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"Economic-environmental" foresight modeling in support to the integrated management paradigm. A framework based on green accounting[1]

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[1] **Abbreviations' list:**
CBA: cost-benefit analysis
DPSIR: Driving forces, Pressures, State, Impact, Responses
MA: Millennium ecosystem assessment
I-O: Input-Output matrix
BAU: business as usual scenarios
ERI: ecological reference index
ICZM: integrated coastal zone Management

Abstract
Decision making processes are often supported by the aggregation of micro-specific (i.e. non-holistic) decision support tools based on low integration approaches such as conventional cost-benefit analysis. Such tools consider a too restricted number of ecosystem services and underestimate their importance. As a result, they take into account only a small amount of stakeholder antagonistic activities regarding the use of ecosystem services, as well as a narrow range of impacts, spatial components and time scales. This is a major drawback given that any environmental issue stems from antagonistic uses of ecosystem services, either in direct, indirect or induced effects. Hence, conventional cost-benefit analysis may influence decision makers in lowering or postponing environmental targets if it is used at early stages of decision making processes. This is for instance allowed in the European water framework directive when costs exceed benefits.

Contrary to micro-specific approaches, the sustainable strategy of integrated management claims for holistic and multidisciplinary approaches. Such approaches are better adapted to the preliminary identification and selection of environmental measures at early stages of decision-making processes. The aim of this paper consists in showing that a green accounting macroeconomic support tool may fulfil integrated environmental management requirements and enable a wide range of ecosystem services to be taken into account. For this purpose, two options are presented. A first option described in this paper follows all the steps of the DPSIR causality chain. The second option consists in exclusively focusing on the steps related to economy-environment interface flows. It requires stakeholders' social deliberation to set environmental norms and build foresight scenarios. Hence, DPSIR causality chain (Driving forces, Pressures, State, Impact, Responses) can be put aside in order to replace the highly uncertain and non-operational P→S→I conventional links by social deliberation and economic-ecologic indicators. It reduces the following drawbacks of the first option: high degree of uncertainty, non-operational tool, and the subsequent lack of holistic properties.

Keywords: green accounting, input-output matrix, ecosystem service, sustainability, DPSIR, integrated management.

1. Introduction

Tools and methodologies for economic evaluation of environment are helpful for decision makers in preserving or restoring environment quality at least economic cost, as required by some European directives (e.g. guidelines for the implementation of the water framework directive from European Commission, 2003). However, during the last decades, management of environmental issues and conflicting anthropogenic uses have been framed by sector-related policies. As a result, numerous efforts have failed to improve environmental quality, as in European coastal zones for instance. According to the Commission européenne (2001, p. 20), this is because environmental impacts were analyzed separately (i.e. through analytical approaches) whereas a holistic[2] analysis was required (UNESCO, 2001, p. 25).

Indeed, decision-making processes are often supported by decision support tools such as conventional cost-benefit analysis (CBA) that are based on low integration approaches and are too “micro-specific” (i.e. “analytic” as opposed to “holistic”):

i) The latter means that they address a narrow range of compartmented ecosystem service categories, which in turn restricts the number of impacts, territorial components and stakeholder antagonistic activities regarding the use of ecosystem services. This is a major drawback for two reasons. First, because ecosystem services are gaining importance as shown by the rising interest for that concept. Indeed, Fisher et al. (2009, pp. 1-2) show that the mention of the concept of ecosystem services in literature has been rising exponentially since 1998 up to 2008. Second, because any environmental issue stems from antagonistic uses of ecosystem services, either in direct, indirect or induced effects (Billé, 2006; O’Connor, 2000).

ii) In addition, analytical tools such as conventional CBA do not only analyze à reduced number of ecosystem services, they also underestimate the importance of ecosystem services that are taken into consideration.

In conventional CBA, those two shortcomings (i and ii) partly arise from the problem of underlying concepts of monetary values aggregated into one single indicator (Cordier et al., unpublished article). This makes conventional CBA likely to underestimate environmental benefits, which in turn may distort the cost/benefit ratio to the detriment of benefits. Hence, it may influence decision makers in lowering or postponing environmental targets. This is for instance permitted by the European water framework directive when costs exceed benefits (European commission, 2003[3]).

As seen above, the concept of ecosystem service is of primary importance. However, although this concept has been profusely discussed and developed in literature (e.g. Fisher et al., 2008 and 2009; Millennium Ecosystem Assessment (MA), 2005), its application and integration into decision support modelling tools is still in its early days (read among others: Weber, 2009, p. 705 ; Grêt-Regamey and Kytzia, 2007). Fisher et al. (2009, p. 645) give a general definition of ecosystem services: “*ecosystem services are the aspects of ecosystems [i.e. ecosystem structures, organizations, process and functions] utilized (actively or passively) to*

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[2] By holistic, we mean any globalizing approach where various elements, usually isolated, are gathered and coordinated in order to achieve results more effectively. It relates to wholes or complete systems rather than analysis of, treatment of, or dissection into parts (Office québécois de la langue française, accessed in October 2008).

[3] Read the following pages: pp. 8-9, 12, 14-18, 24, 116-117, 123-127, 135, 196-197, 206, 208, 215-217.

produce human well-being", either directly or indirectly. This is in line with the even more general definition from the MA (2005, p. V): *"Ecosystem services are the benefits people obtain from ecosystems"* and can be classified into six categories: provisioning, sink, supporting, regulating, cultural, site (based on O'Connor, 2008 ; MA, 2005). However, Fisher et al. (2008, p. 2051 and 2009, p. 644) assert that general definitions are not operational and need to be adapted to the decision-making context. In addition, we would add that it is also needed to adapt ecosystem service definition to the modelling tools used in support to decision making. As a result, for the purpose of our green accounting approaches developed in section 3, we define ecosystem services as any exchange of material or energy inside a process occurring from the environment to the environment, the environment to the economy or the economy to the environment. Such exchanges can also be named "ecologic commodity" and "economic commodity" as in Victor (1972). Jointly, processes are defined as any causality chain and mechanism which, by using material or energy, leads to an identified end or product. This end or product can be positive, neutral or harmful and can be achieved with consciousness or without.

For a better consideration of ecosystem services and subsequently sustainability, Cordier et al. (unpublished article) argue that conventional CBA should be applied only to later stages of decision-making processes with the aim to give a specific focus on a set of measures already selected. Profuse literature do exists on difficulties of conventional CBA, and more broadly environmental economics, to take into account sustainability, strong sustainability as well as physical limit to growth[4]. For a detailed discussion, read among others Ashford (1981), Kelman (1981), van den Bergh (2000), O'Neill and Spash (2000), O'Connor (2000), European commission (2003, p. 124-125), Pearce et al. (2006, p. 25), Ackerman et al. (2007 In: Erickson and Gowdy, 2007, pp. 7-35).

