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DECOIN – Deliverable D2.1 of WP2

Evaluation of selected methodological approaches for environmental analysis and assessment

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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.

2. Assessment of the selected analytical frameworks

2.1. DPSIR

2.1.1. 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).

2.1.2. 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).

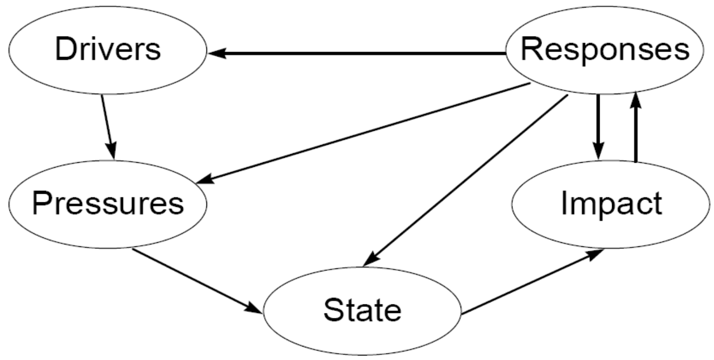

Fig. 1 The Driving forces, Pressures, State, Impacts, Responses framework.

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.

2.1.3. 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.

2.1.4. 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.

2.1.5. 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.

2.2. PSR

2.2.1. 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.

2.2.2. 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.

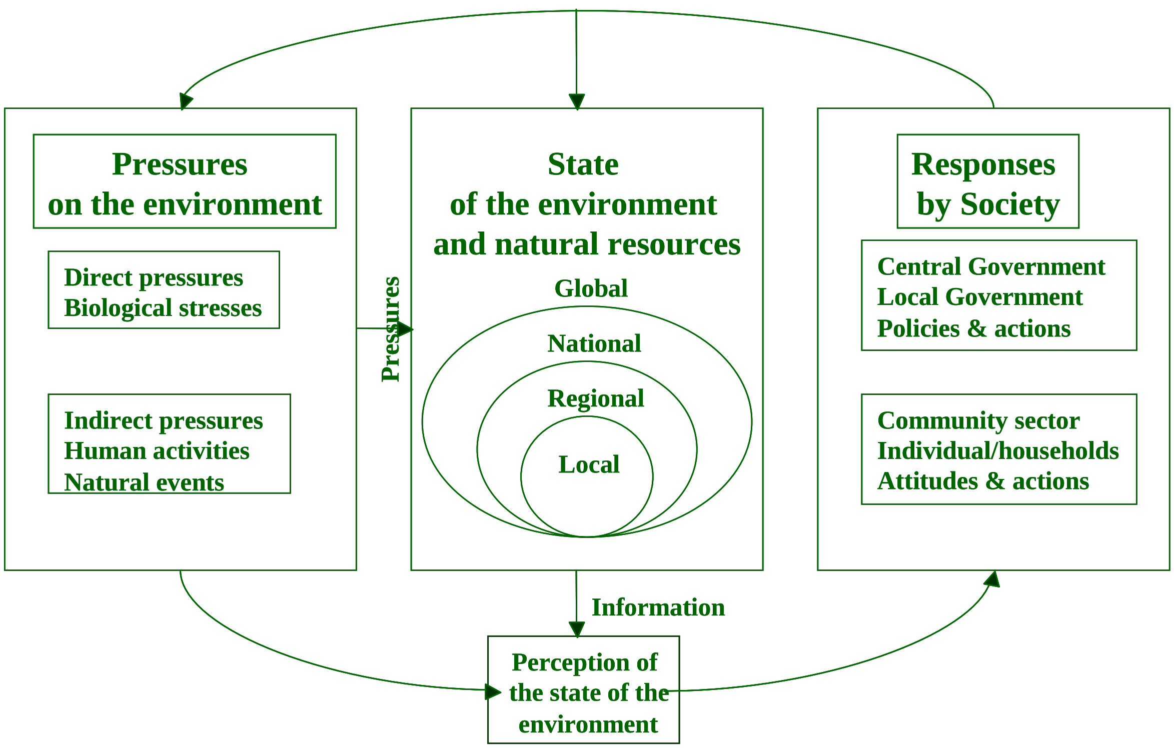

Fig. 2. Pressure-State-Response framework for environmental reporting

2.2.3. 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.

2.2.4. 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.

2.2.5. 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.

2.3. MIPS

2.3.1. 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.

2.3.2. 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).

2.3.3. 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.

2.3.4. 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.

2.3.5. 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.

2.4. STEEPV

2.4.1. 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).

2.4.2. 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.

2.4.3. 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.

