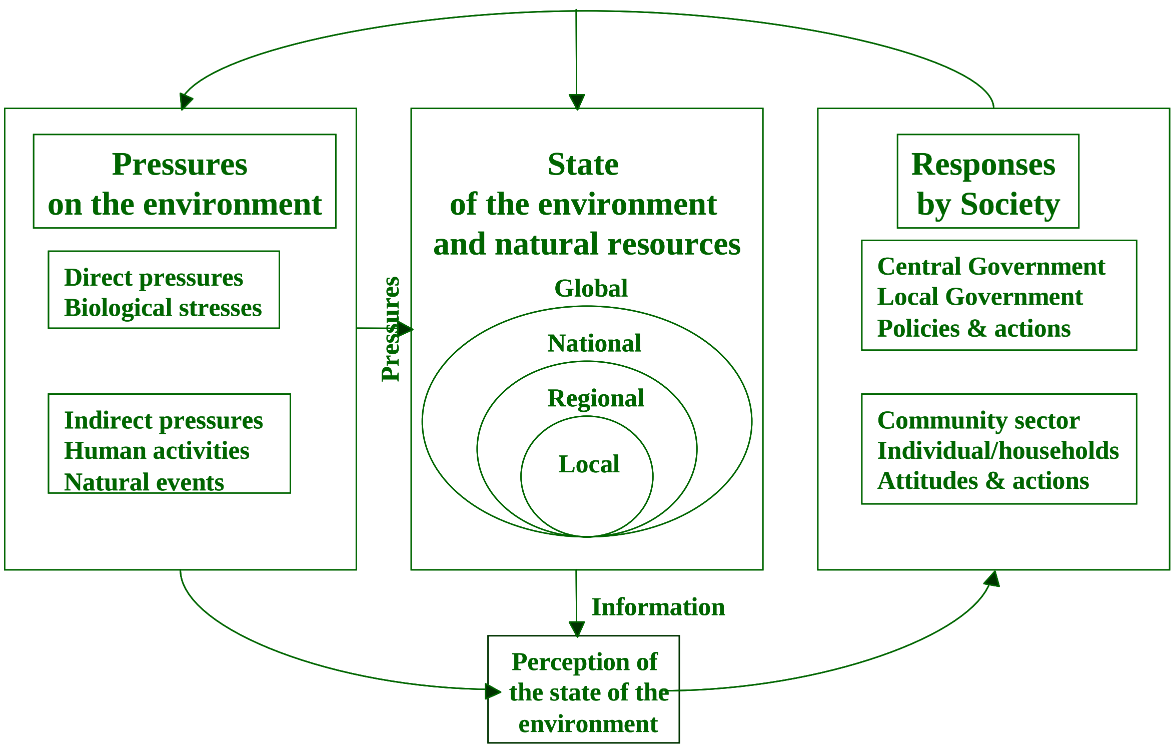

Fig. 2. Pressure-State-Response framework for environmental reporting

3.2.3. Comprehensiveness

The model PSR divided environmental indicators in three components:

1. pressure includes social pressures and natural fluctuations that upset the environment as compared to normal conditions (such as municipal waste generated);
2. state includes essentially quantity and quality related measures (such as density of public green areas and concentration of air pollutants);
3. response measures society's reaction to environmental problems, that is politics oriented to finance environmental projects in order to reduce pressures (i.e. by creating noise barriers), to promote environmental licensing, and other regulatory provisions and incentives, to change behaviours and consumption.

These components are related by a logic relation: the *pressure* modifies the *state* and the *state* requires *response* in order to reduce *pressure.* Regards spatial scales, indicators must be applied and explained respect to ecological, geographical social and economic context.

3.2.4. Reporting capabilities

The PSR framework is a scheme for communication and interpretation of results. It's based on representation of causal relationships between social and environmental elements. This method proposes a scheme with classification criteria in which it is possible to have specific indicators for different environmental dimensions. But indicators are exclusively evaluation instruments, which in order to provide effective interpretations must be supported by scientific information. PSR provides a framework for management by (a) quantifying pressures on the environment, (b) quantifying and measuring change in state, and (c) determining whether pressures and state are related, and whether management intervention has been worthwhile, thereby providing a way of measuring change, and the impact on policies and programmes.

3.2.5. Easiness to use

The PSR is a framework that reduces the number of data input and parameters so that the communication process becomes easier. This method is characterised by its ability to focus on intervention and its ability to divide the evaluation process into three steps evaluating the pressure, state and response separately and identifying correlations between these steps.

3.3. MIPS

3.3.1. Description

Material Input Per Service unit/Material Intensity per unit Service (MIPS) is a theoretical framework for explaining the physical relationship of society and nature in the so-called *socio-economic metabolism*, a concept applied to investigate the interactions between social and natural systems. It is the socio-economic metabolism that exerts pressure upon the environment. It comprises the extraction of materials and energy, their transformation in the processes of production, consumption, and transport and their eventual release into the environment.

3.3.2. Analytical soundness

The method is based on the accounting of material flows, which are diverted from their natural pathways to support modern societal metabolism. The concept of MIPS includes energy intensities by integrating the material flows associated with energy inputs. The calculation of MIPS depends on the implementation of complex protocols, which are affected by a few delicate and crucial choices - the categories to be included in the lexicon (= the universe of variables considered) and the relative production rules (= the protocols adopted in the calculations). However, this is not the problem with this method. All models have deficiencies, but what is important is that they are also useful, and MIPS is certainly useful. The problem with MIPS is that it is a HOW indicator (it is about defining the efficiency of a process) and not a WHAT indicator (a relevant attributes of performance referring to the final state of the system). Unfortunately, at this moment MIPS tends to be associated with normative analysis (the lower the MIPS the better). Rather, it represents a very interesting protocol to define a given quantification of one of the possible criteria of sustainability. Being based on a ceteris paribus view this indicator is not particularly effective when dealing with the analysis of evolutionary changes (e.g. Jevons paradox).

3.3.3. Comprehensiveness

The MIPS concept is not only a measure of material flows used for monitoring progress toward sustainability but it does not perform an integrated analysis of sustainability. It can be used to design the eco-efficiency of goods and infrastructures and, in this way, it provides a quantitative assessment of one piece of the puzzle. This approach is of key importance for the evaluation of the related impacts on the environment, both on a local and a global scale. In fact, there is a close relationship between resource use and environmental impacts and therefore the evaluation of resource use (and the related hidden flows) can be considered an aggregated indirect measure of ecosystem disturbance. Among the several different mass-based methods and indicators, for local scale evaluations, and nationwide material flow analysis (on the national and international levels), MIPS is the one that provides the most *comprehensive* point of view and the largest accounting of input flows. In relation to the distinction made in the theoretical session about sustainability indicators, MIPS is a HOW indicator which deals with an extremely important piece of the puzzle, but still just one piece. Formulating policies using only the analysis of this piece can be misleading.

3.3.4. Reporting capabilities

A general scheme includes indirect flows associated to imports and exports as well as water and air flows through the economy. The categories can be broken down. For instance, within materials of domestic origin the domestic extraction intended for use and unused extraction can be distinguished. Domestic extraction of materials can be further disaggregated (following qualitative criteria determining the choice of relevant categories) into, e.g., fossil fuels, metal ores, industrial minerals, construction minerals and biomass. Each of these broad material groups can be further broken down, e.g. fossil fuels into fuel types, biomass into timber, agricultural harvest, fish catch, etc., in order to measure material inputs and outputs according to generally accepted accounting conventions. If properly framed MIPS is very effective in communicating information about a given attribute of sustainability, both for technical purposes (calculating the overall input/output, looking for future bottlenecks, assessing relative aggregate impact on the environment of alternative processes) and for communicating with the public basic information about the sustainability of human progress.

3.3.5. Easiness to use

A complete material balance for an economy is statistically difficult to achieve since not all material input and output flows are accounted for in a systematic way. Some material flow categories must be estimated and available data complemented by additional estimates. The approach refers to the amount of product which, is able to provide a given final service to the user, but the service ability of a product is very variable and has to be defined case by case. Applications of MIPS are based, right now, on a well developed set of protocols used by different groups. Using these protocols require a certain training and expertise. Also in this case, the most problematic aspect of this tool is not that of generating a number. The issue is how to integrate this methodology into a more flexible grammar capable of generating different indices for different purposes and of being interfaced with other analysis within a multi-dimensional and multi-scale framework of analysis.

3.4. STEEPV

3.4.1. Description

Social, Technology, Economics, Ecology, Politics, Values (STEEPV) provides a framework for assisting in the consideration of different background variables. The STEEPV analysis evolved from ideas developed by Johnson Research Associates in the early 1960s. Schwartz developed the idea further and developed the STEPV analysis in the early 1970s. This type of categorization ensures that opinions are aligned with different aspects of reality. The STEEPV can be used at anytime while dealing with:

- problem solving (usually new problems);
- decision making (identifying needs);
- planning (considering a multi-dimensional relations);
- crisis management (linkages with other dimensions);
- highly uncertain situations (exploring impacts);
- scenario activities .

For example the STEEPV method has been applied to investigate Changes in Operational Environment of Agriculture (Suutarinen J., et al., 2006).

3.4.2. Analytical soundness

It is best used by a close knit group meeting very frequently to work with a complex set of 'mini-scenarios' each of which describes a particular direction of change or an end state or both. There are several sets of mini-scenarios under each letter of the acronym with up to seven elements in each mini-scenario set. The group process is judgmental, with the group seeking to agree or disagree which of the mini-scenarios in each set represent the 'hoped for world' by contrast with the 'real world' that is likely to exist at the time horizon of the study.

3.4.3. Comprehensiveness

It helps to explicitly consider different dimensions of sustainability and to tailor a given issue definition and problem structuring on the specificity of the situation to be dealt with.

This framework can be used to develop evaluations of farm level, national level and global level, but usually it is used on larger-scale scenario development or simply to enable the consensual issues to be worked with for policy processes.

3.4.4. Reporting capabilities

It could be used within a participatory approach in order to guide the identification of relevant factors to be considered in a given situation/problem. This method is not based on calculation protocols or templates. This method generates only qualitative reports based on group discussion.

3.4.5. Easiness to use

This method is easy to use only if one is aware of its qualitative nature. In fact, it is qualitative method used for brainstorming sessions. In fact, it is a brainstorming process based on:

- Collecting as many thoughts as possible (on selected problems or subjects)
- Listing every single idea (without discussing them)
- Evaluating and identifying priorities (Desirable, wild and uncertain issues)

STEEPV is used for dealing with problem solving (usually new problems), decision making (identifying needs), planning (considering a multi-dimensional relations), crisis management (linkages with other dimensions), situations characterized by large doses of uncertainty (exploring impacts) and scenario activities. It helps 'breaking the ice' and moving towards a more dynamic working group.

3.5. ASA

3.5.1. Description

Advanced Sustainability Analysis (ASA) is a mathematical information system developed by Finland Futures Research Centre. It can be used to analyze economic development from different sustainability points of view. ASA focuses on relationships between changes in environmental, economic and/or social variables that can be measured with any preferred indicator or index. ASA applies decomposition analysis in order to divide the observed environmental, social and/or economic variables (indicators) into different components, contributing factors. The sum of all identified and decomposed factors is equal to the total environmental, social and/or economic change. ASA can also be applied to scenario construction based on a trend (forward) or a target (backward) as drivers of the analysis. The driver can be chosen freely among the identified factors that contribute to the change.

3.5.2. Analytical soundness

The aim of the ASA approach is to reveal information of relevant pre-defined reasons for a change towards or away from sustainability (the value of an indicator at the reference year of the analysis), instead of providing an absolute measure such as "ecological footprint", various sustainability indices, and others. This makes ASA a more practical tool for policy analysis. The advantage of ASA is that it concentrates on the affecting factors or reasons of change in time, i.e. driving forces, an essential character of sustainable development.

Specific ASA results can be interpreted as indicators of e.g. dematerialization of production, immaterialization of consumption, or rebound effect. It is also possible to use the ASA approach in assessing sustainable economic growth (e.g as a share of total economic growth) and (required) sustainable technology development rates.