Contrary to micro-specific approaches, the new paradigm of integrated management claims for holistic and multidisciplinary approaches that are better adapted to the identification and selection of environmental measures at early stages of decision processes. Developing decision support tools that fulfil integrated management precepts may be interesting since it is considered as a possible strategy to set society on a sustainable path that respects physical limits to growth imposed by the environment and social criteria. Integrated management consists in a sustainable strategy for an integrated approach to planning and managing anthropogenic activities. It encompasses the whole process of data collection, planning, decision making, implementation, management and follow-up. Its global objective aims at conciliating environmental quality with social and economic targets (i.e. sustainability). In Integrated environmental management, the term "integrated" means connecting separate components[5] together inside a single strategy. Moreover, proper consideration is given to the full range of temporal and spatial scales. Such a strategy must involve all stakeholders in a participative way (Rupprecht Consult – Forschung & Beratung GmbH and International Ocean Institute, 2006). Attention is also given to the numerous tools required to achieve sustainability. They must all be integrated to the strategy (Commission européenne, 2000; Parlement européen et Conseil, 2002). More detailed definitions of integrated management are avalable in UNESCO (2001), Commission européenne (2001), Billé (2006), Rupprecht Consult – Forschung & Beratung GmbH and International Ocean Institute (2006),

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[4] Developments on the strong sustainability principle can be found in Pearce et al. (2006), and on physical limit to growth in Georgescu-Roegen (1979, pp.14 and 17), Latouche (2003), Costanza (2000), Costanza et al. (2006).

[5] Policies, economic sectors, administrative decision levels, territorial physical components and, to the highest possible extent, individual interests.

Commission européenne (2000), Parlement européen et Conseil (2002), Commission européenne (2007).

The aim of this paper consists in showing that holistic-based approaches supported by a green accounting macroeconomic support tools (green Input-output analysis) may fulfil five integrated environmental management requirements including the integration of ecosystem services: i.e. i) coordination, ii) uncertainty management, iii) holistic analysis, iv) stakeholders' participation, and v) consideration for reciprocal influences between environmental, economic and social conditions. For this purpose, two methodological approaches are suggested in section 3.

Second section presents a general background on green accounting decision support tools. In third section, two green accounting approaches are presented allowing for ecosystem services to be integrated into economic analysis of the environment. In fourth section the five specific objectives of integrated management to be fulfilled are analyzed in relationship with the two green accounting options. It also distinguishes advantages and disadvantaged of each of these green accounting approaches. Fifth section gives a discussion on green accounting limitations and opportunities.

2. General background on green accounting decision support tool

Our green accounting approach is based on an integrated tool based on an industry-by-commodity Input-Output matrix (I-O). The environmental components, which provide ecosystem services, are integrated to I-O matrices after greening operations. Environmental components enter in the matrix as an additional sector that produces ecological outputs used as inputs by other sectors (e.g. water is made available by rivers for industrial purpose). In parallel, they receive inputs from other sectors (e.g. rivers receive micro-pollutants from urban and industrial waste waters). The difficulties of monetary valuations are minimized by using the concept of monetization frontier[6]. According to this concept, ecosystem services are split into two groups: those that can be valued through monetization and those that cannot. In that framework, monetary units are only attributed to ecosystem services that can be valued in terms of their direct potential conversion into marketed goods & services. This is the case of some *provisioning services* such as exploitable natural resources (e.g. energy stored in natural gas, food from hunted games). This is also the case of some *cultural services* (e.g. recreational activities in natural areas with entrance fees) as well as *site services* (e.g. land used for waste disposal or buildings).

Physical units are used for ecosystem services without any direct potential conversion into commercial goods & services. This is the case of ecosystem services such as regulating services (e.g. flood control, illnesses regulation), supporting services (e.g. soil formation as a support for food and textile productions), some cultural services (e.g. educational activities through nature observation) and most sink services (e.g. river self-detoxification capacity). All these services do not have any direct market value but are nevertheless of first importance for economic activities and human life to be maintained on the mid- and long term.

[6] The concept of monetization frontier was defined by O'Connor and Steurer (2006) and O'Connor (2000). It allows the monetary valuation drawback to be solved. Such concept is not only theoretical. It can be made operational as shown in the green accounting approaches suggested for instance in SEEA 2003 (UN et al., 2003) and Victor (1972).

3. Two greening approaches for the integration of ecosystem services into green accounting

Two greening approaches are possible for ecosystem services considerations. They can either be carried out both together or only one of them can be selected according to data availability, uncertainties caused by system complexity, as well as financial and time resources allocated to the analysis. Practically, they are built by mixing the models suggested by Isard (1969, In: Victor, 1972, pp. 41-47) and Leontief (1974, pp. 133-157 and 193-216).

3.1 The "full DPSIR green accounting approach"

The first approach enabling ecosystem services to be integrated to the I-O matrix can be called *"full DPSIR green accounting approach"*. This DPSIR[7] based approach allows for an assessment of the impact of a change in ecosystem services on the economy (the change being caused by a policy or any kind of project). In addition to D→P and I→R conventional quantification, the *"full DPSIR green accounting approach"* requires interrelations between all the five steps of the DPSIR causality chain to be quantified. This is in line with the recommendations from Weber (2007, pp. 701, 706), who advises to quantify processes occurring inside the environment (P→S→I steps). This approach affects the kind of greening operations carried out on conventional I-O matrices. For instance, the number of fishes killed or made inedible (Impact) due to metal pollution (Pressure) may be entered in the I-O matrix. This is not allowed in the second approach presented below, because Weber recommendations for P→S→I quantifications are not always possible due to highly complex, indirect and unknown ecosystem services. Figure 1 shows the location of green accounting matrix inside the DPSIR causality chain. It follows the following steps:

- **Driving forces:** I-O matrix gives the production and consumption data, either actual or future in case of scenario simulation. It allows us to identify sources of pollutant emissions and other environmental degradations. Greening operations enable ecosystem services to be integrated to the matrix.

- **Pressures:** environmental technical coefficients allow total pollutant emissions to be calculated according to various scenario of economic production. This allows environmental technical coefficients to be calculated by dividing, for instance, the pollutants emitted by sector of activity per total output (i.e. per total goods & services production).

- **State:** if modelling may help to convert pressure data into state data, then sustainability of the scenario tested can be verified by comparing simulated pollutant concentrations to norms such as those fixed in the water framework directive. In case of high uncertainty on DPSIR causality links due to natural ecosystem complexity and lack of available scientific knowledge, state cannot really be quantified. However sustainability verification is

[7] The DPSIR approach is a descriptive causality chain that can be used as a systemic conceptual model describing the interactions between non-human environmental systems and "anthropo-systems". D as driving forces (basic sectorial trends), P as pressures (human activities directly affecting the environment), S as state (observable changes of the environment), I as impacts (effects of a changed environment), and R as responses (response of society to solve the problem).

possible based on Pressures data, via “economic-ecologic” indicators (e.g. distance to target, eco-factors, ecological footprint, Ecological Reference Index per unit of GDP, etc.).

- **Response:** responses scenarios of policy measures can be simulated. In case the tested scenario is not sustainable, new environmental measures can be proposed by stakeholders through deliberation and enter inside green accounting matrix in the form of new budget allocated to such measures, taxes, etc. This requires technical coefficients to be modified. This allows changes in production patterns to be taken into account. Simultaneously, data on pollutant emissions adapted to the scenarios are entered into the matrix. This allows economic production to be linked to environmental degradation.

- **Impact:** economic and environmental impact are combined and assessed by comparing macroeconomic aggregates and economic-ecologic indicators of business as usual (BAU) scenario to green scenarios (O’Connor and Steurer, 2006). In case of good and accurate scientific data, direct quantification can be done between “state” and “impact” (dashed arrows in figure 1). Otherwise, in case of high complexity causing excessive uncertainty, indirect path is required: “state”→“sustainability verification” → “response” → “impact”. Note that such uncertainty as well as other technical modelling problems are responsible for I to come before R in figure 1 when following numbers from 1 to 11 on bold arrows.

