Human consciousness as a base for sustainability in socio-economic-ecological systems

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Abstract: Sustainability of socio-economic-ecological systems always implies a structural uncertainty coming mainly from the diversity of social values involved in the decision making processes required to manage the system. Such uncertainty cannot be reduced in any way, but needs to be managed if sustainability is to be pursued in its 'strong' meaning. This work proposes a methodology to manage structural uncertainty based upon the integration of elements from ecological economics, sociology and biology. This integration provides an approach to the strong sustainability of systems that is based on human consciousness from the perspective of the biology of knowledge and provides for a more holistic perspective for understanding and managing sustainability.

Keywords: sustainability; reflexivity; structural uncertainty; emergent complex systems; human consciousness; biology of knowledge.

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1 Introduction

The question of the sustainability of human activities has a long history. However, it was the appearance of the Brundtland Report in 1987 that popularised the term 'sustainable development', defined as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" [Brundtland, (1987), p.8].

Since then, the concept has failed to free itself from the nuances and contradictions to which it is vulnerable. Authors such as Naredo (2003) and O'Connor (1998) have drawn attention to such contradictions, in particular the understanding of development simply in terms of economic growth, or growth of macro-economic aggregates expressed in monetary units. Such ideas of development seem to forget that the physical environment is the ultimate source of life-sustaining matter and energy, and the final destination for the waste from human activities, and thus affects the worldwide population in countless ways (Zaba and Clarke, 1994).

In general terms, the greater the growth, the greater the use of resources and the greater the resulting production of waste. The term 'development', however, even when accompanied by the adjective 'sustainable', seems to continue to avoid the real issue, which is that our planet is limited in space and resources. This highlights the dangers of considering sustainable development as economic growth that is sustained (ad infinitum'), rather than on the sustainability of human activities.

Given the former, it is necessary to consider and clarify the biophysical aspect of sustainability as an alternative perspective, but also to recognise the restrictions this imposes on potential economic growth. However, to limit analysis to the biophysical alone would be to omit the fundamental, central element holding together the whole system to be managed in a sustainable way, namely the human aspect of sustainability. In this respect, we clarify how the human aspect is defined, what the consequences are of treating it within a system seeking to be managed in a sustainable way, and how such consequences can be compensated for.

2 The biophysical aspect of sustainability and the physical restrictions to economic growth

This section explores two perspectives on sustainability: the view of an economist, and physical sustainability, which in effect determines the development of a socio-economic system. These two perspectives correspond to two definitions of sustainability; namely 'weak' sustainability and 'strong' sustainability.

As Brand (2009, p.605) points out, "[a]t this conceptual level of sustainability science, basically two positions fight for validity… Weak sustainability holds that utility (or wellbeing) ought to be maintained over intergenerational time scales. In this conception, natural capital and man-made capital are viewed as substitutes within specific production processes. Consequently, the stock of the natural capital can be depleted (unless the utility over time is declining). In contrast, strong sustainability states that natural capital and man-made capital must be viewed as complementary. We are obliged to keep each type of capital intact over time. Thus, the whole stock of natural capital ought to be preserved for current and future generations in the long run".

It is interesting to note that the economists who advocate the concept of weak sustainability have themselves fine-tuned their thinking. As an example, Solow (1993) recognises that ordinary transaction prices do not provide an adequate means of obtaining a complete and accurate evaluation of the stock of capital, and the depletion and deterioration produced in it. He concedes that his argument depends on achieving shadow prices that are roughly correct, and concludes accordingly that we shall end up depending on physical indicators to be able to assess an economy's performance with respect to the use of its environmental resources. However, Naredo (2003) points out that Solow's proposal is not at variance with, but must be based upon, a good knowledge of the interaction of the economic processes and the environment in which they take place.

The strong approach to sustainability, which is the focus of this paper, is founded upon the idea of integrating and inserting the economic system within the system of the biosphere. According to Naredo (2003), this approach is concerned directly with the health of the ecosystems in which the life and economy of human beings interpose themselves. As such, the focus must be on attempting to identify the systems whose viability or (strong) sustainability is at issue, as well as pinpointing the spatial range (with the concomitant availability of resources and waste disposal options) attributed to the systems and the temporal horizon within which their viability is being judged. In terms of the physical systems around which human life is organised (agricultural, industrial or urban systems), it can be maintained that the sustainability of such systems will depend on the capacity they have to provide (and continue providing) themselves with resources and dispose of waste, as well as to control the losses in quality that affect their operation.