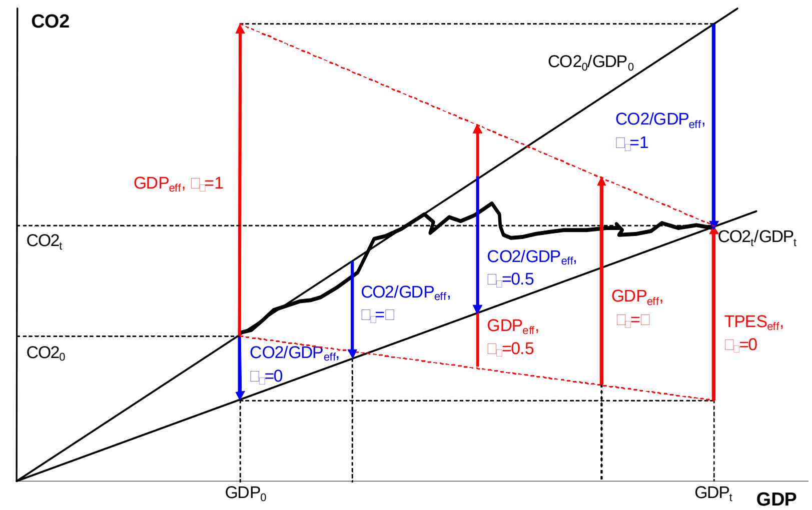

Fig. 3: Decomposition of CO2 change: the effects of CO2/GDP and GDP during a selected time period

The methodology used in the ASA approach is a complete two-factor decomposition analysis with a special feature of chaining the analysis in order to increase the number of explaining factors of the observed change in a selected sustainability indicator. In terms of analytical soundness, ASA suffers from typical problems of decomposition applications. In the chained two-factor decomposition, the order of entering the explaining factors may have some influence to the results. Moreover, also the choice of the value for coefficient λ may influence the results. In ASA, different choices can be made easily, and the differences in results can be analyzed. The actual choices must, however, be decided on a case-specific basis. The above mentioned problems have been recognized in the decomposition literature and attention has been paid to them also in developing the ASA approach.
ASA is a mathematical approach, it can be useful to value the variables trends like CO2, population, GDP.

For example, the analysis can be most easily described by using an example, because it always is case-specific which sets the important phase of interpretation of results. The following shows an ASA for decomposition of CO2 emissions from fuel combustion (Figure 3). An equation for identifying the simplest set of contributing factors to CO2 emissions can be

$$CO2 = \frac{CO2}{GDP} \times GDP \qquad (1)$$

CO2 is carbon dioxide from fuel combustion and GDP is gross domestic product in real prices.
The change of CO2 emissions can be decomposed into the effects of two factors and the decomposition identifies the effects of each contributing factor and a joint effect, which in a complete decomposition must be divided onto the two factors. Figure 2 defines different alternatives for allocating the joint effect, which may give somewhat different results as Figure 2 shows: The coefficient λ defines the share of the joint effect allocated to the effect of CO2/GDP, and 1- λ defines the share allocated to the effect of GDP. When λ =0 the joint effect is allocated totally to the effect of GDP, and λ =1 allocates it totally to the effect of CO2/GDP. λ =0.5 allocates half of the joint effect to both effects. λ can be given any value ($0 \leq \lambda \leq 1$), one possibility s to allocate the joint effect in relation to the relative changes of the contributing effects.

This kind of analysis can be applied to multiple effects as well. The two-factor decomposition presented above can be chained by taking a result from the first decomposition as a starting point for further decomposition, and the new results can then be decomposed again. Equation (2) identifies five contributing factors that can be calculated by using the chained two-factor decomposition:

$$CO2 = \frac{CO2}{TPES} \times \frac{TPES}{FEC} \times \frac{FEC}{GDP} \times \frac{GDP}{POP} \times POP \qquad (2)$$

In equation (2), CO2 is carbon dioxide emissions from fuel combustion; GDP is gross domestic product in real prices; TPES is total primary energy supply (including all fuels and other forms of primary energy, i.e. before the combustion process and transfer and distribution of electricity or heat); FEC is final energy consumption (i.e. the consumption of energy carriers such as district heat and electricity, and fuels used directly in residential heating, industry, and transport); and POP is the amount of population in the selected country.

CO2 emissions first decomposed into the effects of CO2/TPES and TPES. The effect of TPES is further decomposed in to the effects of TPES/FEC and FEC, and this kind of chaining will be repeated until the whole content of equation (1) has been decomposed. The results can then be presented e.g. as percentage changes from the base year CO2 emissions, as shown in Figure 4.

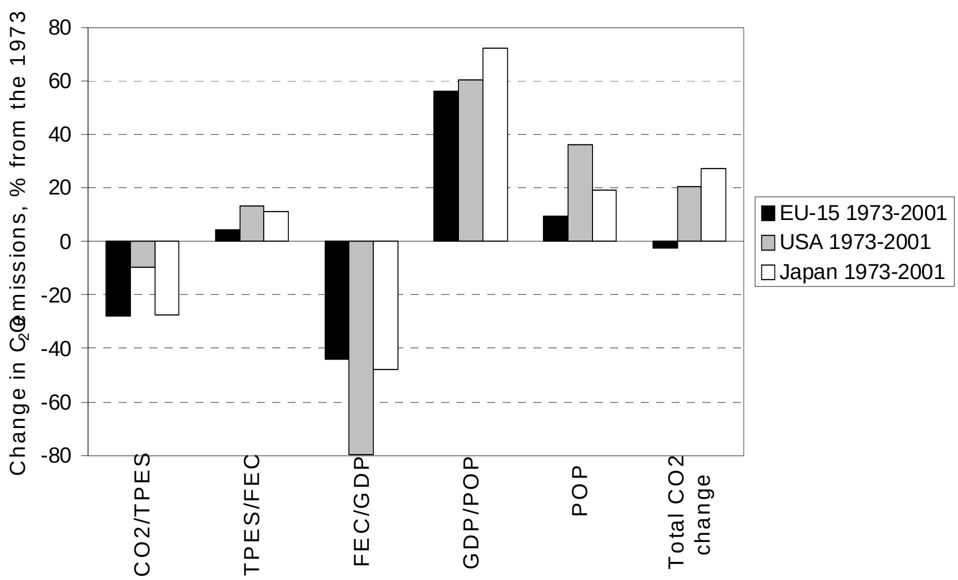

Fig. 4. ASA of the change in CO2 emissions from fuel combustion in the EU-15, in the USA, and in Japan 1973–2001. Data source: International Energy Agency

The factors identified in equation (1) are described and interpreted in the following. The factor CO2/TPES refers to the contribution of the change in the CO2 intensity of the entire energy system that has been influences by a switch from on energy form to another (technology). Negative values for this factor would imply a switch from fuels with a high carbon content to energy sources with a lower carbon content, e.g. from coal to natural gas or nuclear power. Positive values would imply an increasing effect on CO2 emissions due to the opposite type of fuel switch.

The factor TPES/FEC refers to the efficiency of the energy transformation system, i.e. efficiency in transforming primary energy into different energy carriers such as electricity or heat. This can be influenced by e.g. a switch from fuel use to electricity or vice versa, or technological changes in fuel combustion. Positive values for this factor would imply an increasing use of electricity instead of other energy sources. Negative values would imply an opposite change of direction, i.e. technological changes such as a switch to combined heat and power (CHP) production instead of separate heat and electricity production.

The factor FEC/GDP refers to the energy intensity of the whole economy. This can be influenced by several factors, such as changes in the industrial structure from energy intensive to less energy intensive industrial branches, a shift from industrial production towards services in terms of GDP shares, or technological development inside energy-consuming fields of the economy. Negative values for this factor would imply that European countries have decreased their energy intensity structure of the economy.

The factor GDP/POP refers to the amount of economic activity per capita which can be influenced foremost by economic growth. The positive values for this factor would imply that continuous economic growth per capita has increased CO2 emissions. Negative values would imply a decreasing effect on CO2 emissions due to a decrease in GDP per capita.

The factor POP refers to changes in the population figure brought about by birth and death rates as well as by international migration. The positive values for this factor would imply that population growth increases CO2 emissions, and negative values would imply a decrease in the effect of CO2 emissions as a result of decrease in the population.

In the rest of the DECOIN project we will verify both the applicability and the usefulness of this approach when dealing with multi-scale dynamics in which it is unavoidable to find non-linearity and possible catastrophic events.

3.5.3. Comprehensiveness

In addition to the requirements of quantitative indicators in time series format (at least data from two years for all indicators at the same spatial level is needed), ASA has no other methodological limitations to analyze different dimensions of sustainability with different time scales and different spatial coverage. This may give a reason to consider ASA as a very comprehensive approach to analyze the driving factors of the studied issue. On the other hand, ASA can analyze only one issue in a single analysis, which sets a limit to comprehensiveness in terms of coverage of various sustainability-related issues in the current analysis. Moreover, results of other sustainability evaluation approaches (including sustainability development indicators and various sustainability indices based on them) can be used in ASA. Taking this into account, the capabilities of the ASA approach are almost unlimited. However, identification of the driving forces is fully a case-specific issue, and the construction of a relevant identity with a reasonable meaning for each factor in the identity may be challenging, especially if the number of explaining factors is high. ASA is extremely flexible (it is a grammar which makes it possible to link different conceptualizations – semantic categories - with different expressions of the relative constraints using proxy variables – formal categories) and it makes it possible to analyse different dimensions of sustainability, and different time scales.

3.5.4. Reporting capabilities

Understanding the type of sustainability indicators generated by ASA approach requires understanding the idea of decomposition analysis, which is not difficult. The ASA results can be presented either in a table or graphical format (line, bar or area graphs) when dealing with general characterization. Data for e.g. the reference year and most recent year is enough for a bar graph, line and area graphs can be used if data is available also for the years in between. In this case, it is possible to develop the visualization towards animation (an excellent example of a possible format can be found at http://www.gapminder.org). However, these results are not always self-explaining; in some cases they may require an interpretation, especially if the analysis is carried out in order to provide policy recommendations. On the positive side, the decomposition methodology is fully transparent in the current case-specific Microsoft Excel spreadsheet format of the ASA approach even if more work is required before being able to define the limit of applicability to analysis of structural changes of economies across different hierarchical levels If the visualization is to be further developed the methodology remains the same but requires a detailed documentation in order to keep the transparency.

3.5.5. Easiness to use

At the moment, this is perhaps the weakest point of the ASA approach. Data input in its easiest form is only a copy-paste operation. However, changing the reference year, order of entering the variables into the chained two-factor decomposition, or the value of the coefficient λ requires relatively lot of work in the current versions of the MS Excel spreadsheets. Flexibility of use with different quality of data is not a major problem until we are talking about the quality of quantitative data. However, data for all variables included in the analysis must be relevant for the studied spatial coverage.

3.6. MSIASM

3.6.1. Description:

Multi-Scale Integrated-Analysis of Societal and Ecological Metabolism (MSIASEM) is a multi-purpose meta-grammar which explicitly addresses the challenge of handling the quality checks referring to both “semantic quality” – when dealing with different legitimate perspective about what “sustainability means - and “syntax quality” – when crunching numbers referring to different scales and different disciplinary fields e.g. €, Kg and MJ.

The MSIASM approach has been developed to provide such a holistic tool. MSIASM can establish an effective link among quantitative representations of the interaction of socio-economic systems and ecosystems in terms of congruent relations between: (1) flows of euros, water, commercial energy, food, water, and other key materials (including books) both per hour of human activity and per hectare of land; and (2) relevant characteristics of the socioeconomic systems defined in terms of the lexicon (= the given selection of categories) used to do the accounting of: (i) hours of human activity; and (ii) hectares of land use. These categories [e.g. labour in different economic sectors, leisure time, land used in agriculture, or in residential] will depend on demographic structures, codified social roles, capital intensity, technical coefficient, life styles (the mix of goods and services produced and consumed in the society). This makes it possible to study the interference induced by societal metabolism on ecosystem metabolism, and to link the changes and drivers taking place within the structure of the societal metabolism to changes in land covers and land uses. In quantitative terms MSIASM provides a skeleton of expected relations among different flows and the characteristics of different societal elements, defined at different scales, using different analytical disciplines. In this way it provides a linkage over changes in the values taken by relevant variables used for economic, social, technical, ecological analysis. A key conceptual tools is ***Mosaic Effect Across levels*** – how to establish a relation between the characteristics of the ratio of “flow” over a “fund” element (either $/hour, $/ha, or MJ/hour of MJ/ha);

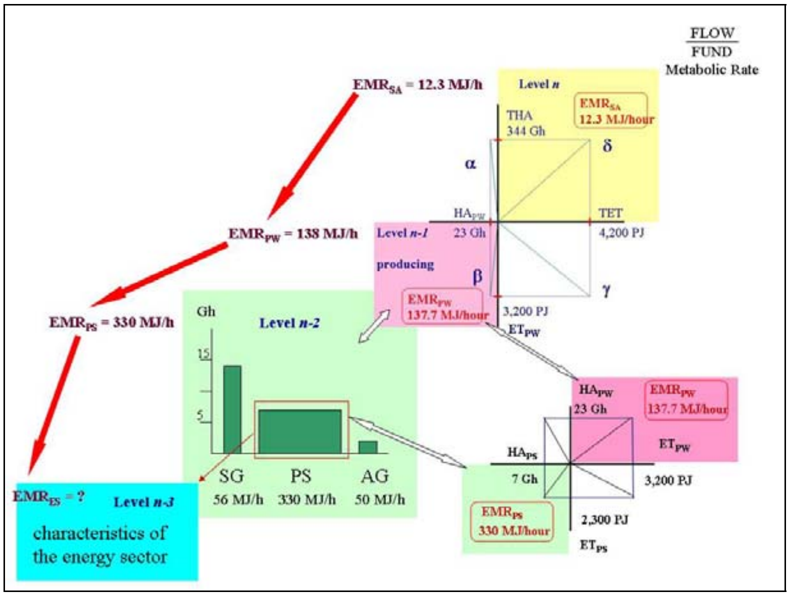

Fig. 5 Relation of congruence over: (i) fund; (ii) flow; (iii) flow/fund; across three contiguous levels [the whole ←→ parts]

In alternative, the ratio of flows (money, energy, materials) per unit of human activity can also be calculated against the fund "land, use". That is the same type of analysis can be obtained by characterizing the typical value of the flows, in different compartments, per unit of area (e.g. hectare) allocated in a given typology of land use.