For instance, in the case of a change in the use of sink services provided by rivers, the *“full DPSIR green accounting approach”* would imply firstly to convert each unit of economic production (Driving forces) into the amount of pollutants discharged into rivers (Pressures). Secondly, this amount of pollutant discharge would have to be converted into concentration values in the surface water (State). Third, based on concentration values, we should be able to quantify, for example, the impact on the quality of goods produced by companies that are used to pump water in rivers for their industrial process (Impact). And finally, we should be able to quantify the effect of a measure (Response) on Pressures, State, Impact and Driving forces (example of measure: investing in new specific water treatment technologies).

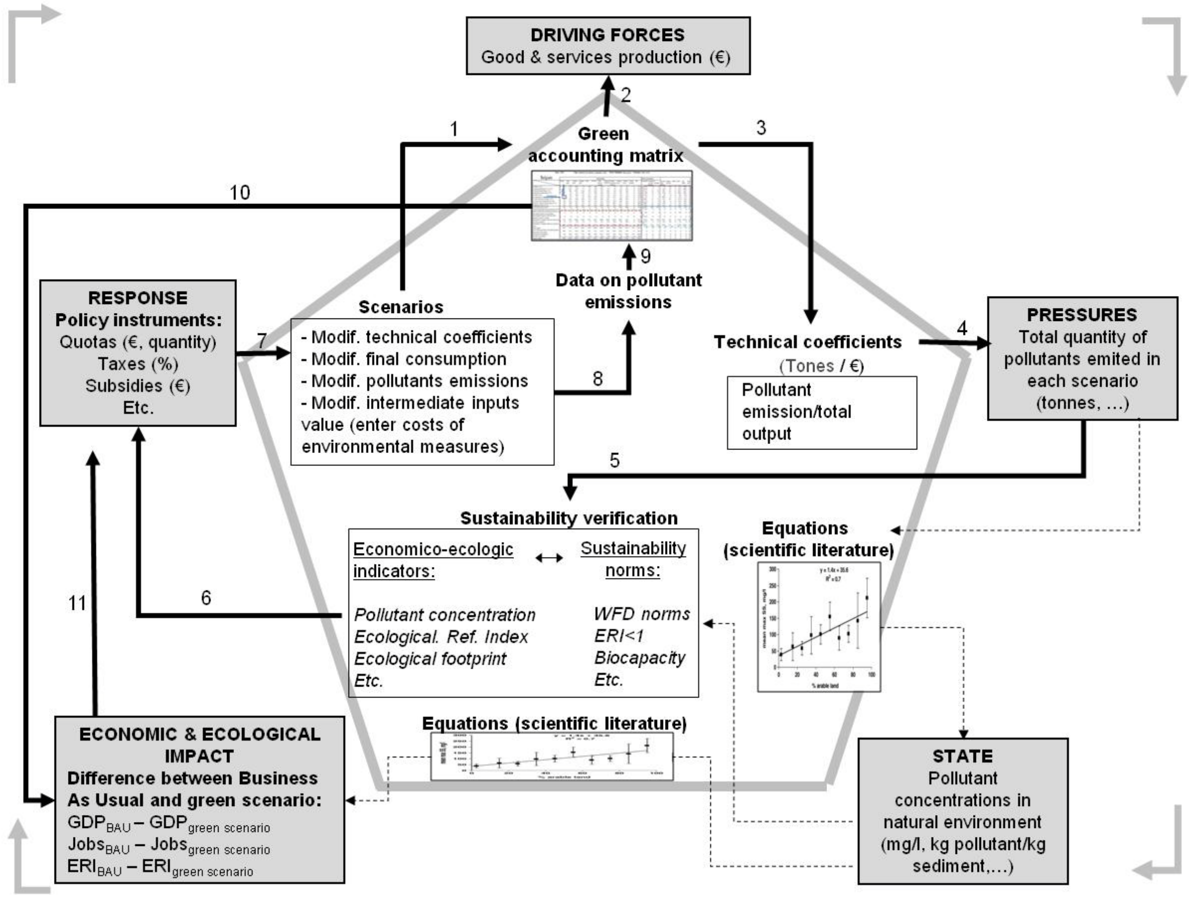

Figure 1. Methodological conceptual scheme showing the integration of green accounting matrix inside the DPSIR causality chain. The integrative and holistic properties of green accounting matrix enable interrelations between environment and economy to be identified and described (and sometimes quantified) inside the DPSIR relationships. Dashed arrows show DPSIR causality links that are uneasy and often impossible to quantify. Numbers from 1 to 11 and bold arrows show the path to follow for building the model when the lack of scientific data and the complexity of natural systems do not enable P→S→I links to be quantified (section 4.2). ERI = Ecological Reference Index = [pollutant emissions in tones per year] / [acceptable levels of pollutant emissions in tones per year (based on toxicological or ecological reference)]

3.2 The "interface flows deliberative green accounting approach"

This second greening approach offers a second way of ecosystem services integration into holistic economic analysis. It focuses only on services exchanges at the economy-environment interfaces, in both directions. The use of our definition (read introduction) of ecosystem services to a real case study implies an analysis through the frame shown in figure 2. This frame is fairly similar to the suggestion from Fisher et al. (2009, pp. 646, 648, 649), except that they named "final services", "intermediate services" and "benefits" what we respectively called "process", "Environmental resource", and "End or product". However, our definition differs from the one from Fisher et al. (2009, p. 645) in that we allow for negative "end or product" resulting from the process. This enables disamenities to be easier entered into green accounting modelling. Our definition also allows for non-human beneficiaries (and non-human damaged), which is not explicitly accepted in the definition from MA, (2005) and Fisher et al. This offers the advantage to keep open the possibility to model processes occurring inside the environment although this is hardly possible at the moment due to high uncertainty caused by high complexity of natural systems (read below). In addition, this implies that ecosystem services do not need human beneficiaries to be defined as a service. This allows for the precautionary principle to be fully applied in modelling for decision making. This principle states that some ecosystem services are useful to human life and activities although they are currently ignored or underestimated (more development in Cordier et al., unpublished article).

Ecosystem services segmentation	**1. Process**		**2. Environmental resource used in the process (material or energy)**		**3. End or product (resulting from the process)**		**4. Ecosystem service categories***
Example 1	Building construction	→	Extraction of alluvial aggregates on which natural wetlands habitats grow for construction purposes	→	Cement production, embankment, buildings	→	Provisioning and site services
Example 2	Habitat destruction	→	Extraction of alluvial aggregates on which natural wetlands habitats grow for construction purposes	→	Reduction in natural wetlands surface and biodiversity	→	Support, regulating, provisioning and sink services

Figure 2. Segmentation of ecosystem services into four components based on our definition for green accounting modelling purpose (read our definition in introduction).
* Ecosystem services categories: provisioning, sink, supporting, regulating, cultural, site (based on O'Connor, 2008 and MA, 2005).

The *"interface flows deliberative green accounting approach"* includes exchanges of material and energy in both directions: from economy to environment (e.g. pollutant emissions by industry and households into waters) and the opposite, i.e. from environment to economy (e.g. supply of clean water by rivers and aquifers to industrial process). This is respectively represented by cell n°2 and n°4 in figure 3. It allows economy-environment reciprocal interrelations to be identified, described and quantified. Exchanges of services inside natural systems between various environmental compartments are not assessed (i.e. P→S→I steps) to avoid the uncertainty problem mentioned below in section 4.2. This includes for instance the quantification of heavy metal bioaccumulated inside aquatic organisms according to the metallic concentration in urban waste water discharge. This is represented in figure 3 by cell n°3. Cell n°1 covers all economy-economy exchanges as represented in conventional I-O matrices (e.g. exchange of natural fibres produced by agriculture and provided to textile industry as intermediate input). Responses are represented by the surrounding ellipse. They can be implemented at all levels of economic and ecosystem services exchanges. Appendix A offers a more complete description of the model described in figure 3.