2.4.4. 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.

2.4.5. 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.

2.5. ASA

2.5.1. 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.

2.5.2. 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.

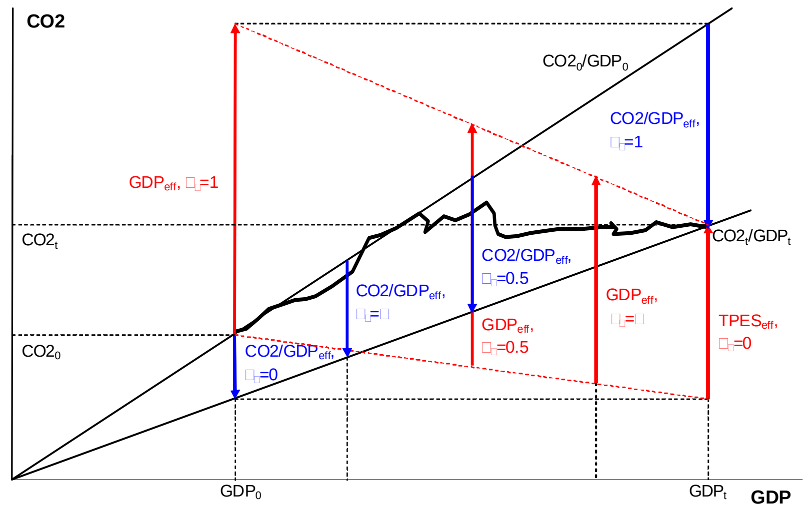

Fig. 3: Decomposition of CO2 change: the effects of CO2/GDP and GDP during a selected time period

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.

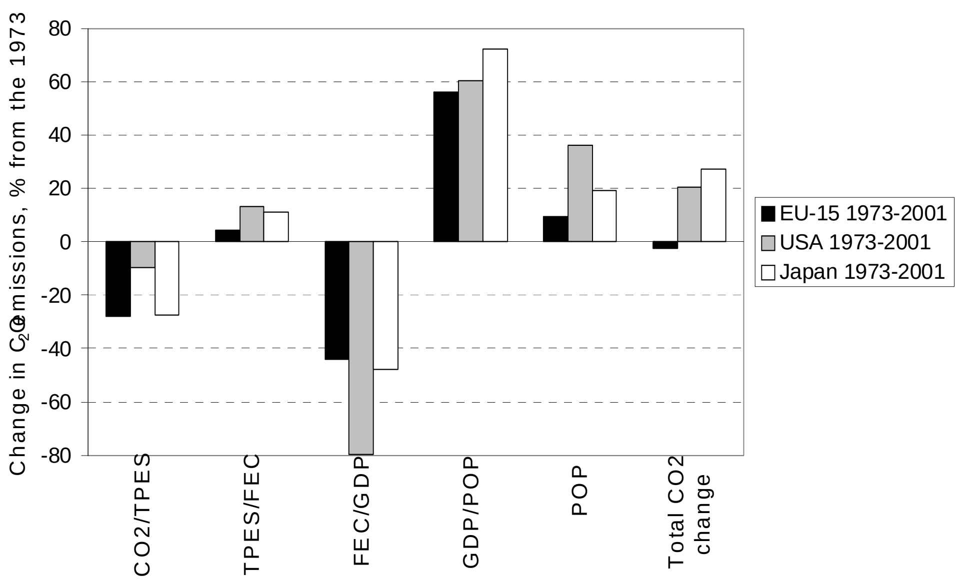

Fig. 4. ASA of the change in CO2 emissions from fuel combustion in the EU-15, in the USA, and in Japan 1973–2001. Data source: International Energy Agency

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.

2.5.3. 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.

2.5.4. 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.

2.5.5. 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.

2.6. MSIASM

2.6.1. 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);