The "mosaic effect" across levels makes it possible to have a parallel analysis of the characteristics of the various elements determining the metabolism of a socio-economic system across different hierarchical levels and scales.

An example of the application of this conceptual tool is given in Fig.6.

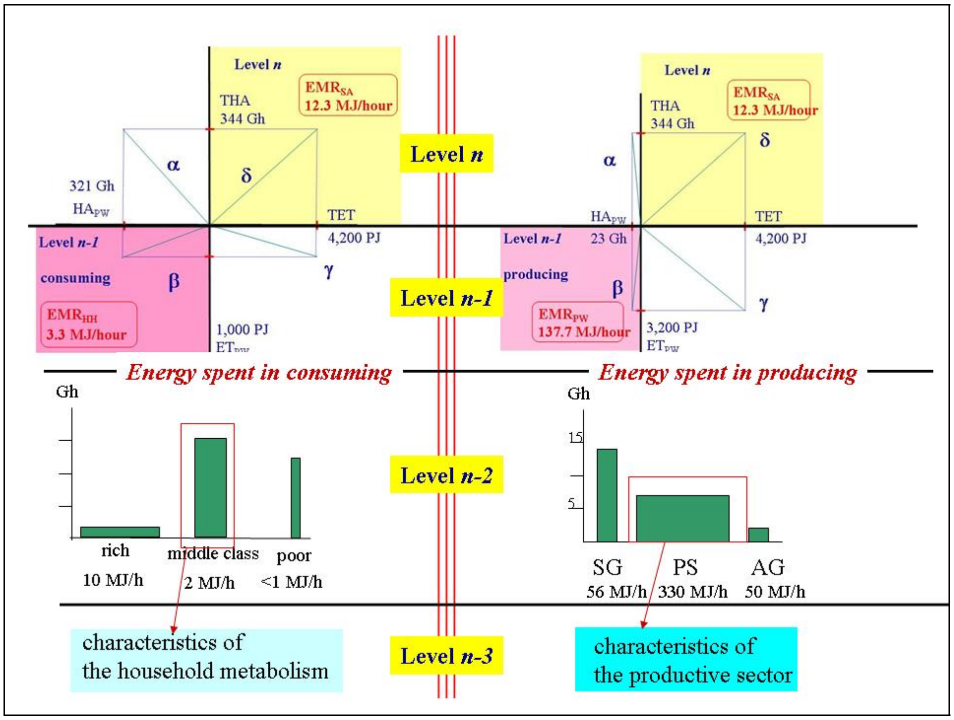

Fig. 6 Parallel analysis of the characteristics of various elements (Fund: HA and Flow: ET) across hierarchical levels

The ultimate goal of the MSIASM approach is to keep coherence in the representation of the metabolism of socioeconomic systems across different hierarchical levels (the whole, the parts, sub-parts) and across different dimensions of analysis (flows of added value, energy, matter in relation to requirement of human activity and land uses). To check the congruence of the various representation of performance (the characteristics of the different compartments described at different levels and scales) the MSIASM approach uses another key conceptual tool: ***Impredicative Loop Analysis*** – in complex systems the characteristics of the parts affect/are affected by the characteristics of the whole and viceversa. When "***Mosaic Effect***" and "***Impredicative Loop Analysis***" are used in combination, it becomes possible to generate a "Sudoku effect" on the resulting integrated system of accounting of relevant flows across hierarchical levels.

3.6.2. Analytical soundness

The MSIASM approach is an operationalization of Georgescu-Roegen's idea of bioeconomics. The theory behind the multi-purpose meta-grammar is also well developed (after 15 year of research, 2 books and more than 30 papers published with theoretical studies and applications). According to *analytical soundness*, it provides an integrated analysis which explicitly addresses economic, social and biophysical feasibility and constraints. Biophysical feasibility and constraints are analyzed in relation to:

1. socioeconomic factors affecting the modality of production and consumption;
2. technical coefficients related to energy and material transformation processes;
3. demographic dynamics;
4. the profiles of both human time allocation and land uses over the various economic sectors as determined by cultural and political factors

The resulting integrated representation of constraints can be easily interfaced with: (A) conventional economic analysis; and (B) ecological analysis of the impact on ecosystem health. The ecological impact results from the lack of compatibility of the density and pace of the flows of energy and matter metabolized by society in relation to the supply and sink capacity of the ecosystems embedding the society. The applicability of the method to study the interference of human activity on the metabolism of terrestrial ecosystems has been verified at the local scale (household/village level in two projects China and Viet-nam), but it has yet to be proved at the national level (this is one of the task of the DECOIN project).

3.6.3. Comprehensiveness

Regarding to *comprehensiveness*, the MSIASM approach characterizes socio-economic systems as metabolic systems organized on nested hierarchical levels whose survival depends on their ability of stabilizing a continuous supply of inputs – the flow elements – e.g. energy, food, added value and useful material flows, which have to be made available and consumed. This approach makes it possible to characterize socio-economic systems at different levels (e.g. households, towns, provinces, regions, whole countries, macro-economic regions), each one associated with a dynamic budget: in each element the flows elements have to stabilise the given structure of the funds elements. That is, socio-economic systems invest their fund elements: - that is available human activity (human time uses), available land (land uses) and capital (technology uses) - in stabilizing their metabolism with the required amount of flow elements – the material, energy and monetary flows associated with the production and consumption of goods and services.

2.6.4. Reporting capabilities

So far the method resulted very promising for its extreme versatility and for its ability to bridge semantics to syntax (*reporting capability*). MSIASEM approach is very effective in providing simultaneously, different representations of different compartments defined at different levels and using different variables. In relation to the transparency of the methodology, since the various characterizations are related to each other within a Sudoku-type grammar (one can check the congruence with the higher and lower hierarchical level of analysis in relation to the different dimension of sustainability), they are very open and transparent to different quality checks. These checks can be based on the adoption of different criteria of analysis or different types of knowledge referring to different hierarchical levels.

3.6.5. Easiness to use

MSIASM is very powerful in sharing meaning about numbers when working in interdisciplinary team and for interfacing scientists with the rest of society. It is also extremely effective at pointing out at hidden constraints usually missed by analyses based on a single scale and dimension. This method isn’t easy to use, because it uses complex data and its application requires a high level of expertise to be applied. In relation to this problem, the idea is to develop a series of procedures in which the user will be helped in selecting the appropriate protocols to operate such a grammar. The development of a user-friendly interface is one of the task of the DECOIN project.

3.7. SUMMA

3.7.1. Description

SUstainability Multicriteria Multiscale Assessment (SUMMA) approach provides a conceptual framework for multicriteria multiscale decision-making, in which the different perspectives are not forced to combine, but retain their full wealth of information, on the basis of which wise decisions can be made, also taking into account important external factors such as social and economic welfare. The most important aspect of SUMMA is the consistency of data, i.e. all calculated indicators from different methods and different space-time scales are based on the same set of experimental data, the consistency of which is a-priori ensured. A second very important factor is the routinely performed sensitivity analysis, which ensures that results are critically checked for errors and uncertainty.

3.7.2. Analytical soundness

The SUMMA approach is based on a selection of upstream and downstream methods, which offer complementary points of view on the complex issue of environmental impact assessment. The upstream methods used in this approach are *Material Flow Accounting, Embodied Energy Analysis, Exergy Analysis* and *Emergy Accounting*, while the downstream method (assessment of downstream impact categories) used in SUMMA approach is *CML2 baseline 2000* (Figure 7).

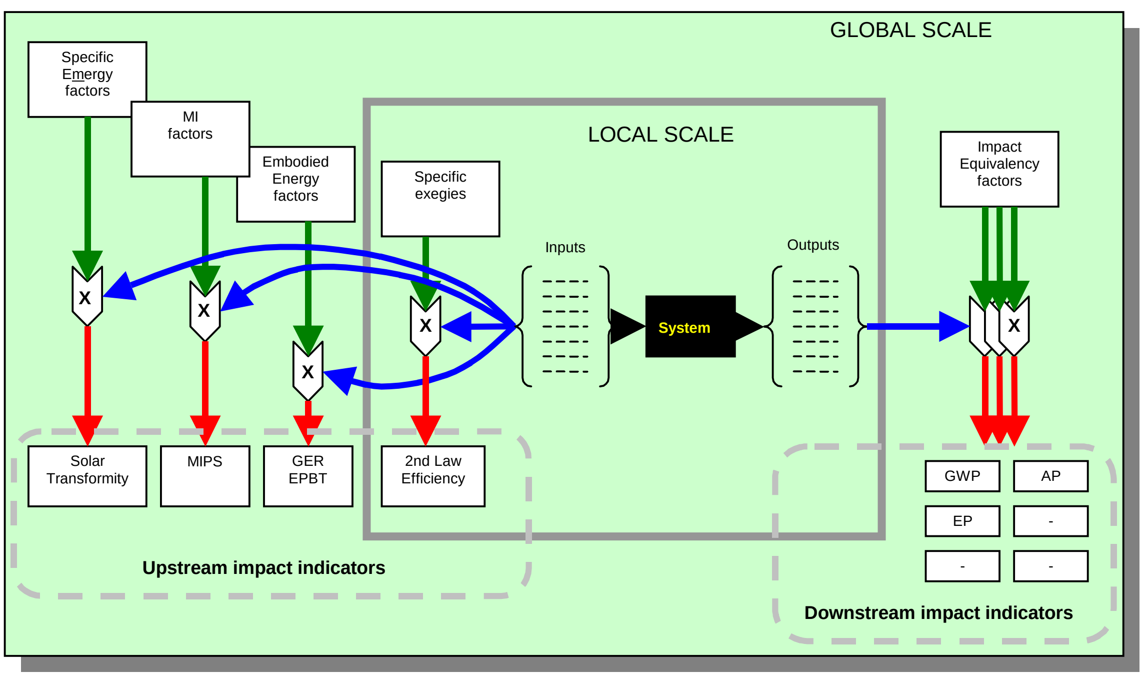

Fig.7. SUMMA- application scheme of the employed environmental impact assessment methods and calculated indicators

The analysed system or process is treated as a "Black Box", and a thorough inventory of all the input and output flows is firstly performed on its local scale. It is important to underline that this inventory forms the common basis for all subsequent impact assessments, which are carried out in parallel, thus ensuring the maximum consistency of the input data and inherent assumptions as well as comparability of results. Each individual assessment method is applied according to its own set of rules. The "upstream" methods are concerned with the inputs, and account for the depletion of environmental resources, while the "downstream" methods are applied to the outputs, and look at the environmental consequences of the emissions. The calculated impact indicators are then interpreted within a comparative framework, in which the results of each method are set up against each other and contribute to providing a comprehensive picture on which conclusions can be drawn.

The following paragraphs briefly describe the theoretical basis of the various methods combined in the SUMMA approach.

The *Material Flow Accounting* method (Schmidt-Bleek, 1993; Hinterberger e Stiller, 1998; Bargigli *et al.*, 2004) aims at evaluating the environmental disturbance associated with the withdrawal or divertion of material flows from their natural ecosystemic pathways. In this method, appropriate Material Intensity factors (g/unit) are multiplied by each input, respectively accounting for the total amount of abiotic matter, water, air and biotic matter that is directly or indirectly required in order to provide that very same input to the system. The resulting Material Intensities (MIs) of the individual inputs are then separately summed together for each environmental compartment (again: abiotic matter, water, air and biotic matter), and assigned to the system's output as a quantitative measure of its cumulative environmental burden from that compartment (often referred to as "Ecological Rucksack").

The *Embodied Energy Analysis* method (Slesser, 1974; Herendeen, 1998) deals with the gross (direct and indirect) energy requirement of the analysed system, and offers useful insight on the first-law energy efficiency of the analysed system on the global scale, taking into consideration all the employed commercial energy supplies. In this method, all the material and energy inputs to the analysed system are multiplied by appropriate Oil Equivalent factors (g/unit), and the cumulative embodied energy requirement of the system's output is then computed as the sum of the individual Oil Equivalents of the inputs. Oil Equivalents can be converted to energy units by multiplying by the standard calorific value of 1 g of raw oil (41,860 J/g).