The gap generated by the eviction of environment-environment exchanges (P→S→I steps) is compensated because levels of suitable ecosystem services preservation (i.e. State and Impact quality) are determined thanks to social deliberation. It can take for instance the form of democratic representatives' assembly for drawing up law and regulations (e.g. norms fixed in European directives). Social deliberation can also occur in the form of stakeholders meeting gathered for arbitration, consensual or non-consensual dialogue, negotiation, etc. (read section 4.2 and 4.4). In both cases, it should be carried out in the light of scientific knowledge and economic-ecologic indicators produced by green accounting as well as other tools in the framework of a multi-criteria analysis. For that purpose, green accounting modelling is used to assess the impact of sustainable/precautionary levels on the environment and economy. Various possibilities of environmental measure implementation can be simulated inside a green scenario. Thereby, the *"interface flows deliberative green accounting approach"* aims at identifying environmental assets and economic sectors to be targeted by environmental measures at least socioeconomic cost and adverse impact. This approach is completed by a sensitivity analysis of the reaction of the economy to various levels of environmental standards. In other words, the tool enables a development path toward sustainability to be drawn up by decision makers.

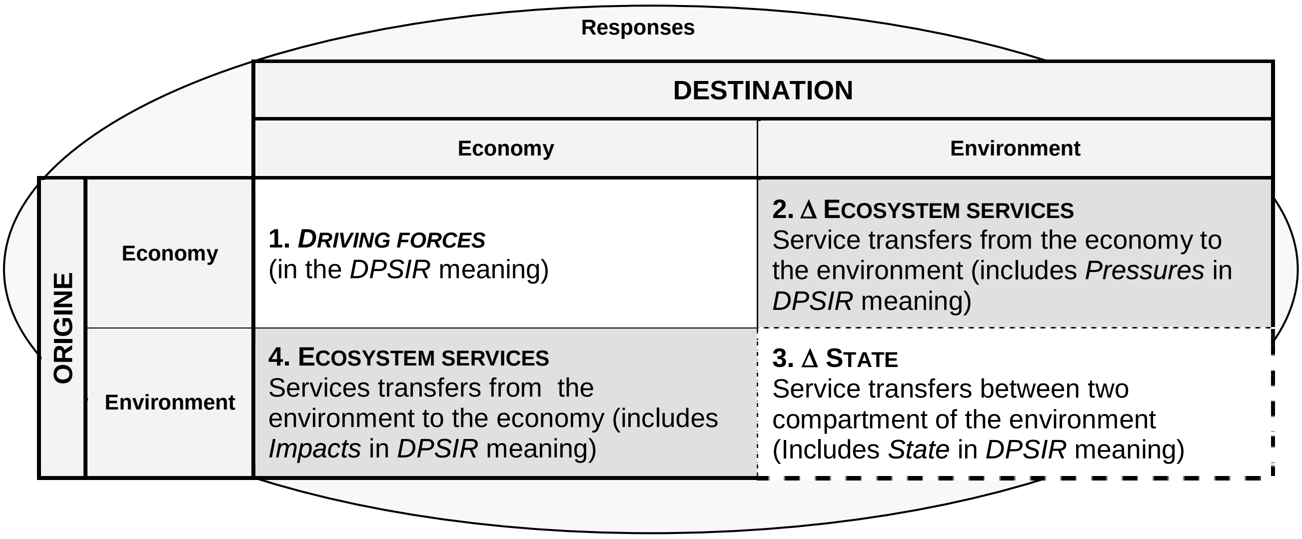

Figure 3. Methodological operational scheme for the quantification of economy-environment interrelations. Shaded cells n° 2 and 4 are economy-environment interfaces targeted by the "interface flows deliberative green accounting approach". Cell n°3 is dashed because of the complexity to quantify flows crossing environment-environment interfaces. Source: adapted from 0'Connor (2008).

4. The integrated management paradigm and compliance of green accounting approaches

Integrated management consists in the coordination of anthropogenic activities into a sustainability trend. The practice of integrated management extends back at least to 1965 with the first integrated coastal management program by the San Francisco Bay Conservation and Development Commission. But it progressively spread all over the world and at the beginning of 2002, 145 countries and semi-sovereign states had initiated 622 integrated coastal zone management (ICZM) efforts at national and sub-national scales. *"Now ICZM is practiced all over the globe and is part of the rhetoric for sustainable development"* (Sorensen, 2002, pp. 1-3, 3-1). Despite the paradigm of integrated management has been profusely developed for coastal zones and water quality issues, its main precepts remain valid for any other kind of areas and environmental issues.

For sustainability to be achieved, integrated management targets five specific objectives (Commission européenne, 2001): i) coordination, ii) uncertainty management, iii) holistic analysis, iv) stakeholders' participation, and v) consideration for reciprocal influences between environmental, economic and social conditions. In Cordier et al. (unpublished article), it is explained how conventional CBA, and more broadly environmental economics, reveal unable to fulfil these fives requirements. This is because it focuses on setting a monetary value on environmental assets, which is based on the aggregation of individuals' preferences (meant to reflect the common good for the whole society). This leads to strongly reduce the number of ecosystem services taken into consideration as well as underestimating their importance. Conversely, ecological economics and some green accounting approach focus rather on identification, process description, quantification and modelling of interrelations between anthropogenic activities and the environment (van den Bergh, 2000). This enables the 5 integrated management requirements to be fulfilled. They will be individually analyzed in this section together with the main advantages of green accounting.

4.1 Coordination between antagonistic activities

Any current sustainable issue consists in antagonistic relationships between stakeholders at different spatial and temporal scales for the use of ecosystem services (Billé, 2006; O'Connor, 2000). There are three categories of stakeholders' antagonistic interrelations regarding environmental assets:

i) direct antagonism between stakeholders for the use of a same ecosystem service,
ii) indirect antagonism between stakeholders through the alteration of a same environmental asset (but using two different ecosystem services provided by this asset),
iii) induced antagonism: the second-order impact of a change in one sector on another economically related sector caused by an environmental measure or an economic activity.

Analyzing stakeholders' interrelations processes is important in order to understand antagonistic activities and allow them to be further managed, i.e. promote coordination between stakeholders into a logical plan that enable sustainability to happen. Thereby, it is important to develop tools that allow for description of the process of favouring some and disadvantaging other stakeholders for environmental objective to be reached. As a result, economic approaches used at first decisional stages of decision making processes, should consider a wide range of stakeholder categories in order to show trade-offs between stakeholders antagonistic activities. It should also use several indicators to measure these antagonisms and weight up the impact of favouring one stakeholder group on others. It would enable qualitative and quantitative description of interrelations processes. This is essential to the identification, understanding, managing and resolution of ecological and economic conflicts, which are the keys to sustainability achievement.

Three reasons can be argued in favour of green accounting approaches for the description and quantification of stakeholders' antagonistic interrelations. First, I-O matrices are inherently multi-sector related and interrelations between all economic sectors can be quantified through economic and ecologic commodities exchanges. Beside economic sectors antagonisms, individuals' antagonisms can also be taken into account at the social deliberation steps, for instance by uncovering hidden individual interests (read section 4.4 below on stakeholders' participation). Second, the use of multiple "economic-ecologic" indicators avoids conventional CBA drawbacks mentioned above relating to single monetary value indicator. Indeed, results of green accounting modelling are expressed either in detailed economic and environmental data or in a set of various aggregated indicators (purely economic, ecologic as well as economic-ecologic indicators). It allows process description of interrelations and enables trade-offs to be understood. Third, green I-O analysis (and more specifically the "*interface flows deliberative green accounting approach"*) enables a wide range of ecosystem services to be taken into account (read below). As a consequence, numerous stakeholder antagonistic interrelations can be considered since ecosystem services are the object of such antagonisms (read section 4.3).