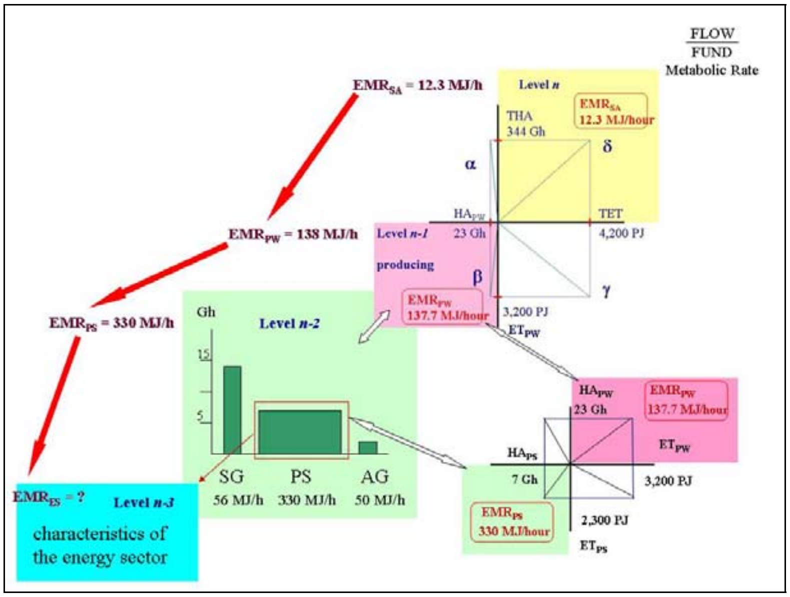

Fig. 5 Relation of congruence over: (i) fund; (ii) flow; (iii) flow/fund; across three contiguous levels [the whole ←→ parts]

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.

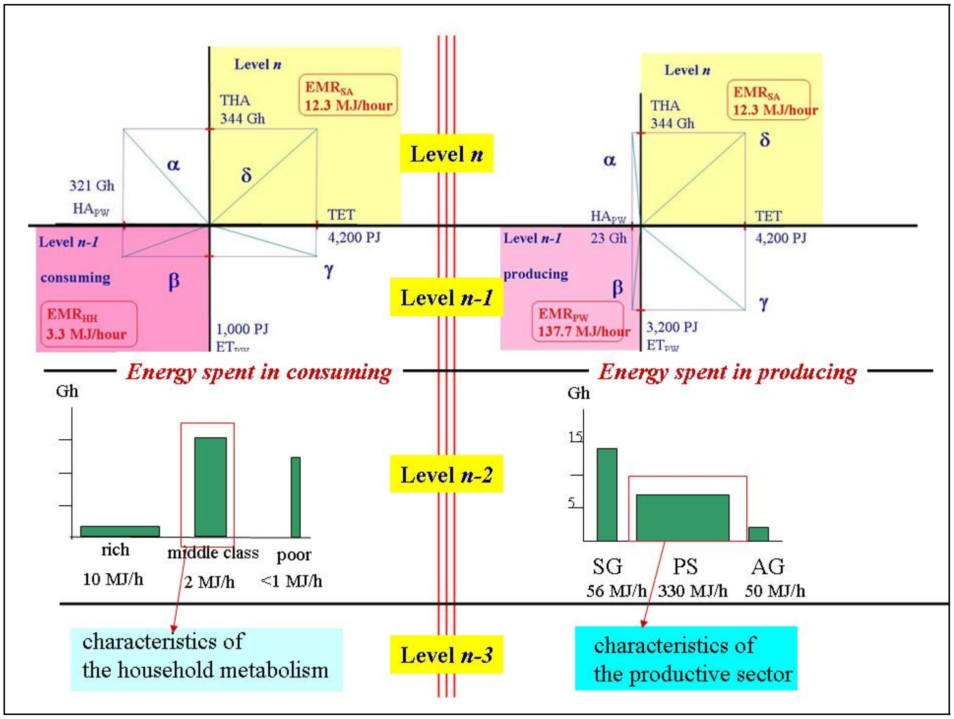

Fig. 6 Parallel analysis of the characteristics of various elements (Fund: HA and Flow: ET) across hierarchical levels

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.

2.6.2. 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).

2.6.3. 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.

2.6.5. 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.

2.7. SUMMA

2.7.1. 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.

2.7.2. 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).