The *Exergy Analysis* method (as described in Szargut *et al.*, 1998) is used in SUMMA exclusively on the local scale of the analysed system in order to ascertain the process second-law performance efficiency, as well as to provide the basis (a suitable numeraire) for the following application of the Emergy method. Each input to the system is accounted for in terms of its exergy content, calculated according to the rules proposed by Szargut. The ratio of the exergy content of the system's output to the sum of the input exergies is a measure of the maximum conversion efficiency attainable in theoretical reversible conditions (real cases always show conversion efficiencies lower that theoretical ones). Exergy has also sometimes been suggested as an ecological metric to gauge ecosystem health and stability, but in this approach it is strictly used for thermodynamic evaluation of the systems under study, leaving the evaluation of direct and indirect ecosystem disturbance to the Emergy method, as well as to the "downstream" impact categories described below.

The *Emergy Accounting* method (Odum, 1996; Brown and Ulgiati, 2004) also looks at the environmental performance of the system on the global scale, but this time also taking into account all the free environmental inputs such as sunlight, wind, rain, as well as the indirect environmental support embodied in human labour and services, which are not usually included in traditional embodied energy analyses. Moreover, the accounting is extended back in time to include the environmental work needed for resource formation. All inputs are accounted for in terms of their solar emergy, defined as the total amount of solar available energy (exergy) that was directly or indirectly required to make a given product or to support a given flow, and measured in solar equivalent Joules (seJ). The amount of emergy that was originally required to provide one unit of each input is referred to as its specific emergy (seJ/unit) or transformity (seJ/J), and can be considered a "quality" factor which functions as a measure of the intensity of the support provided by the biosphere to the input under study (such a support may be referred to as "Ecological Footprint", borrowing the term from Wackernagel and Rees' approach (1996) which uses amounts of productive land as measure of footprint). The specific emergy or transformity of the system's output is calculated as the sum of the total emergy embodied in the necessary inputs to the system, respectively divided by the output mass or exergy. The total emergy requirement thus calculated can be interpreted as an indication of the total appropriation of environmental services by the analysed human activity. In particular, while the total *non-renewable* emergy input to the system under study provides a quantitative estimate of global non-renewable resource depletion, the total *renewable* emergy requirement is a measure of all the natural exchange-pool resources that are diverted from their natural pathways, and that can therefore no longer provide their natural ecosystemic functions. The ecological relevance of the Emergy methodology was recently discussed in detail in a special issue of Ecological Modelling, volume 178, where the scientific career of its founder, H.T. Odum, is illustrated.

The *downstream method*, such as *CML2 baseline 2000,* provides a measure for the potential environmental damage of airborne, liquid and solid emissions by means of appropriate equivalence factors to selected reference compounds for each impact category. The impact potential of the analysed system for each category is calculated by multiplying all emissions by their respective impact equivalence factors, and then summing the results. The CML2 method was selected among other similar methods for its versatility and completeness. The analysed impact categories are:

1. *Global Warming Potential*, expressed in gram CO_2 equivalent per gram of product;
2. *Acidification Potential*, expressed in gram SO_2 equivalent per gram of product;
3. *Eutrophication Potential*, expressed in gram PO_4^{3-} equivalent per gram of product;
4. *Tropospheric Ozone and Photosmog Formation Potential*, in gram ethene equivalent per gram of product;
5. *Stratospheric Ozone Depletion Potential*, in gram CFC-11 equivalent per g of product;
6. *Ecotoxicity Potential*, in gram 1,4-dichlorobenzene equivalent per gram of product (this category is then sub-divided into freshwater, soil and sea water eco-toxicity potentials).

All these methods have been clearly developed and applied. However, these methods have, like all the methods, limits of applicability. Exploring these limits is one of the task of the DECOIN project.

3.7.3. Comprehensiveness

Within the framework of this downstream approach, the possibility for an update of the specific equivalence factors remains open for the future, as is usually the case for any equivalence factor. Similarly, the inclusion of further impact categories (e.g. radioactivity), in order to meet the specific requirements of the analysed case-study, is also theoretically possible. Indicators, obtained through the joint application of the above methods, allow an estimate of the environmental performance of investigated system. SUMMA is an innovative integrated approach to environmental impact assessment. Its main objective is to overcome the inherent shortcomings of all single-criterion approaches, which constitute the vast majority of the Life Cycle Assessments performed to date in the scientific literature, and which invariably lead to partial and often misleading results. Instead, in SUMMA approach the main idea is the separation of indicators that provides a much more comprehensive environmental profile. This way interpretation becomes easier for analysts and much more reliable, since results do not hide important specific details. The rationale is that specific questions at specific scales require different methods in order to be addressed. The SUMMA framework can be used at different scales, like product, process, town, province, region, countries (*comprehensiveness).* Simpler versions of the approach have already been successfully applied to several case-studies, among which mineral mining and refining (Bargigli and Ulgiati, 2003; Tabacco et al., 2003; Canino et al., 2005; Cherubini et al., 2005; Simoncini et al., 2005.), agricultural processes and biomass fuels (Ulgiati, 2001), renewable energy options (e.g., photovoltaics, Raugei et al., 2007), selected energy sources and carriers (natural gas, syngas from coal gasification and hydrogen from steam reforming) and conversion devices (Natural Gas Combined Cycle power plants and Molten Carbonate Fuel Cells) (Raugei et al., 2003a; Raugei et al., 2003b; Raugei et al., 2005).

In general SUMMA does not deal directly with the characterization and analysis referring to changes in socio-economic variables - such as demographic changes, social indicators, economic variables. It can however, interface the analysis of relevant technical conversions under human control with ecological impact and with the effects that technical changes can induce on socio-economic variables.

3.7.4. Reporting capabilities

SUMMA uses sustainability indicators, calculation procedures and schemes elaborated from different methods (*Material Flow Accounting, Embodied Energy Analysis, Exergy Analysis* and *Emergy Accounting*). In the end it's possible to analyze the evolution of indicators through graphical forms as well as to allocate impacts and burdens to different regional scales and areas.

In the *reporting capability*, the added value of SUMMA approach consists in:

- comprehensive assessment of a system's matter and energy use performance at different scales;
- the use of the same inventory analysis and inherent assumptions as the common basis for all the employed impact assessment methods;
- the possibility to cross-check the results of the single methods and identify sources of errors and misunderstandings;
- the possibility to perform a consistent multi-parametric sensitivity analysis within a single coherent framework.

For the moment, this method still reflects its origins, as a tool more specifically built for the evaluation of technical solutions, rather than for the analysis of the sustainability of whole countries. Application of SUMMA to the performance of urban systems was successfully made. The possible scaling-up of this approach to wider scales – e.g. to large regions and countries - is one of the task of DECOIN.

3.7.5. Easiness to use

SUMMA does not present special difficulties for the analyst. It builds on well known methods and uses them synergic ally, so that each calculation procedure provides the basis to another. The final result is a set of indicators which are relatively easy to describe and interpret. However, at the moment applications of SUMMA require a high level of expertise. This is because the grammars and protocols included in this approach (EMergy analysis, embodied energy analysis, LCA) are already difficult to be handled by themselves. An additional open problem is represented by the decision of which mix - within this set of possible tools - should be adopted for dealing with different typologies of problems. Again, one of the task of the DECOIN project is exactly the standardization of procedures for the combination and selection of the grammars and protocols used in SUMMA in relation to possible typologies of applications.

3.8. Comparison of frameworks

Table 1 summarizes the findings of the above Sections, by comparing the attributes of the investigated frameworks and those of the two additional methods for spatial allocation, which are described in the Appendix. It clearly appears that the expected integration among these frameworks will have to conserve the attributes of each method while trying to develop a synergic procedure for both qualitative and quantitative assessment of the dimensions of sustainability.

Table 1. Summary of the evaluation of the investigated frameworks (Symbols summarize the evaluation provided in the text)

Method	Type of method		Input needed						Output delivered				Use of software or calculation procedures		Focus on		Global Evaluation			
	Quantitative	Qualitative	Energetic Thermodynamic	Economic Social	Environmental	Concepts/Ideas	Statistical	Direct & indirect Material Flow	Quantitative Indicators	Qualitative Indicators	Recommendations	Trends Scenarios	Yes	No	Process	Area	Analytical soundness	Comprehensiveness	Reporting capability	Easiness to use
DPSIR		X				X				X	X			X		X	☹	☺	☺	☺
PSR		X				X				X	X			X		X	☹	☹	=	☺
MIPS	X				X			X	X				X		X		☹	☹	=	☺
STEEPV		X				X	X			X	X			X		X	☹	☺	☺	☺
ASA	X		X	X	X		X		X			X	X		X	X	☺	☺	☺	☹
MSIASEM	X		X	X			X		X				X			X	☺	☺	☺	☹
SUMMA	X		X		X			X	X				X		X		☺	☺	☺	☹
Spatial Allocation of impacts	X		X		X		X		X				X		X	X	☺	=	☺	☹
Spatial Allocation of CO2	X				X				X				X		X	X	☹	=	=	☹

4. Facing the challenge of integrated assessment: the need of orchestrating and checking the choice and use of integrated set of indicators of sustainability

4.1 Introduction

From the previous discussion of the different analytical frameworks (DPSIR, STEEPV, MSR, MIPS, ASA, MSIASEM, SUMMA) it is clear that there is no single analytical framework which can deliver the perfect combination of "focus" (issue definition) and "indicators" (relevant data). Some of these analytical frameworks have the goal to improve the quality of the chosen narratives behind the choice of indicators - the qualitative frameworks (DPSIR, STEEP). That is, they deal with "the big picture" in epistemological terms: what is relevant and what should be considered for developing a useful analysis. Other analytical methods are more related to the quantitative aspect of the analysis: how to obtain a pertinent analysis (e.g. quantitative assessment) useful for characterizing the situation under investigation. For this reason, we claim that it is necessary to combine together different analytical frameworks to achieve an integration between: (i) qualitative and quantitative analysis; (ii) different types of quantitative analysis referring to different disciplinary dimensions (e.g. economic, demography, ecology, thermodynamic); and (iii) different types of perceptions and representations of the investigate system referring to different levels and scales (e.g. individual, household, town, regions, country, the planet).

In the rest of this section we first define two key distinctions over concepts, which are very relevant for understanding the challenge associated with the choice and use of indicators in the field of sustainability. These key distinctions are emerging in the literature of "Science for Governance" and have been already adopted in the activity of major international projects (e.g. Millennium Ecosystem Assessment, International Assessment of Agricultural Science and Technology for Development). Then we provide a comparison of the different analytical frameworks based on the adoption of these concepts. Finally, we provide an outline of a meta-procedure which should be implemented to perform the required quality checks in an integrated assessment [= choice and use of indicators for dealing with sustainability issues] both on the semantic and the syntactic side.

4.2 Key distinctions related to integrated assessment

4.2.1 The distinction between Integrated Assessment and Integrated Analysis

According to the definition given by Millennium Ecosystem Assessment (MEA, 2005) **an assessment** must go through three distinct quality checks related to its: (1) scientific credibility; (2) political legitimacy; and (3) practical usefulness for guiding action – i.e. in a process of decision making.

This definition entails a crucial difference between an "assessment" and an "analysis":

**** "an assessment"*** implies acknowledging and handling with a pertinent analysis:

(i) the unavoidable presence of legitimate contrasting goals and values found in social actors; (ii) the unavoidable presence of uncertainty when dealing with the future; together with
(iii) the specificity of the context in which the assessment is implemented.

That is, an assessment must address not only the robustness in relation to analytical issues but also the relevance in relation to semantic issues, which entails normative implications (choosing what to do) referring to situations which are "all special". ***An assessment must be able to provide a quality check on both the semantic and the syntax used in the evaluation***;

**** "an analysis"*** refers to the production of data and the calculation of models and indicators within a given issue definition/problem structuring. That is, the application of a protocol of analysis assumes "by default" as relevant and useful the given issue definition and problem structuring. The focus of the analysis is on delivering the required indicator or model, based on a given selection of criteria (the semantic perception) of sustainability problems. ***A protocol of analysis does not address the quality of the semantic behind the choice of the given scale, proxy variables and production rules.***

4.2.2. The distinction between "relevant attribute" and "indicator" of sustainability

In the same way, it is possible to make a distinction between a "relevant attribute" of sustainability - e.g. economic growth (which is a semantic conceptualization) - and the relative quantification obtained using a proxy variable - e.g. "€ of 2001" used to calculate the GDP of the year 2006. It should be noted that a quantification of the semantic concept "economic growth" – a relevant attribute of the system - can be obtained using different proxy variables – quantitative indicators. Not only the GDP can be calculated in relation to a given currency of a given year ("US$ of 1997" versus "€ of 2001"), but it can be corrected in relation to Purchasing Parity Power (PPP), or even corrected for including - in the final quantitative assessment - hidden environmental costs (e.g. Green GDP accounting). But this distinction between the semantic definition of a "relevant attribute" of sustainability and the selection of a proxy variable – the quantitative variable used for gathering data - still misses another important aspect associated with the concept of indicator. In fact, in order to arrive to the definition of "an indicator of sustainability" (referring to a given relevant attribute) it is important to contextualize (to give meaning to the number used in the analysis). The value taken by the proxy variable, used to characterize the investigated system in relation to the chosen attribute, can have different meanings in different contexts. For example, a given quantitative assessment of the level of economic growth based on the attribute GDP - "10,000 € per household per year" - would represent an extremely good result in China, and a step backward in Germany. This is to say that the generation of an indicator requires combination of: (i) a semantic choice of a relevant attribute (criterion) of sustainability; (ii) a choice of a proxy variable capable of quantifying such an attribute (protocols for its calculation); (iii) the gathering of the required dataset; (iv) the choice of a set of targets and benchmarks making possible the interpretation of the value taken by the proxy variable in relation to the selected criterion of performance.