4.2 Uncertainty management

Integrated management recognizes explicitly the inherent uncertainty related to the environment and its future which explains the precautionary principle (Commission européenne, 2001). Indeed, the environment is complex and varies in space and time. A complete understanding of natural systems is not realistically possible to achieve. Consequently, there is no complete scientific methodology enabling a full quantification of the role and importance of environmental assets for living being and human activities. Thereby, any scientific approach of environment has to deal with and manage high uncertainty degree.

For quantitative modelling purpose, figure 1 and the *"full DPSIR green accounting approach"* are mostly non-operational. For the needs of quantification of economy-environment interrelations, it is rather operational to identify at which process an environmental asset participates than its location in DPSIR steps. More specifically, the quantification of interrelations requires knowing the services provided by the environment to the economy and vice versa (read introduction for our definition of "ecosystem service" and "process" built for the purpose of green accounting). If at the operational step of modelling, the focus was kept on DPSIR approach, quantification of interrelations would be impossible. One of the main reasons explaining that assertion is the uncertainty caused by the complexity inherent to pressures-state and state-impacts causalities. In the first approach, the two first steps of interface quantification (Driving forces → Pressure) are not trivial but remain possible. However, the quantification of Pressure → State relationships causes difficulties when carried out for long periods (several months or years) and at larger scales than a field or a river section (even small watersheds of 10 000 km^2 are too large). Actually, although it is under debate since 40 years with the attempt of Isard (1969, *In:* Victor, 1972, p. 47), it remains impossible even with the most recent progress in scientific knowledge and existing physico-biological models (this is shown by dashed arrows in figure 1). Indeed, no statistical correlation can be found at the moment between observed pollutant emissions (Pressure) into rivers of a watershed and observed concentration (State) in those same rivers. As asserted by Fisher et al. (2009, p. 648), *"our knowledge of the ecological dynamics responsible for ecosystem services […] is still in early days"*. This is true even for very well known pollutants such as nitrate and phosphates in watersheds profusely studied since more than 20 years such as the Seine-Normandie watershed in France – Personal comment from Billen (2008). This is due first to the profuse amount of variables (chemical, physical and biological characteristics of natural environment) changing through time and space, as well as the complex, and unpredictable character of natural ecosystems. In other words, the effect of background noise on pollutant concentration variability is mostly higher than the signal (anthropogenic pollutant emissions-caused concentration factor). Second, it can be due to the lack of reliability of concentration measurements. All this explains that the causality link between ecosystem services changes and economic activities are uneasy to demonstrate and quantify.

The same problem can be mentioned in the case of the link between state and impacts. It is not easy to quantify as shown by the indirect bold arrows that connect State to Impact box in figure 1.

The second green accounting approach, the *"interface flows deliberative green accounting approach"* (section 3.2), is an endeavour to reduce the uncertainty shortcoming by by-passing the P→S→I steps, i.e. exchanges of ecosystem services occurring inside the environment (cell n°3 in figure 3). By this way, the number of ecosystem services categories is not limited contrary to indirect and uncertain services in the first green accounting approach described above. The by-pass of P→S→I steps through the setting of Responses (i.e. environmental norms) on Driving forces and Pressure leads to changes in the question asked by the method and to the introduction of the precautionary principle. Indeed, in the "full DPSIR green accounting approach", the main question was basically about "what is the impact of economic activities on environmental quality". In the *"interface flows deliberative green accounting approach"*, the question is instead "what would be the impact on anthropogenic activities if a precautionary minimum level of environmental quality was achieved"? Although an accurate precautionary level is difficult to set – i.e. the exact effect of economic activities on environmental state and impact are not fully known inside the DPSIR causality chain – it can however be approximated through "economic-ecologic" indicators. Such indicators enable us to determine if the society follows or not a sustainable path.

4.3 Holistic analysis

Environmental issues need holistic studies with wide scales of analysis. For instance coastal tourism cannot be effectively addressed if no consideration is given to water resources, land use, employment conditions, impact of tourism on natural habitats, competition between tourism activities and other commercial activities. Such analysis must include a vast range of i) impacts occurring in a same environmental issue (e.g. impacts on basic needs, economic and recreational activities), ii) different stakeholders categories, iii) different time scales and various territorial components at which impacts do occur (e.g. soils, surface and underground waters at 20, 50 and 100 years time horizon). Integrated management will inherently cover these three elements by carrying out holistic analysis that focuses on a wide range of ecosystem services. Consequently, a holistic frame contributes to avoid a pitfall commonly committed in analytical approaches such as conventional CBA. Indeed, it enables macro-scale considerations and various territorial compartments to be taken into account (more development in Cordier et al., unpublished article).

Holistic properties of green accounting are partly ensured by the use of multi-unit and multi-dimensional indicators. They enable to deal with ecosystem services. However, between the two approaches presented in section 3, the *"full DPSIR green accounting approach"* does not fulfil holistic requirements of integrated management. Uncertainty strongly limits the holistic properties of the "full DPSIR green accounting approach". Indeed, the inherent uncertainty on supporting and regulating services, as well as most sink and some cultural services (MA, 2005, pp. 40, 101) makes them uneasy to be taken into account by the first approach. It stems from their complex and indirect relationship with people. For instance, supporting services affect humans only because they are necessary to the functioning of all other ecosystem services, which are themselves directly useful to anthropogenic activities. As a consequence, causality links between supporting services and economic impacts are highly indirect, complex and chaotic and the quantification of their DPSIR causality links is probably impossible. This is a major drawback, which turns this approach into a kind of "*weak sustainability approach"*. Consequently, this approach can only take into account provisioning, site, some cultural and only few sink services. As shown in Cordier et al. (unpublished article), on a list of 29 ecosystem services sub-categories, only 13 are directly affecting people and can therefore be analyzed through the *"full DPSIR green accounting approach"*. However, this assertion is not true if the monetization frontier is "crossed". In Grêt-Regamey and Kytzia, (2007, p. 788), assessments are built for sink services of carbon sequestration through CO_2 market prices, provisioning services of biomass production through production costs in agriculture and forestry, and regulating services of avalanches natural protection through damages caused to buildings, vehicles and facilities. Such market price approaches face many inconsistencies with the concept of ecosystem services, sustainability and the paradigm of integrated management (read more development in Cordier et al., unpublished article).

Beside the problem of uncertainty, the restricted amount of ecosystem services that can technically be considered by the "full DPSIR green accounting approach" limits as well its holistic properties. It relates to the problem that a same environmental asset simultaneously participates to various processes. Indeed, according to the process considered, a change in wetlands area for instance, can be categorized as an impact, a response or a state in the DPSIR causality chain. This would result in a technical problem in the quantification of economy-environment interrelations. Some processes would require to be neglected for the model to be operational, work properly and the amount of data to be possible to collect in reasonable time and financial constraints. Therefore, it would lead to even greater reduction in the number of ecosystem services that can be analyzed.

To sum up, the *"full DPSIR green accounting approach"* is non-operational because of i) technical problems due to the simultaneous participation of environmental assets to various processes (section 4.3), ii) high uncertainty related to the complex and indirect effect of many ecosystem services on people (section 4.2 and 4.3).