In agreement with the former view, other authors point out that "the characterization of sustainability in terms of the 'strong' criterion of non-negative change over time in stocks of specified 'natural capital' is based on direct physical measurement of important stocks and flows" [Martinez-Alier et al., (1998), p.284]. Thus we believe that if we really want to deal with the problem of sustainability, monetary reductionism to a physical reductionism is not the solution. Instead, it is necessary to take into consideration the human aspect of sustainability. This perspective will be discussed next.

3 The human aspect of sustainability, and structural uncertainty in complex, reflexive systems

3.1 'Integrated' human wellbeing as the objective of development

In order to fully consider the integrated sense of sustainability associated with strong sustainability, it is necessary to recognise that a key objective of economic development

is to support human wellbeing, and that human wellbeing is connected with more factors than just the consumption of economic goods and services.

O'Connor (1998) uses a structural economic perspective to address these aspects of wellbeing by considering the goods and services provided by nature (natural resources, waste reception, functions that are indispensable for life, relaxation and pleasure) as complementary to the goods and services produced by human beings. The two groups of goods and services contribute to human wellbeing in ways that are inseparable or irreducible, but qualitatively distinct from each other. As such, their significance in terms of wellbeing is specified as complementary but incommensurable.

Other authors however, have approached the concept of sustainability by placing greater emphasis on the systemic dimensions, i.e., the relationship between human economic systems and ecological systems (Costanza et al., 1991), which are much more dynamic, but normally slower to change. Within this relationship:

1 human life can continue indefinitely

2 human beings can prosper

3 human cultures can develop.

However, the effects of human activities are circumscribed in such a way that the biodiversity, complexity and function of the life-supporting ecological system are not destroyed.

In general, the diversity of approaches to the concept of strong sustainability suggests the adoption of sustainability that guides human activities towards achieving wellbeing beyond the logic of a market operating within isolated monetary values. Thus we need to take directly into account the restrictions imposed by nature (Funtowicz and Ravetz, 1994; Munda et al., 1994; Norgaard, 1994; Faucheux and O'Connor, 1997; Munda, 1997; Martinez-Alier et al., 1998; Amigues et al., 2004; Sagoff, 2008). This also requires us to consider the reality of the human being as a more complex individual than the rational *homo economicus* who acts to maximise his or her own benefit, not just as an individual who interacts with their environment and with other human beings in terms of mere competition (Ekins and Max-Neef, 1992; Martinez-Alier and O'Connor, 1999; Siebenhüner, 2000; Van den Bergh et al., 2000; Martinez-Alier, 2002; Ikeme, 2003). As such, we propose the hypothesis that individual wellbeing may depend on social wellbeing and on the good condition of the environment. It thus becomes necessary to establish policies and norms that reconcile individual and social wellbeing and a healthy environment by resolving the conflicts of interests between different agents by means of dialogue and participation. The Eco-integrated methodology for Structural Uncertainty Management (ESUM) methodology proposed in this paper is intended as a tool for establishing such policies. In essence, ESUM combines knowledge of the socio-economic and ecological system with participatory processes and technical matrix of impacts, evaluation and conclusion. Before applying ESUM it is necessary to examine the nature of systems, social multi-criteria evaluation and structural uncertainty.

3.2 Complex, reflexive and emergent systems

The question of the nature of interaction and interdependence of individual, society and environment in human systems within the ecosystems we inhabit, leads us to the need to explain the 'complex, reflexive and emergent' systems proposed by post-normal science.

Complex systems (such as ecosystems) are systems in which the relevant aspects of a particular problem cannot be covered by any single perspective (Funtowicz et al., 1999; Rosen, 1977), while *complex reflexive systems* (such as human systems) are systems with two special properties: 'self-consciousness' and 'purpose'. As pointed out by Munda (2004), these properties entail an additional leap in complexity when it comes to attempting to describe them. In fact, the presence of self-awareness and purpose (reflexivity) allows these systems constantly to add new qualities and attributes that have to be taken into account when exploring or describing their behaviour. This is the property of *emergence*, i.e., through the decisions they take, human beings can cause new properties to emerge in the system.