Also in relation to the distinction between a "relevant attribute" and "indicator" we find that an analysis of sustainability based on the choice and use of a set of indicators requires the ability of interfacing semantics (open procedures) and syntax (formal protocols). This is especially true when: (i) the assessment and the indicators refer to different scales, contexts and dimensions of analysis; (ii) policies based on this analysis will affect the lives of social actors carrying legitimate but contrasting perspectives about development goals.

4.3 Another look at the comparison of the analytical frameworks discussed so far

By using the distinctions illustrated in the previous section we can say that the generation of sustainability indicators entails two distinct challenges. It requires the ability to perform both:

3. a wise choice of semantic categories (criteria/attributes to be included in the analysis) for issue definition and problem structuring; and
4. a pertinent choice of formal categories and production rules (protocols). The chosen set of proxy variables, after the gathering of the relative data, must be able to provide, within the chosen issue definition/problem structuring, a reliable quantitative output for characterizing situations, options and determining, whenever possible, causal relations.

This distinction makes it possible to adopt a new criterion of classification for the analytical frameworks discussed so far:

A. methods that explicitly address the need of performing a quality check on the validity of semantic choices. These semantic choices can refer to both: (1) the choices behind the issue definition used for quantification - e.g. Is the criterion/attribute to which an individual indicator refers to a valid one? Is the choice of the given set of relevant attributes (criteria) used to characterize the sustainability of a system relevant? (2) the choices behind the selection of a lexicon and production rules used in the quantification in relation to the particular context - e.g. is the chosen protocol pertinent in this special situation? Are the chosen proxy variables reflecting the semantic associated with the chosen attributes? Do we have access to reliable data if we decide to use this indicator in this context?

B. methods that focus only on the specification and implementation of a given protocol. These methods assume that the quality control on both the semantic and the applicability of the relative protocol to the particular issue to be dealt with, is guaranteed "by default".

In relation to this new criterion we can say that the methods analyzed in this report and defined as "qualitative" represent an attempt to deal **on the semantic side**. They deal with the problem of how to control the quality of the choice of "issue definition" and "problem structuring". For this reason they are not based on the application of a given formal protocol (e.g. like done by MIPS), but rather they require a participatory process capable of addressing the challenges implied by the "Deep Sustainability Semantics" [= answering questions such as: Sustainability of what? Sustainability for whom? Sustainability at which cost? Sustainability for how long? (Tainter, 2008)].

When dealing with ***"deep semantic questions about sustainability"*** we have to perform a quality check in relation to NORMATIVE implications. In fact, a given issue definition unavoidably reflects the choice of a given story-telling about sustainability. IF we admit the unavoidable presence of: (i) different legitimate perspectives about what should be sustained and for whom (different story-tellers about sustainability); (ii) uncertainty and genuine ignorance affecting the data and the different models, the choice of issue definition and problem structuring (the set of relevant attributes about which indicators are required); THEN the choice of how to answer "deep semantic questions about sustainability" becomes a very sensitive one. This is to say that such a choice cannot be performed by "scientific experts" alone in isolation from social actors. It requires the interfacing of process generating quantitative analysis with participatory procedures.

In relation to this issue DPSIR represents a framework in which it is possible to include previous deliberation in the selection of indicators through a participatory process. This is a framework semantically open, in which participatory processes can address the key relationships between policy, society, economy and biodiversity, in a much more legitimate way. Even if DPSIR does not provide a very strict protocol itself, it suggests a procedure to select categories to describe society and environmental relationship. There are other methods (e.g. Soft System Methodology developed by Checkland – e.g. Checkland and Schole 1990) that elaborate more about the procedure to be adopted when implementing this approach. The STEEPV method also addresses, in part, the issue of quality control on the choice of issue definition and problem structuring by suggesting brainstorming sessions, as a participatory approach, in order to guide the identification of relevant factors to be considered in a given situation.

When dealing with the ability of building a ***commensurate experience about sustainability*** the quality check deals with DESCRIPTIVE implications. That is when admitting that quantitative models are based on a drastic simplification of the complexity associated with sustainability, we have to acknowledge that using models entails a massive loss of information about sustainability. In order to be able to look at the details within a given descriptive domain we must loose track of the details of other processes taking place at different scales in different descriptive domains. As a consequence of this fact we have to remember always the line “all models are wrong, but some are useful” (Box, 1979). The information coming from models based on the adoption of a given dimension of analysis and a given scale must always be integrated with the information coming from other models, other dimensions of analysis and other scales. The use of indicators in the field of sustainability must always be coupled to a quality check about the chosen mix of criteria and attributes, referring to key dimensions and scales.

In relation to this issue STEEPV is useful to develop evaluations of farm level, national level and global level. It can be used for dealing decision making (identifying needs), planning (considering a multi-dimensional relations), crisis management (linkages with other dimensions), situations characterized by large doses of uncertainty (exploring impacts) and scenario activities (see above Section 2.4.5). The MSIASEM makes it possible to check the usefulness of the overall output of indicators, benchmarks and targets in relation in relation to the goal of the analysis.

5. Recommendations on relevant steps for integrated assessment

All frameworks investigated share common features to be highlighted and limits to be overcome. An integration procedure needs to identify crucial steps that are mandatory for the reliability of the results and factors that may enhance or decrease their applicability to a real case or to a larger number of cases. Figure 8 shows a very schematic step-by-step diagram of the main phases of such a procedure. Some stes are more qualitative, others are mainly based on quantitative data. In all, both aspects must be taken into proper account, provided that the procedure is based on an agreed upon identification of the problems and the goal, a shared awareness of uncertainties that may affect the results as well as of the meaning of calculated indicators, and finally a joint discussion of the results and their applicability.

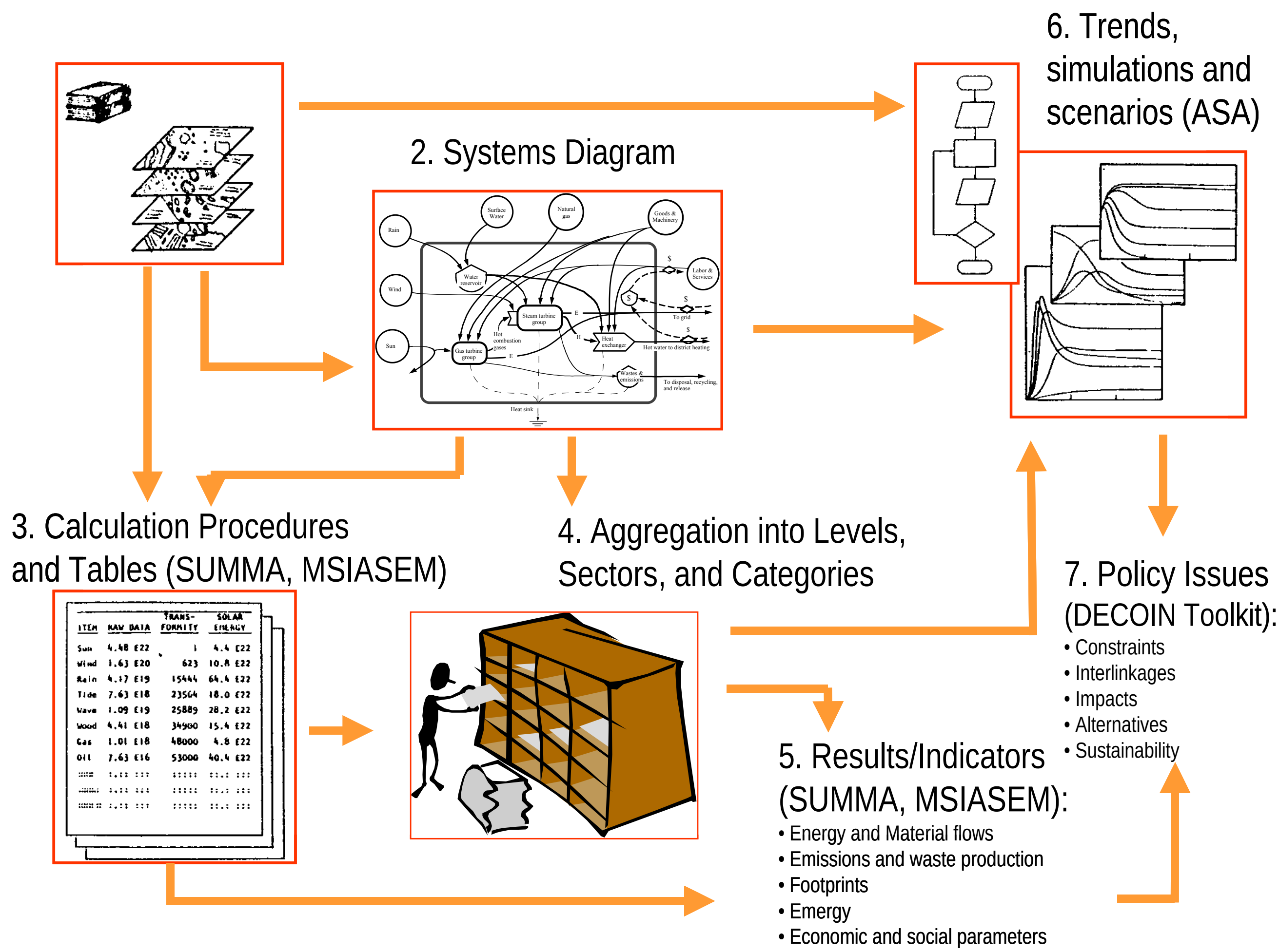

Figure 8. Phases of a multimethod and multiscale process/system evaluation.

Further explanation of steps in Figure 8:

1. Identification of the problem – issue definitions, choice of narratives [semantic framing]
2. Systems Diagrams -Selection of grammars useful for problem structuring [bridging semantic and syntax]
3. Calculation Procedures - Development of dictionaries (protocols, primary data and resulting datasets) [implementing the chosen syntax for representation]
4. Aggregation - Integrating grammars across levels, scales and dimensions [integrated analysis]

5. Results/Indicators - Multi-Objective Characterization reflecting the chosen issue definition/formalization
6. Trends - Scenarios analysis based on a multi-scale integrated representation
7. Policy Issues - Deliberation on policy issues

Therefore, according to the scheme of Figure 8, the following are the most relevant issues that need to be dealt with for an integrated assessment toolkit:

- Identification of the problems by the analyst or policy maker
- Identification and gathering of stake-holders (institutional analysis/ participatory process)
- Identification of the system, drawing a systems diagram (components, levels, interactions, input and output flows)
- Understanding the perception of the problems by stake-holders
- Collection of data (units, quality, uncertainty, references)
- Organizing raw data (tables, diagram)
- Classification of data (sectors, levels, categories, attributes)
- Processing of data and calculations of indicators (all levels, sectors, categories, attributes)
- Monitoring changes of intensity factors over time (technical, economic and social)
- Quality control (sensitivity analysis: influence of data errors; participatory integrated assessment:uncertainty and misunderstandings of problems perception)
- Influence of presence and lack of feedbacks across scales
- Discussion of results (meaning of indicators) versus attributes, perceptions, goals
- Policy Issues: Constraints, interlinkages, impacts, alternatives, sustainability

5.1 Perception of a problem by different actors and stakeholder

Different actors and stakeholder assign very different importance and priorities to the various aspects of a process. There is no way to prevent or dismiss the existence of these different perspectives and legitimate interests. It is therefore of paramount importance not to assign an absolute meaning to any of the numerical results that are generated within any given evaluation procedure. This would imply the possibility of assuming as an absolute priority the numerical indication of performance obtained when considering only one aspect of a given problem definition. This risk can be avoided by operating with an iterative procedure capable of putting on the discussion table all the aspects and interests that are considered important by some of the actors and stakeholders. The analysts cannot and should not just focus on those aspects that he/she considers the most important (e.g., the contribution to the global warming), because in so doing it would ignore different perceptions of priorities inducing a loss of legitimacy in the credibility of the quantitative analysis and a consequent lack of involvement for the majority of the other stakeholders. The analyst should also always keep in mind the existence of important ethical issues entailed by stakeholders that cannot represent themselves in the assessment (other species, future generations) as well as the existence of common goods and resources that can be used but should not be converted into private property (clean air, fresh water, healthy oceans, biodiversity, etc). Such an awareness will affect the inclusion in the assessment of tools (e.g. emergy analysis), that also take into account the environmental support and services provided for free by nature and the importance of which is most often disregarded.