This lack of holistic properties of the "full DPSIR green accounting approach" can be improved by using the *"interface flows deliberative green accounting approach"*. Indeed, the uncertainty shortcoming is reduced by the focus on economy-environment flows of ecosystem services. This also allows us to discard DPSIR steps. The gap between P→S→I steps is replaced by social deliberation (read below section 4.4). As a result the second green accounting approach enables all kind of economy↔ environment functional relationships to be identified. This is a necessary prerequisite to the identification of anthropogenic activities for which measures are required in order to reach an effective result on environmental quality improvement. It also allows for the identification of stakeholder categories to be targeted for environmental objectives to be achieved at least socioeconomic cost. Thereby, it brings a support to inconveniences distribution, one of the key actions of integrated management.

4.4 Stakeholder participation

Integrated management cannot be effective if stakeholders are not regularly included in a participative way (Commission européenne, 2001; UNESCO, 2001, p. 12). Promoting stakeholders' participation seeks three goals regarding integrated management accomplishment:

i) First, build rules together whose legitimacy can be less contested. Numerous examples in all European Union show that if stakeholders are not involved in decision making, they are likely to reject environmental planning, norms or any other inconvenience distribution drawn up by decision makers (Commission européenne, 2001). As a result, environmental laws and regulations are likely to lack of enforcement.

ii) Second, avoid environmental measures ineffectiveness caused by unknown or misunderstood antagonistic activities. This requires stakeholders' participation to a process of common understanding of antagonistic activities regarding environmental targets.

iii) Third, as already explained above in section 3.2 and 4.2, stakeholders' participation to social deliberation (as defined in section 3.2) is essential for diminishing the inherent drawback of natural systems: its uncertainty caused by its complexity and the subsequent difficulty to set precautionary minimum levels. It can take the form of stakeholders' meetings or drawing up of environmental laws. Indeed, precautionary levels are sometimes already set in laws, which are a form of social deliberation occurring between democratic representatives. Hence, social deliberation is an attempt to solve the difficulty highlighted by Fisher et al. (2008, p. 2055) to set precautionary levels under continuing uncertainty. It is also an attempt to solve the difficulty to quantify through green accounting, regulating and some cultural services (as highlighted by Weber, 2009, p. 705) as well as supporting services and most sink services. Economic-environmental indicators contribute to inform stakeholders on the sustainable nature of various options for precautionary level to be set.

Stakeholders' participation can take the form of various processes such as arbitration against some logics in favour of others, negotiation, consensual or non-consensual dialogue, communication, awareness rising, unilateral decision taken by one decision maker, etc. Those processes end up at the creation of instruments enabling human activities to be regulated or "coordinated": taxes, laws and rules, agreements, norms, etc. (Billé, 2006). Such process of multi-stakeholders deliberation must be enlightened by available scientific knowledge to ensure that the final decision has been well informed. This will contribute to ensure the sustainability of stakeholders' final decision. Nonetheless, it could happen that stakeholders end up with a non-sustainable final decision or even a non-sustainable precautionary level. In that case, the role of green accounting indicators would consist in ensuring that stakeholders are fully aware of that. Thereby, this would allow green accounting to contribute to the need identified by Beuret and Pennanguer (2002) for clarifications in governance and decision making processes. Indeed, green accounting could allow particular interests hidden behind common societal interests to be uncovered, and disadvantaged or favoured stakeholders categories to be identified. This offers a better understanding of arbitration justification and creates conditions of more equity to happen. Subsequently, spreading such information would make possible social control to take place through counter-powers (e.g. legal actions, social movements such as strikes and petitions, media) to force powerful stakeholders (politics, industrial lobbies, neighbourhood committees, etc.) to fulfil sustainability requirements.

The "*interface flows deliberative green accounting approach*" lends easily itself to stakeholders' participation. It even relies on it for reliable figures to be produced. Social deliberation may be used to feed the building of decision support tools such as green accounting. Indeed, first, stakeholders' participation is essential at the step of scenario building if they are to properly reflect needs, projects and reality. Such scenario simulation is conducted in green accounting foresight in order to enlighten decision makers and other stakeholders on impacts of environmental policy options. Second, participation may also be useful for data collection, correction of data collected in literature and national or regional statistics or verification of data modifications (read survey and non-survey I-O methods in Miller and Blair, 1985; Round, 1983). Third, green accounting actively contributes to social deliberation by providing a set of multi-indicators to stakeholders in order to allow them to select environmental measures and set precautionary levels in absence of certainty but nevertheless under advises based on the best available knowledge.

4.5 Improve simultaneously environmental, social and economic conditions

Integrated management requires not only environmental preservation to be targeted but also the improvement of economic and social conditions. This is essential since environmental and socio-economic goals are inherently linked to each other (Commission européenne, 2001). Not understanding how environment influences social and economic conditions might conduct to unexpected adverse socio-economic impacts of inappropriate political measures.

The inherent holistic property of green accounting enables a wide range of ecosystem services to be considered. Yet, the six categories of ecosystem services inherently encapsulate natural ecosystems, economic and social conditions. Economic conditions are for instance covered by provisioning services, social conditions by cultural service and environmental conditions by sink services.

Green accounting multiple indicators allow for trade-offs and reciprocal influence between social, economic and environmental conditions to be analyzed. This is not possible through single indicators techniques such as conventional CBA or even ecological footprint (if used as the sole indicator). In addition, physical units' indicators enable social or environmental conditions to be assessed even in absence of reliable monetary value (read the concept of monetisation frontier in section 2).

5. Discussion

Nevertheless, green accounting suffers several limits as shown in Weber et al. (2007, pp. 700-701). First, boundaries transfer can be a problem, especially when flows exchanges with areas outside of the zone covered by the matrix exceed exchanges inside. This limits the variety of responses (environmental measures) that can be modelled with green accounting approach. In addition, pollutant emissions outside of the defined area (e.g. national or regional territory) for imported products are not taken into account, which can lead to overall pollution underestimations. Second, linear relations are mostly assumed between inputs and outputs from different sectors as well as between outputs and final demand which is not necessarily reflecting the reality. Nevertheless, validation of the model is possible in order to calculate error percentage due to this assumption. Third, environmental measures might affect prices of commodities produced by companies. As a result, the modification of the demand due to price variation must be integrated into green accounting models (computable general equilibrium models) but this makes them heavier to handle because of numerous products and/or diverse response functions. In addition, such models rely on highly disputable assumptions on consumers behaviours. Fourth, green accounting modelling gives a static vision of the economy, thereby dynamic projections are uneasy. This would however be interesting for the creation of fully systemic models. Finally, green accounting is most suitably compiled for national areas on an annual basis. Environmental issues which are seasonal (such as shortages of water in the summer) or local (such as a reduction in water quality in a particular location) do not lend themselves easily to analysis in the accounts. Although quarterly and regional accounts are feasible in theory, in practice few countries have the data from which to compile such accounts (UN et al., 2003, p.22). However, regionalization techniques of national data do exist.