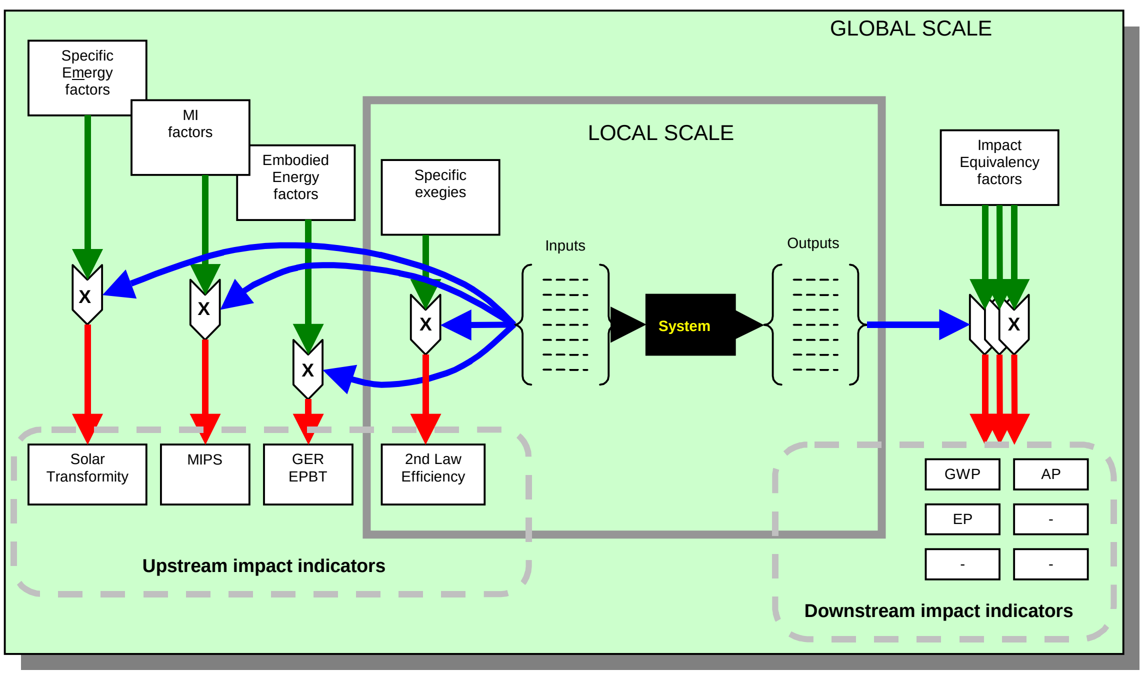

Fig.7. SUMMA- application scheme of the employed environmental impact assessment methods and calculated indicators

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.

2.7.3. 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.

2.7.4. 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.

2.7.5. Easiness to use

SUMMA does not present special difficulties for the analyst. It builds on well known methods and uses them synergically, 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. 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.

Chapter 4 summarizes these findings 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. This will be the task of Work Package 2 between months 13 and 18.

4. 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	☹	=	=	☹

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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 8):

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.

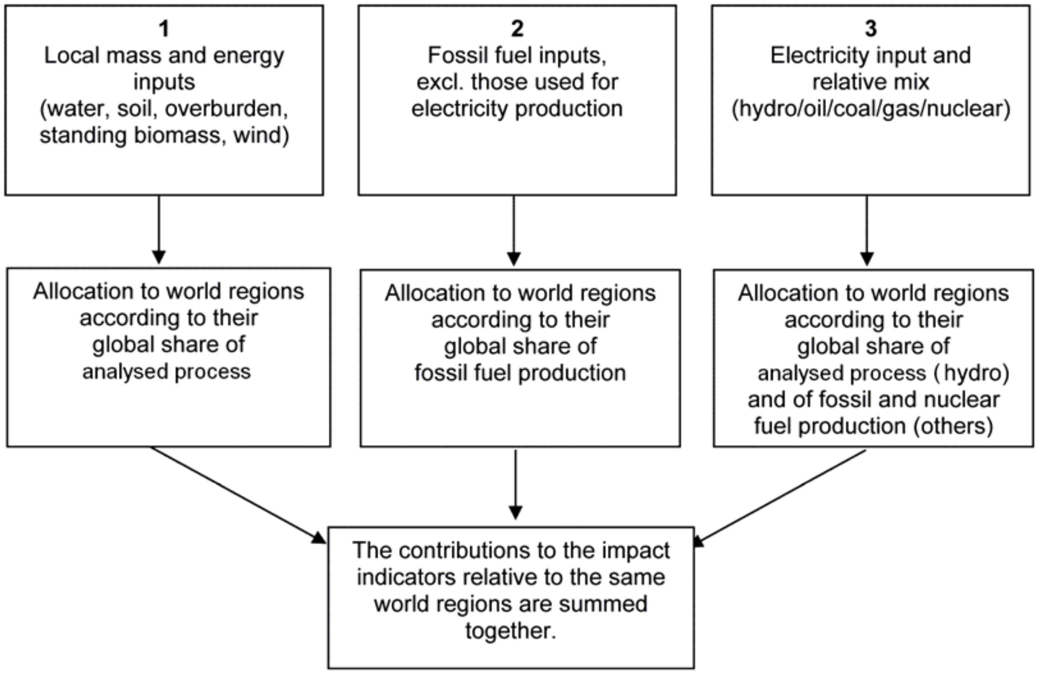

Fig. 8: Flowchart of the proposed allocation procedure.

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:

$$\mathrm{P}_r = \frac{\mathrm{P}_r}{TPES_r} \bullet \frac{TPES_r}{FEC_r} \bullet FEC_r$$

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.