5.2 Selection of grammars useful for problem structuring [bridging semantic and syntax]

A grammar can be defined as an expected set of relations between semantic categories and formal categories in a given representation of a system. To clarify this concept we can use a familiar example of grammars adopted by the system diagrams (Odum, 1971; 1996) originally used in the field of theoretical ecology. These diagrams assign expected roles to different elements of an ecosystem, which, in this way, can be characterized in terms of a given pattern of interaction among elements having known characteristics. This representation requires assuming the validity of the local representation (we can know ahead the type of inputs, outputs, and the input/output for each node) and the validity of the global representation (we can predict that the connections among nodes and the type of interactions of the whole network with its environment will remain the same in the time duration of the analysis). By adopting these assumptions, it becomes possible to characterize and assess the performance of a system characterized using a grammar in relation to a set of goals (objectives) set by the analyst.

In the example of ecological studies, the purpose of the system diagram is to conduct a critical inventory of processes, storages and flows that are important to the system under consideration and are therefore necessary to evaluate. Components and flows within diagrams are arranged from left to right reflecting more available energy flow on the left, decreasing to the right with each successive energy transformation. The same approach based on the use of grammars and flow diagrams can be applied to the analysis of socioeconomic systems. For example, a simple diagram of a regional economy with trade with surrounding economies is shown in Figure 9, while an agro-industrial system for fuel production from biomass is shown in Figure 10. The left to right organization also corresponds to increasing scale of territory and turnover time. As illustrated in both Figures, the choice of a grammar entails the definition of a lexicon (what the system is, what the elements are and what is done by the system). In these two examples every energy transformation box has more than one input, including larger energy flows from the left, lesser amounts from units in parallel, and small but important controlling energies feeding back from the right.

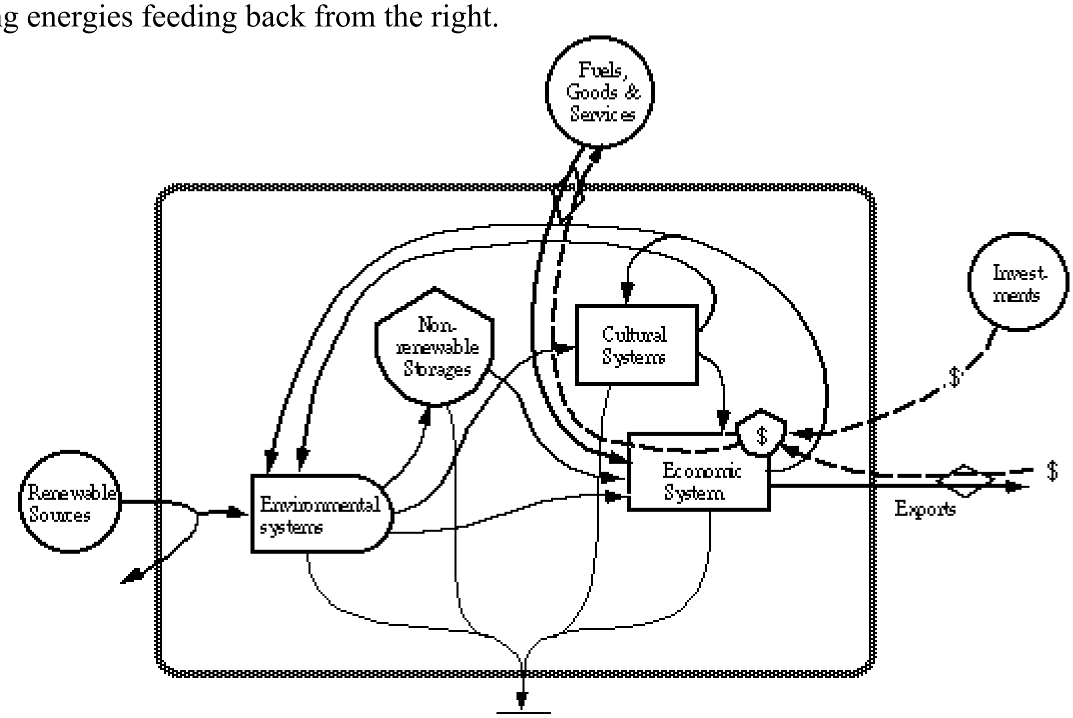

Figure 9. Systems diagram of a regional economy that has developed trade with external markets.

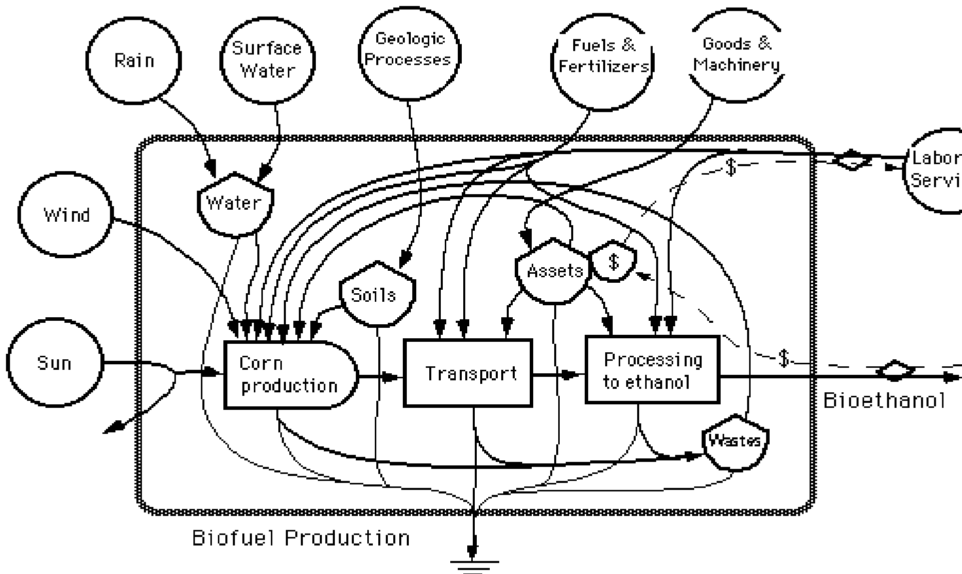

Figure 10. Biomass to biofuel production steps

The choice made when defining the grammar (in this case the system diagram) are important are crucial for preliminary identification of main system's features. For this reason the choice of the grammar is a key step of the process of assessment. It is a step in which the involvement stakeholders is essential; they can indicate to the scientists perspectives, relevant attributes of performance and at the same time they can learn from the scientists hidden relations and feed-backs. Unlike traditional flow-sheet diagrams, systems diagram highlight not only how the main input is processed step-by-step to yield the final product, but also what are the other driving forces (including those associated with natural processess), the interacting components and the feedback flows from higher to lower steps. If properly designed, the integration of several complementing system diagrams (grammars), reflecting different dimensions of analysis and scales, can provide a richer and more useful picture of the system, in its wholeness, preventing the adoption of reductionistic points of view – i.e. dangerous simplifications of such a wholeness in mono-scale, mono-dimensional analysis. A discussion over the most useful selection of grammars, in relation to a given problem identification, may serve as a basis for an informed discussion with social actors, for the identification of major driving forces, inventory and quantification of the size of flows and components. In turn, this provides a quality control on the semantic used, later on, to generate a quantitative representation based on numerical tables of input and output flows.

5.3 Collecting data, checking them for quality and biophysical benchmarking, assessing reliability at different scales (Development of dictionaries - protocols, primary data and resulting datasets)

Data about input and output flows are crucial for analysis and assessment. Although not all relevant aspects for sustainability studies can be quantified, nor they need to, both the size and performance of the investigated system in relation to the different grammars used to represent it, it is important as the starting point for further discussion. The size of a socio-economic system can be measured in number of people (when adopting a grammar relevant for demography); in € of GDP (when adopting a grammar relevant for economics); in GJ of tons of oil equivalent (when adopting a grammar relevant for biophysical analysis); or (EMJoules – solar joules equivalent of ecological activitiy – when using a grammar reflecting an ecological reading of the interaction society/environment). The present report does not aim at discussing in depth the problem of data quality and meaning. Yet, no investigation can be considered reliable if a clear quality check and benchmarking of data is not performed, based on agreed upon protocols and procedures. Therefore, the investigator should be able to collect and double check data at different scales (local, global) and levels (individual process, whole sector, region, nation) as well as over longer time series. These data are affected by different uncertainties that must be acknowledged by the analyst and relate to different priorities and interests. Their meaning must be check against the priorities and the structure/dynamics of the level to which they refer and must also be interpreted in the light of the upper and lower levels that they affect or by which they are affected. We need, borrowing Odum's concepts, to adopt simultaneously both microscopic and macroscopic points of view. Figure 11 (based again on the type of grammar/system graph developed by H.T. Odum) provides a view of selected different levels and scales supporting and feeding back each other.

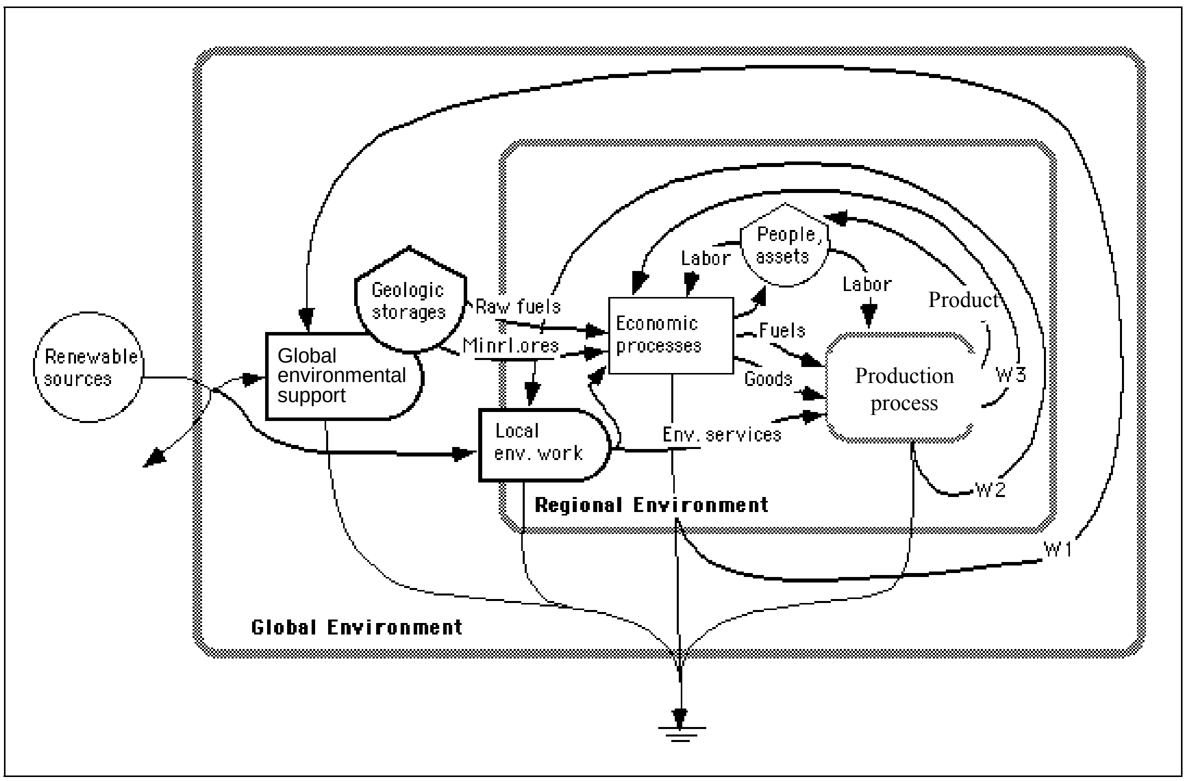

Figure 11. Systems diagram showing a production process supported by larger scale processes and sources. Reinforcing feedbacks from process to lower steps are also shown.

Collecting data referring simultaneously at different levels and scales is one of the most difficult challenges for the investigator and calls for reliable and comprehensive statistical monitoring by local and governmental boards and agencies. Therefore, a procedure for the assessment of sustainability and unsustainability trends needs to rely on and to be supported by a very efficient and effective data collection and processing statistical service, at local, regional and national levels, not to talk of the need for international statistical databases.