In spite of its limits, the *"interface flows deliberative green accounting approach"* presented in that paper brings a new step for solving the three following difficulties encountered by economic decision support tools for the purpose of integrated environmental management:

i) The proper location of economic tools inside decision making processes: green accounting offers an interesting complementary alternative to conventional CBA drawbacks. Conversely to conventional CBA, which is basically normative and defines *ex-ante* decision-making criteria, green accounting offers a description of possible consequences of decision processes and lets stakeholders to structure the decision-making criteria related to social choices. Its holistic and integrative properties make it a suitable tool at early stages of decision making process for identification and selection of policy options. This is important because when too micro-specific tools such as conventional CBA are used at early stages, the risk is high to neglect important ecosystem services with economic, social and environmental consequences (Cordier et al., unpublished article). Conventional CBA may illustrate and offer a specific focus on one or only few aspects of possible options of environmental measures already identified (UNESCO, 2001, p. 37). This is of particular interest for instance in the case of floods due to climate change and lack of adaptation measures such as dams for instance. Indeed, hedonic prices methodology reveals to be useful to assess the subsequent depreciation of real estate value. This information might be useful if land owners are to be compensated by public authorities for this loss.

ii) Uncertainty management: the *"interface flows deliberative green accounting approach"* developed in this paper attempts to reduce an important difficulty: the high uncertainty stemming from the complexity inherent to anthropo-ecosystems. This impedes very important ecosystem services to be ignored and underestimated just because uncertainty makes impossible any reliable quantification as it however happens in conventional CBA.

iii) Difficulties in setting sustainable levels in physical units: the uncertainty management offered by *"interface flows deliberative green accounting approach"* adds a new difficulty. It requires the setting of sustainable/precautionary levels. However, this can be solved through stakeholders' participation into a social deliberative process (drawing up of environmental laws included).

6. Conclusion

This paper proposes a methodological framework for economic and environmental foresight based on green accounting tools. Such tools enable to bring support to sustainable policies in the respect of the integrated management paradigm.

We have shown that for the purpose of green accounting modelling, building a more accurate definition of ecosystem services that is based on material and energy exchanges in both directions at the interface economy/environment (*“interface flows deliberative green accounting approach”)* was more operational and allowed a wider range of ecosystem services to be included into economic assessment of the environment. As a result, numerous stakeholders’ categories, territorial components, time scales and impacts can be considered. This range is large enough to strongly diminish the risks of ignoring important environmental, social and economic impacts of political options. Conversely, remaining in a DPSIR framework (*“full DPSIR green accounting approach”*) causes technical difficulties and restricts strongly the amount of ecosystem services taken into account. Hence, similarly to conventional CBA, it reduces green accounting contributions to sustainability if used at early stage of decision making process.

The methodology suggested in this paper is being tested on a real case study in Seine aval sub-basin (France).

Appendix A. Formulation of an *"interface flows deliberative green accounting approach"*

Commodity by industry I-O matrices (or "supply-use tables") suits well for the building of *"interface flows deliberative green accounting approach"*. Below, table 1 offers a prototype of a green accounting table, which is based on a mix version of the models suggested by Isard (1969, In: Victor, 1972, pp. 41-47) and Leontief (1974, pp. 133-157 and 193-216). The greening operations enabling environment to be integrated into the I-O matrix are mentioned below:

1. A line with ecological commodities entering into economic activities is added to conventional I-O matrix (Isard, 1969). This helps environmental impact on damaged sector to be assessed.
2. A column for pollutant emissions from economy into the environment is added to conventional I-O matrix (Isard, 1969; Leontief, 1974, pp. 133-157 and 193-216). This may help decision makers in identifying commodities and industries that should be regulated.
3. Another column is added to each economic sector for "anti-pollution" activities (e.g. industrial waste water treatment) (Leontief, 1974, pp. 133-157 and 193-216). This enables us to assess the impact of environment on economic production and employment.
4. Modifications of technical coefficients of conventional I-O matrix in order to take into account changes in production due to new environmental measures (e.g. technological changes in production, cleaner substitute materials, etc.).

Table 1 shows that our Isard/Leontief table includes 9 matrices, 8 vectors and 1 scalar. A summarized version is given in figure 3.

Table 1. An economic-ecologic Input-Output table (modified from Victor, 1972, p. 56).

		Economic commodities **1, …, *n***	**Industries** **1, …, *m***		**Final Demand** **1, …, *f***	**Total**	**Ecologic commodities**		
			Conventional activities	**Anti-pollution activities**			**Land** ***n*+1, …, *t***	**Air** ***t*+1, …, *v***	**Water** ***v*+1, …, *z***
Economic commodities	**1,** **…** ***n***		a_{ij} A Economic commodities used as inputs into industrial activities	a^*_{ij} A^*	b_{ij} B	c_j c		g_{ji} G	Example: Heavy metals leaching into rivers due to road and fuel consumption by car drivers (through urban waste water treatment plants that collect contaminated roads runoff)
Industries	**1,** **…** ***m***	d_{ji} D Economic commodities produced as outputs by industrial activities				e_j e	Example: Tones/yr of residual sludge stored on land	f_{ji} F	Example: Tones/yr of heavy metals emitted into rivers by industrial waste water
Primary inputs	**1,** **.** **.** **.** ***p***		h_{ij} H	h^*_{ij} H^*	k_{ij} K	l_i l			
Total		c_i c'	e_j e'	e^*_j e'^*	o_j o'	p		q_i q'	
Ecologic commodities	**Land** ***n*+1,** **…** ***t*** **Air** ***t*+1,** **…** **v** **Water** ***v*+1,** **…** ***z***	s_{ij} S Example: Heavy metals (ecologic commodity) ingested by consumers with contaminated oysters (economic commodity)	r_{ij} R Example: Tones/yr of heavy metals in water from contaminated rivers pumped for industrial processes			t_i t	Fourth quadrant suggested by Isard (1969): We decided to ignore it because of too high complexity and uncertainty, which is inherent to natural systems at macro-scale (time and geographical scales).		

Notation from table 1 (adapted from Victor, 1972, pp. 56-58): Capital letters are used for matrices; lower case letters are used for vectors and scalars. Dark cell are lines and columns added to conventional commodity by industry I-O matrices by greening operation. Note that cells n° 2, 4, 3 and Responses from figure 3, respectively correspond to matrices *G* and *F*, *S* and *R*, *A* and *D*, and *A** and *H** from table 1.

- **Matrix *A* (order *n* x m) = intermediate inputs:** an element a_{ij} in this matrix shows the input of the i^{th} economic commodity to the j^{th} conventional industry ($i = 1, \ldots, n$; $j = 1, \ldots, m$). **Matrix *A** ** is the same as matrix *A* but for industrial activities with anti-pollution target.

- **Matrix *B* (*n* x *f*) = final demand:** an element b_{ij} in this matrix shows the final demand for the i^{th} economic commodity by the j^{th} category of final demand ($i = 1, \ldots, n$; $j = 1, \ldots, f$). The categories of final demand include consumer expenditures, government expenditures, fixed capital formation, change in inventories and exports. Imports are entered as a negative demand for economic commodities.

- **Vector *c* (*n* x 1) = total input per comodity:** an element c_i in this vector, found by summing the elements of the i^{th} row of matrices *A* and *B*, shows the total domestic supply of the i^{th} economic commodity to industries and final demand ($i = 1, \ldots, n$).

- **Matrix *D* (*m* x *n*) = outputs produced by industries:** an element d_{ji} in this matrix shows the output of the i^{th} economic commodity by the j^{th} industry ($i = 1, \ldots, n$; $j = 1, \ldots, m$).

- **Vector *e* (*m* x 1) = total output per industry:** an element e_j in this vector, found by summing the elements of the j^{th} row of matrix *D*, shows the total industrial output of the j^{th} industry ($j = 1, \ldots, m$).

- **Matrix *F* (*m* x (*z*-*n*+1) = Environmental degradation caused by industrial production:** an element f_{ji} in this matrix shows the discharge of the i^{th} ecologic commodity by the j^{th} industry ($j = 1, \ldots, m$). *When* $i = n+1, \ldots, t$ the discharge is onto land. *When* $i = t+1, \ldots, v$ the discharge is into air. *When* $i = v+1, \ldots, z$ the discharge is into water ($i = n+1, \ldots, z$).

- **Matrix *G* (*n* x (*z*-*n*+1) = Environmental degradation caused by final consumption:** an element g_{ji} in this matrix shows the output of the i^{th} ecologic commodity discharged as a result of the final demand for the j^{th} economic commodity ($j = 1, \ldots, n$). For *i* values, refer the Matrix F.

- **Matrix *H* (*p* x *m*):** an element h_{ij} in this matrix shows the expenditures on the i^{th} primary input (e.g. wages and salaries) by the j^{th} conventional industry ($i = 1, \ldots, p$; $j = 1, \ldots, m$). **Matrix *H** ** is the same as matrix *H* but for anti-pollution activities.

- **Matrix *K* (*p* x *f*):** an element k_{ij} shows the expenditures on the i^{th} primary input by the j^{th} category of final demand ($i = 1, \ldots, p$; $j = 1, \ldots, f$).

- **Vector *l* (*p* x 1) = total primary input per category of primary inputs:** an element l_i in this vector, found by summing the elements of the i^{th} row of matrices *H* and *K*, shows the total expenditures on the i^{th} primary input ($i = 1, \ldots, p$).

- **Vector *c'* (*1* x *n*) = total output per commodity:** an element c_i of this vector, found by summing the elements of the i^{th} column of matrix *D*, shows the total output of economic commodity ($i = 1, \ldots, n$). *c'* is the transpose of the vector *c*.

- **Vector *e'* (*1* x *m*) = total inputs per industry:** an element e_j of this vector, found by summing the elements of the j^{th} columns of matrices *A* and *H*, shows the total economic inputs of the j^{th} conventional industry ($j = 1, \ldots, m$). *e'* is the transpose of the vector *e*. **Vector *e'**** is the same as vector *e'* but for anti-pollution activities.

- **Vector *o'* (*1* x *f*):** an element o_j of this vector, found by summing the elements of the i^{th} column of matrices *B* and *K*, shows the total expenditures by the i^{th} category of final demand on economic commodities and primary inputs ($j = 1, \ldots, f$).

- **Scalar *p* = GDP at market prices:** the scalar *p* is equal to the sum of the elements of vector *o*'. It is also equal to the sum of the elements of vector *l*. The fact that *p* equals both of these summations reflects the identity of gross domestic expenditures and gross product.

- **Vector *q'* (*1* x (*z*-*n*+1)) = total ecologic commodities going out from the economy into the environment (i.e. total pollutant emissions):** an element q_i in this vector, found by summing the i^{th} element of the columns of matrices *F* and *G*, shows the total output of the i^{th} ecologic commodity. For *i* values, refer the Matrix F.

- **Matrix *R* ((*z*-*n*+1) x *m*) = total ecologic commodities entering into the economy :** an element r_{ij} in this matrix shows the input of the i^{th} ecologic commodity used by the j^{th} industry ($i = n+1, \ldots, z; j = 1, \ldots, m$).

- **Matrix *S* ((*z*-*n*+1) x *n*):** an element h_{ij} in this matrix shows the input of the i^{th} ecologic commodity used in conjunction with the final demand for the j^{th} economic commodity ($i = n+1, \ldots, z; j = 1, \ldots, n$).

- **Vector *t* ((*z*-*n*+1) x 1):** an element t_i of this vector, found by summing the elements of the i^{th} row of matrices *R* and *S*, shows the total input of the i^{th} ecologic commodity to industry and final demand.

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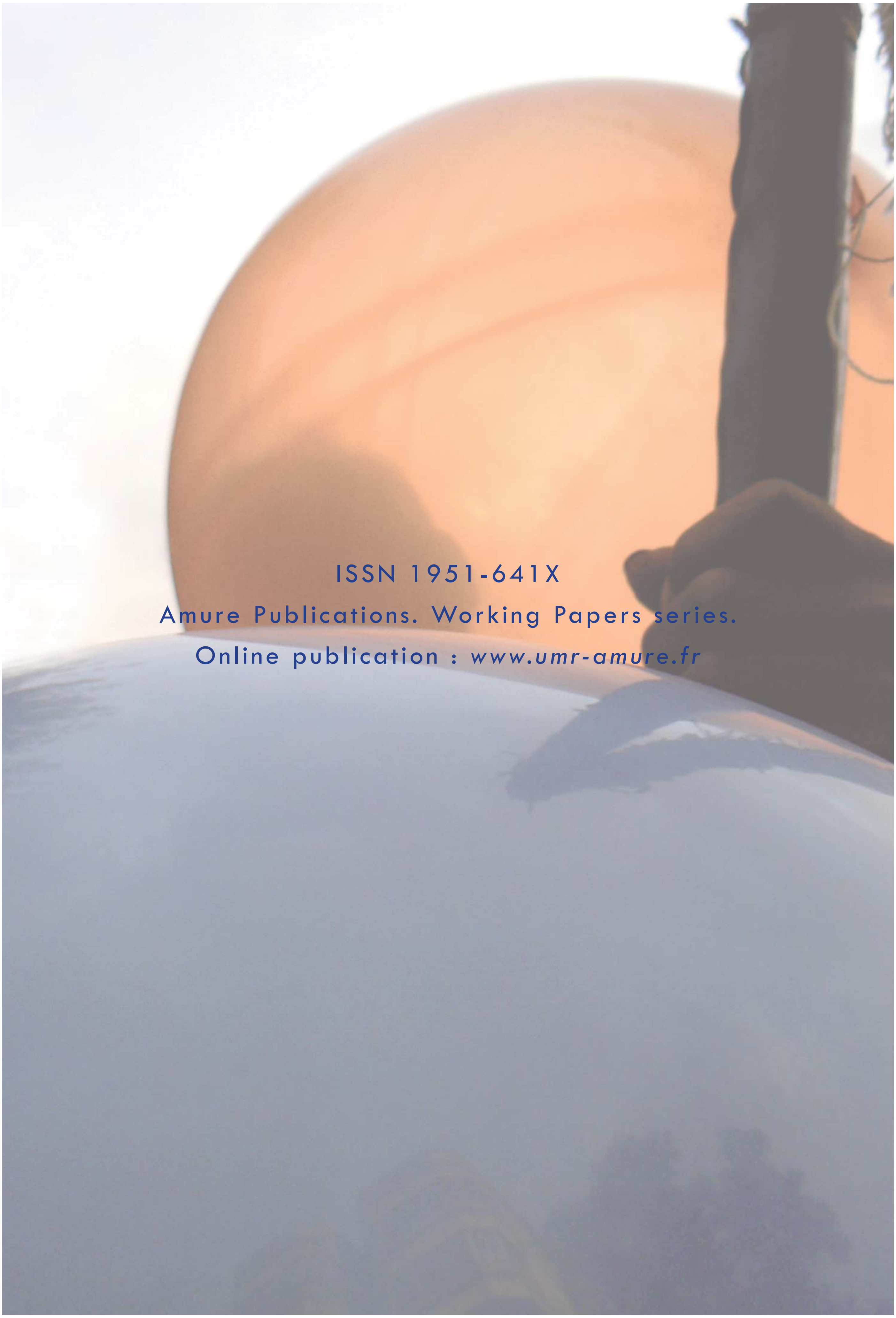

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