5.4 Checking reliability of Intensity Factors

Once the main input and output flows are identified, they can be processed by means of technical and environmental Intensity Factors, that account for upstream and downstream impacts (e.g. material withdrawal in support to a given input flow or ecotoxicity of a given output flow). In this way several evaluation techniques (material flow accounting, embodied energy, emergy, ecological footprint, potential impact assessment, etc.) can be used, depending on the goal of the analysis, to provide an evaluation of the relation of the system with the surrounding environment at different spatial and time scales. However, this approach is effective to shed light on the performance of a system as far as its ability to process matter, energy and information is considered at a given point in time (e.g. at a give year). If the same behaviour has to be investigated over a larger window of time (decades, or more), then it is unavoidable to find increasing doses of uncertainty on the estimates. In fact, the assumptions of validity of the representation based on system graph discussed above, tend to become less reliable on larger time durations. Technical and environmental intensity factors (the identity of the flows of input, flows of output to and from the different elements, the input/input ratios) as well as the stability of the interaction of the whole network with its surroundings are not easy to extrapolate into the future. These values (determining the transformities and the effect of large scale feed-backs) are always time and location specific, since they are of course dependent on technology and resource availability, and may change over time, thus affecting the final values of calculated indicators. If we keep using the same Intensity Factors (e.g., energy intensity of steel or fertilizers, or material rucksack for a given product) for the calculation of performance indicators over one or two decades, we are risking to generate very unreliable indicators. The issue of scale – how to handle a multi-scale dataset - should, therefore, be a key concern for quantitative analysis. The analyst should be sure that (a) the duration of the analysis (the time window of the study) is not too long compared to the speed of the technological development in the sector or process studied (the pace at which the identities of the elements of the graph are evolving in time); (b) if there is uncertainty about potential changes in the Intensity Factors, the effect of this uncertainty is properly accounted in the results. These two points should be considered very carefully by those (individual scientists, Agencies, Governments) who decide to start monitoring selected technical, environmental or social phenomena using this approach. If the problem of time dependence of technical factors is addressed, they can be easily recalculated each year by means of commercially available or ad-hoc created LCA software tools. If flows and Intensity Factors are monitored and recalculated yearly, a less uncertain database becomes available for future studies, comparison and more reliable scenario-making. It should be noted, however, that this solution can deal with the uncertainty referring to the formalization of a given grammar (on the syntax side), but not on the uncertainty about the validity of the grammar associated with the system graph – whether or not the original system diagram became obsolete (on the semantic side).

5.5 Feedbacks from higher to lower levels

Sustainability assessments rely on many different features and requirements (traditionally indicated as social, environmental and economic pillars). This is why different type of grammars are required to address these different perceptions/representations of the issue of sustainability. However, the internal structure of a given network of transformations is also very important. The interaction and integration among systems components, the internal exchange of resources and services, the identification of matter and energy flows to, from and within a system (LCA), the demand for environmental support, and finally the efficiency of resource and decreased emissions, are of paramount importance for more sustainable production patterns. Systemic ecological principles can be used to study the sustainability of socio-economic patterns of production and consumption. For example, ecological systems increase complexity by reinforcing their resource basis, pulling in new resources, and stabilizing structure and diversity of components by means of feedback actions of higher to lower levels. Recognizing the existence of feedbacks and reinforcing their action is an important tool for achieving sustainability. Assessments should therefore focus on the need for suitable and stable feedback flows. Awareness of the importance of such flows must be an important part of the discussion among stakeholders as well as of the evaluation of results. Indicators of feedback circulation of energy and matter flows should be developed at all scales and used to complement other indicators of performance coming from the application of other grammars – e.g. economic analysis, social analysis, ethical considerations.

5.6 Meaning of calculated indicators according to scale, goals and actors.

Calculated indicators such as energy intensity, life expectancy, efficiency, emissions, literacy, etc. may have different meaning and relevance at different scales, depending on the pertinent interests and priorities. We should not expect that an indicator should be useful at all scales and in relation to different criteria of performance. A wise choice should be based on the agreed mix of goals and should consider the existing uncertainty and legitimate but contrasting perspectives about priorities. This implies that the absolute maximization or minimization of some objective function should never be the target. A procedure for sustainability assessment should be able to double check the values of calculated indicators against the priorities and constraints identified for each scale and category of stakeholders. By no means a given table of indicators – i.e. a set of numbers - should become a basis for policy, especially when meaning of indicators and constraints on their relevant categories are not clearly assessed at the scale of interest and correlated to the larger and smaller scales.

5.7 Sensitivity analysis

No need to spend too many words in order to support the idea that a sustainability assessment procedure must also involve a careful sensitivity analysis in all its steps. Since many factors are involved, since some of them are affected by significant uncertainty, since some of them (Intensity factors) may change over time, and finally since flows and results are correlated each other and may have amplification and feedback effects, the procedure must be capable of at least describing the influence of factors to each other, also by means of so-called influence diagrams. If a calculation procedure is implemented, sensitivity checks are mandatory at least for largest flows or for those flows that are more likely to depend on technology changes or rapidly evolving economic factors.

6. Conclusions

In this report we have examined different analytical frameworks adopted in the last years for sustainability assessment.

The analysis shows that DPSIR, PSR and STEEPV frameworks are good for structured brainstorming, use qualitative input data and have shortcomings as a tool for establishing good communication between researchers, on the one hand, and stakeholders and policy makers on the other.

The problem with these frameworks is their lack, so far, of efforts to find a satisfactory way of dealing with the multiple attitudes and definitions of issues by stakeholders and the general public.

On the other hand, ASA, MSIASEM and SUMMA are quantitative methods and use different kinds of software or calculation procedures to value individual processes (SUMMA approach) or territorial areas (ASA, MSIASEM). The MIPS method has been already incorporated within the SUMMA, while the DPSIR method is a later and more comprehensive version of PSR. Therefore, we remain with two frameworks (DPSIR and STEEPV) which are very good for a qualitative problem structuring and description of the process/system characteristics and three frameworks (SUMMA, MSIASEM and ASA) which are very good in quantitative analysis and interpretation/integration of results related to the different dimensions of sustainability, although one of them (SUMMA) focuses mainly on processes and the other two deal with area-related systems and dynamics.

Application of different frameworks together requires that their common features are recognized, merits implemented and drawbacks removed. We identified in this Deliverable (from Work package 2) the theoretical and practical aspects that must be taken into proper account while developing an integrated tool kit for sustainability assessment, with special focus on the possibility of integrating a selected set of qualitative and quantitative frameworks operating at different scales.

7. Documents used in the review

DPSIR:

1. Borja A., Galparsoro I., Solaun O., Muxika I.B, Tello E.M., Uriarte A., Valencia V., 2006. The European Water Framework Directive and the DPSIR, a methodological approach to assess the risk of failing to achieve good ecological status, Estuarine, Coastal and Shelf Science 66: 84-96.
2. Svarstad H., Petersenb L. K., Rothmanc D., Siepeld H., Watzold F., 2008. Discursive biases of the environmental research framework DPSIR, Land Use Policy 25: 116–125.
3. Denisov N., Grenasberg M., Hislop L., Schipper E. L. and Sørensen M., 2000. Cities Environment Reports On the Internet: understanding the CEROI template, UNEP/GRID-Arendal, Norway.
4. Trombino G., Cinnirella S., Pesenti E., Algieri A. and Pirrone N. 2003. DPSIR approach as a useful tool to shape a sustainable development strategy for the Po catchment-adriatic costal zone continuum, Geophysical Research Abstracts, Vol. 5, 12212.
5. Vacik H., Wolfslehner B., Seidl R. and Lexer M. J., 2007. Integrating the DPSIR - approach and the Analytic Network Process for the assessment of forest management strategies Department of Forest and Soil Sciences, Institute of Silviculture, University of Natural Resources and Applied Life Sciences, Peter-Jordanstr. 82, A-1190 Vienna, Austria.
6. L. Maxim, M. O'Connor, J.H. Spangerberger, 2007. Framing the DPSIR Framework at European scale or the socio-economic analysis of biodiversity, Cahiers DU C3ED.

PSR:

1. László Pintér L., Zahedi K., David R., Cressman D. R., 2000. Capacity Building for Integrated Environmental Assessment and Reporting, International Institute for Sustainable Development (IISD) United Nations Environment Programme (UNEP) Ecologistics International, Ltd.
2. Boothroyd I. and Drury M., Presentation on "Sustainable resource management: A Pressure-State-Response framework for sustainability in the urban environment".

MIPS:

1. Bargigli S., Raugei M. and Ulgiati S., 2005. Mass accounting and mass-based indicators.
2. Ritthoff M., Rohm H., Liedtke C., 2002, Calculating MIPS resource productivity of products and services, Wuppertal Spazial 27eWuppertal Institute for Climate, Environmental and Energy at the Science Centre Norton Rhine-Westphalia.
3. Ellard D. J., 1994. MIPS Assembly Language Programming CS50 Discussion and Project Book
4. European Commission, 2001. Economy-wide material flow accounts and derived indicators: a methodological guide, Office for official publication for European Communities, Luxemburg.
5. Hinterberger F., Schmidt-Bleek F., 1999 FORUM Dematerialization, MIPS and Factor 10 Physical sustainability indicators as a social device, *Ecological Economics* 29: 53–56

STEEPV

1. Rafael Popper, 2003. The STEEPV method, a framework for structured brainstorming, presentation in International Workshop on FORESIGHT, Sofia, Bulgaria.
2. Loveridge D., 2002. The STEEPV acronym and process - a clarification.

3. Vinnari M., 2007, The future of meat consumption — Expert views from Finland, *Technological Forecasting & Social Change* in press.

ASA

1. Luukkanen J., Vehmas J., Kaivo-Oja J., 2005. Energy use and CO2 emissions from fuel combustion in the OECD and non-OECD countries: Trends based on decomposition analysis *Futura* 2-3: 129-145.
2. Luukkanen J., Vehmas J., Kinnunen V., Kuntsi-Reunanen E., Kaivo-oja J. 2005. Converging CO_2 emission to equal per capita levels: mission possible? *Technical Report FFRC-Publication 2-2005,* Tampere.

MSIASEM

1. Ramos-Martin J., Giampietro M., Mayumi K., 2007. On China's exosomatic energy metabolism: An application of multi-scale integrated analysis of societal metabolism (MSIASM), *Ecological Economics* 63: 174-191.
2. Giampietro M. 2003. *Multi-Scale Integrated Analysis of Agro-ecosystems.* CRC Press, Boca Raton, 472 pp.
3. Giampietro, M. (guest editor) 2000. Societal Metabolism─Part 1 of 2: Introduction of the Analytical Tool in Theory, Examples, and Validation of Basic Assumptions. Special issue of *Population and Environment* 22 (No. 2): 97-254.
4. Giampietro, M. (guest editor) 2001. *Societal Metabolism. Part 2 of 2: Specific Applications to Case Studies.* Special issue of *Population and Environment* 22 (No. 3): 257-352.

SUMMA

1. Ulgiati, S., Bargigli, S., and Raugei, M., 2003. Can a Process Sustainability be Assessed by means of Thermodynamic and Ecological Impact categories? *Ecological Questions*, 3:153-168, (2003).
2. Ulgiati, S., Bargigli, S., and Raugei, M., 2004. Integrated Indicators to Assess Design, Performance and Environmental Sustainability of Energy Conversion Processes. In: Integrative Approaches towards Sustainability in the Baltic Sea Region. Series on Environmental Education, Communication and Sustainability, N. 15. Walter Leal Filho/Arnold Ubelis (eds.). Peter Lang Publisher, Frankfurt am Main, Germany, 2004, pp. 211-232.
3. Ulgiati S., Raugei M., and Bargigli S., 2006. Overcoming the inadequacy of single-criterion approaches to Life Cycle Assessment. *Ecological Modelling*, 190: 432–442.
4. Cherubini, F., Bargigli, S., and Ulgiati, S., 2007. Waste management. From landfill to energy and material recovery. A multi-method approach. Paper presented at the 20th International Conference ECOS 2007, Book of Proceedings, edited by A Mirandola, O. Arnas and A. Lazzaretto, Volume I, pp. 231-240, SGE Editoriali Publisher, ISBN 88-89884-08-8

8. References

Bargigli, S., and Ulgiati, S. (2003). Emergy and Life-Cycle Assessment of Steel Production in Europe. In: Emergy Synthesis. Theory and Applications of Emergy Methodology – 2. M.T. Brown, H.T. Odum, D. Tilley, and S. Ulgiati (Editors), published by the Center for Environmental Policy, University of Florida, Gainesville, FL, 2003, ISBN 0-9707325-1-1, pp. 141-155.

Bargigli, S., Raugei, M., Ulgiati, S., 2004a. Mass flow analysis and mass-based indicators. In: Handbook of Ecological Indicators for Assessment of Ecosystem Health. CRC Press, 439 pp.

Bargigli, S., Raugei, M., Ulgiati, S., 2004b. Comparison of thermodynamic and environmental indexes of natural gas, syngas and hydrogen production processes. Energy 29 (12–15), 2145–2159.

Box, G.E.P., 1979 Robustness is the strategy of scientific model building. In R.L. Launer and G.N. Wilkinson (Editors) *Robustness in Statistics* Academic Press N.Y. pp. 201-236.

Brown, M.T., Ulgiati, S., 2004. Energy quality, emergy, and transformity: H.T. Odum's contributions to quantifying and understanding systems. Ecol. Modell. 178 (1–2), 201–213.

Canino, M., Nivala A., and Ulgiati, S. (2005). A thermodynamic and environmental assessment of lanthanide chloride production from bastnaesite. Paper presented at the Second International Conference on "Sustainable Development Indicators in the Mineral Industries – SDIMI 2005", 18 - 20 May 2005, Aachen, Germany. Book of Proceedings, 2005.

Checkland P., and Scholes J. 1990 *Soft-Systems Methodology in Action* Chicester: John Wiley.

Cherubini, F., Bargigli, S., Raugei, M., and Ulgiati, S. (2005). LCA of magnesium extraction and processing. Technology overview. Paper presented at the Second International Conference on "Sustainable Development Indicators in the Mineral Industries – SDIMI 2005", 18 - 20 May 2005, Aachen, Germany. Book of Proceedings, 2005.

EEA, 1995. Europe's Environment: the Dobris Assessment. European Environment Agency, Copenhagen.

EEA, 2001. Environmental Signals 2001. European Environment Agency, Copenhagen.

Herendeen, R., 1998. Embodied energy, embodied everything . . .now what? In: Proceedings of the First International Workshop Advances in Energy Studies. Energy Flows in Ecology and Economy, 13-48/642, MUSIS, Roma, Italy.

Hinterberger, F., Stiller, H., 1998. Energy and material flows. In: Proceedings of the First International Workshop Advances in Energy Studies. Energy Flows in Ecology and Economy, 275- 286/642, MUSIS, Roma, Italy.

Holten-Andersen J., Paalby H., Christensen N., Wier M., Andersen F.M., 1995. Recommendations on strategies for integrated assessment of broad environmental problems. Report submitted to the European Environment Agency (EEA) by the National Environmental Research Institute (NERI), Denmark.

Millennium Ecosystem Assessment (MEA) 2005 Vol. 4 "*Multiscale Assessments – findings of the Sub-global Assessments Working Group*" .

Odum, H.T., 1996. Environmental Accounting: Emergy and Environmental Decision Making. Wiley, New York, NY, USA, p. 370.

OECD, 1991. Environmental Indicators, a Preliminary Set. OECD, Paris.

OECD, 1993. Organisation for Economic Co-operation and Development (OECD) core set of indicators for environmental performance reviews. OECD Environment Monographs No. 83, Paris. Retrieved on 13 March, 2005 from http://www.oecd.org/dataoecd/32/20/31558547.pdf.

Rapport D., Friend A., 1979. Towards a Comprehensive Framework for Environmental Statistics: a Stress–response Approach. Statistics Canada Catalogue 11-510. Minister of Supply and Services Canada, Ottawa.

Raugei M., 2006. Advances in Life Cycle Assessment: Method Integration and Geographic Allocation of Environmental Impact (case studies: advanced photovoltaics and primary aluminium). PhD thesis, University of Siena, Italy.

Raugei M., Cherubini F., Ulgiati S., 2007. A new look at the geographic distribution of resource depletion (ecological rucksack) in Environmental Accounting / MFA - two case studies from the mineral industry: Al and Mg. *J. Ind. Ecol.*, submitted.

Raugei M., Ulgiati S., 2007. A novel approach to the problem of geographic allocation of environmental impact in LCA, with special focus on the MFA method. *Ecol. Model.*, submitted

Schmidt-Bleek, F., 1993. MIPS re-visited. Fresenius Environ. Bull.2, 407–412.

Simoncini E., Raugei M. and Ulgiati S. (2005). Life Cycle Assessment of Synthetic Rutile Production Using The ERMS/EARS Process. Paper presented at the Second International Conference on "Sustainable Development Indicators in the Mineral Industries – SDIMI 2005", 18 - 20 May 2005, Aachen, Germany. Book of Proceedings, 2005.

Slesser,M. (Ed.), 1974. Energy Analysis Workshop on Methodology and Conventions. IFIAS, Stockholm, Sweden, 89 pp.

Suutarinen J., Rikkonen P., Pehkonen A., Karttunen J., Tuure V.M., Louhelainen K., Rautiainen R., 2006.Changes in Operational Environment of Agriculture –Impacts to Working Environment, lecture given. Finnish Institute of Occupation Health.http://www.ttl.fi/NR/rdonlyres/45E74A50-BF0A-4146-87CD-C3CA985063A6/0/Suutarinen.pdf.

Szargut, J., Morris, D.R., 1998. In: Steward, F.R. (Ed.), Exergy Analysis of Thermal, Chemical, and Metallurgical Processes. Hemisphere, New York, NY, USA, 332 pp.

Tabacco, A.M:, Bargigli, S., Raugei, M., and Ulgiati, S. (2003). Life Cycle, Exergy and Emergy Assessment of Metallic Chromium Production from Ore. In: "Advances in Energy Studies. Reconsidering the Importance of Energy", S. Ulgiati, M.T. Brown, M. Giampietro, R.A. Herendeen, and K. Mayumi, Editors. SGE Publisher Padova, Italy, 2003, 619-628. ISBN 88-86281-81-1.

Tainter, J. 2008 Energy, Resources and the Semantic of Sustainability In. S. Ulgiati (Editor) *Proceedings of the Biennial International Workshop Advances in Energy Studies (5): "Perspectives into energy futures"*. Servizi Grafici Editoriali, Padova, Italy

Ulgiati S., Raugei M. and Bargigli S., 2006. Overcoming the inadequacy of single-criterion approaches to Life Cycle Assessment. *Ecol. Model.*, 190(3-4):432–442

Ulgiati, S. (2001). A Comprehensive Energy and Economic Assessment of Biofuels: When "Green" Is Not Enough. Critical Reviews in Plant Sciences, 20: 71-106.

United Nations Environment Program, 2002. Global Environmental Outlook 3. Earthscan, London.

United Nations, 1996. Indicators of sustainable development. Division for Sustainable Development.

United Nations, 1999. Work Programme on Indicators of Sustainable Development of the Commission on Sustainable Development. Division for Sustainable Development, Department of Economic and Social Affairs, New York.

United Nations, 2001. Indicators of sustainable development: framework and methodologies. Background Paper No. 3, Commission on Sustainable Development, Division for Sustainable evelopment, Department of Economic and Social Affairs, New York.

APPENDIX: Spatial allocation of impacts

(proposals for upgrade and integration of methods and frameworks within DECOIN)

Summary of comments contributed by: **Parthenope University team** (Marco Raugei and Sergio Ulgiati) and **Vrije Universiteit Team (**Peter Nijkamp).

The present review is based on the following documents delivered to the DECOIN Working Group and available in their full version***:***

1. Raugei M., Ulgiati S. , 2007. A novel approach to the problem of Geographic allocation of environmental impact in LCA whit special focus on the MFA method.
2. Nijkamp P., 2007. Note on a Spatial (Multiregional) ASA

1. Spatial Allocation of Impacts

(Raugei, M., and Ulgiati, S.)

Spatial Allocation of Impacts is an innovative method based on a new allocation procedure whereby the impact indicators, calculated by means of widely-accepted LCIA methods, can be allocated to those world regions that are specifically involved in the analyzed processes. This method uses a matrix algebra which allows to split environmental impact indicators (both “downstream”, such as Acidification Potential, Eutrophication Potential, ect, and “upstream”, such as Material Intensities) in portions, which are geographically attributed to the different world regions. This innovative procedure extracts new information from aggregated indicators which are usually only calculated on the global scale, and is able to take into account the complex web of international links which lie behind all industrial activities. This requires the availability of database and sophisticated calculation procedures.

The procedure is comprised of the following steps (see flowchart in Figure 12):

1. The up-to-date percentages of the total world production of the analyzed primary material for each world region are determined, making use of the available statistical yearbooks.
2. The second step takes into account the fossil fuels (oil, coal and natural gas) that are required during the life cycle of the analyzed material as direct inputs, excluding those that are employed for electricity production.
3. The third step takes into account electricity use, differentiated in: electricity from oil, from coal, from natural gas, hydroelectricity (the most common type of “renewable” electricity) and nuclear electricity.

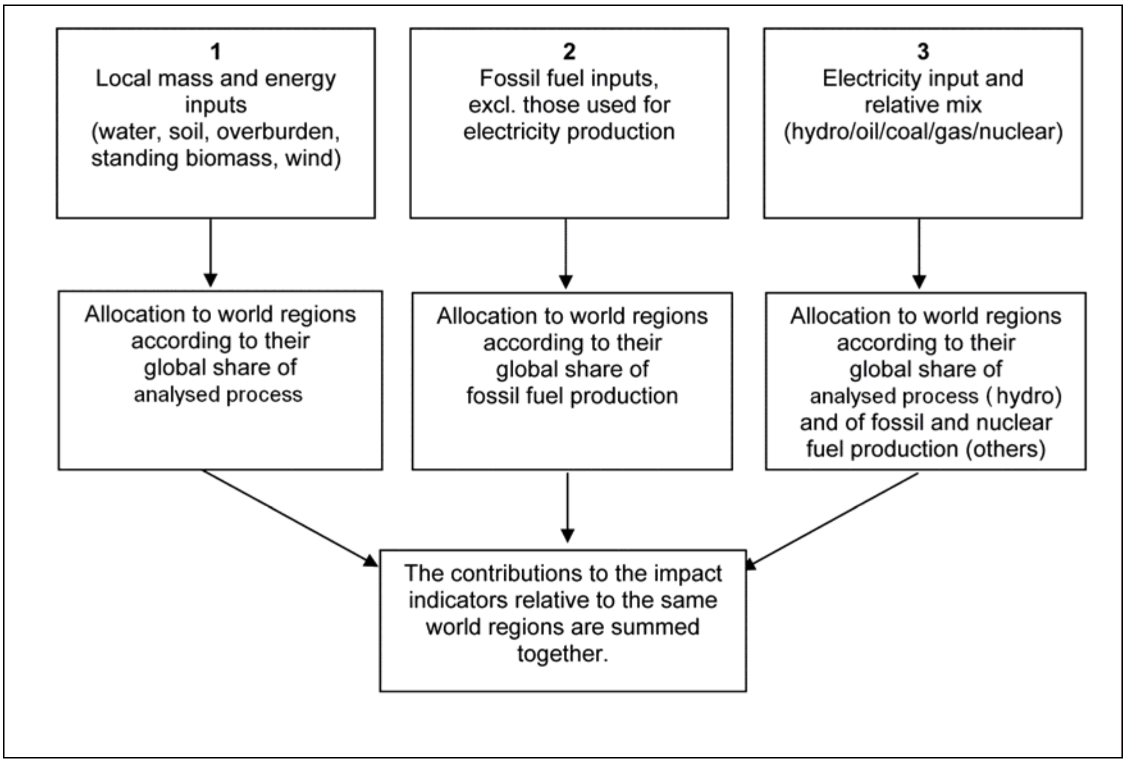

Fig. 12: Flowchart of the proposed allocation procedure.

The result is the complete regional allocation of the impact indicators of the analyzed commodity, whereby the analyst can see which are the world regions that are more heavily impacted in terms of "downstream" impact (Acidification Potential, Eutrophication Potential, etc.), and depletion of material resources (Material Intensities).

Finally, the procedure could be extensively and routinely applied in an ever-increasing number of analyses, also with a higher level of detail, and could even be helpful as a tool in the difficult and complex process of seeking international agreements aiming at adequately compensating for the uneven distribution of environmental and resource burdens among world regions and countries.

2. Spatial Allocation of CO2

(Peter Nijkamp)

This approach supposes the world is subdivided into R regions r (r = 1, …, R) which all generate a region-specific volume of pollution in relation to the use of fossil fuels P_x.

If there are no interactive forces between these regions – in terms of ecological interdependencies or spatial spillovers of pollutants e.g. - the standard decomposition function for each region r would be straightforward:

$$P_r = \frac{P_r}{TPES_r} \bullet \frac{TPES_r}{FEC_r} \bullet FEC_r$$

if the volume of P_r generated in a given region *r* can be exported to other regions, the simple equation will change. Similarly, if P_r is imported into region r, again a new picture emerges. In that case, the ambient volume of pollution in region r is equal to:

$$P_r^A = P_r + IP_r - EP_r$$

where IP_r and EP_r are respectively imports and exports of P_r for region r. In case of multiple regions in a closed system, IP_r may be written as:

$$IP_r = \sum_{\substack{r^1=1 \\ r^1 \neq r}}^{R} a_{r^1 r} P_{r^1} ,$$

where a_{rr} is the share of total CO2 emission generated in region r^1 and diffused to region r. The coefficient a_{rr} can be determined e.g. by a spatial Gaussian distribution curve.

This method is based on the statement that CO2 is a global factor. The specific nature of CO2 makes it more difficult to handle it, as it may diffuse into the atmosphere or get down as sink in oceans etc. This would mean that our spatial diffusion model would have to be extended with a sink component (for water, atmosphere, perhaps land or forest) in order to obtain a consistent picture.