The systems whose viability or (strong) sustainability is to be assessed consist of a base ecosystem at the heart of which lies the socio-economic system. These systems are complex given the quantity and complexity of interactions they present and therefore require more than one perspective for analysis. The systems are also reflexive and emergent, since they contain human systems. This characterisation of systems as complex, reflexive and emergent is supported by the work of Funtowicz and Ravetz (e.g., 1991, 1993) within the epistemological framework provided by post-normal science. This was used in an attempt to solve economic decision-making problems in present-day social and environmental contexts where facts and values are undetermined, risks are great, and decisions cannot be delayed. This leads to conflict, which Martinez-Alier et al. (1998) point out are incommensurable and need to be faced up to. Incommensurability in this context being the absence of a common unit of measurement, this involves applying a plurality of values, and rejecting not only monetary reductionism (as pointed out previously) but also physical reductionism (e.g., eco-energetic evaluation). However, incommensurability does not mean incomparability. The 'weak' comparability of various options can be considered without resorting to a single type of value. The concept of incommensurability is clarified by Munda (2004) who distinguishes between technical and social incommensurability. Technical incommensurability is a product of the multidimensional nature and the complexity of the phenomena that are observed. Social incommensurability is derived from the concepts of reflexive complexity and post-normal science, and reflects the fact that a multiplicity of legitimate values exist within society. A multi/interdisciplinary approach is proposed as the most adequate way of dealing with technical incommensurability, while public participation and transparency throughout the decision-making processes, i.e., the first technical proposals to the final results, are suggested for dealing with social incommensurability. In other words, it is a question of increasing the research community to include those agents involved in varying degrees in the problem addressed by the decision-making process to enrich the process itself.

Given this requirement, social multi-criteria evaluation, to which we now turn, proves highly useful.

4 Social multi-criteria evaluation

In the context of systems that are complex, reflexive and emergent, it is necessary to use a tool of multi-criterial assessment that is capable of coping with the elements of incommensurability and uncertainty inherent to these systems. This tool is what Munda (2004) has called 'social multi-criteria evaluation'. The author emphasises that any model is a representation of reality based on a number of arbitrary hypotheses, and this implies

that there may be two or more potential representations of the real system. Therefore, what really matters in a multi-criteria framework is the process, since the result of the evaluation will be determined by how the problem is structured. In these terms, the method applied is a framework. Such a framework needs to be as consistent and as transparent as possible but must not mistake computation for decision-making. The importance of the decision-making process was highlighted by Simon (1976) drawing distinction between the concepts of substantive and procedural rationality. Substantive rationality being rationality in decision-making when considered independently of the manner in which the decision is made and evaluated relative to the results of the choice. Procedural rationality however takes into account how the decision is reached. Therefore, the rationality of the evaluation refers to the decision-making process itself.

Supporting this idea of holism, Roy (1996) claims that in general, it is impossible to determine whether a decision is good or bad, based solely on a mathematical model. All aspects of the entire process contribute to its quality and success or failure.

5 Managing structural uncertainty

5.1 The sources of uncertainty

An important feature of reflexivity to be borne in mind is the implication that the manner in which humans represent a given policy problem in need of solution necessarily reflects the perceptions, values and interests of those who are structuring the problem. For this reason, the uncertainty in question goes beyond the stochastic probability that results when various future states of the system are possible depending on a specific action. Uncertainty of this sort has been studied sufficiently by probability theory and statistics. As such, we focus on uncertainty that is encountered in complex, reflexive systems. This uncertainty has to do, not with whether a particular fact occurs or not, but rather with understanding and describing the fact in itself. It is in this context that 'fuzzy uncertainty' arises. This makes it necessary to explain the various dimensions of the problem at issue, using information that is not always quantitative, i.e., that is not precise, certain, exhaustive and unequivocal, and that as such may be measured as a ratio or interval but may be impossible to measure in absolute terms.

Within the context of post-normal science, taxonomy of the sources of uncertainty has been drawn up as described in Van Asselt (2000). According to this taxonomy, at the highest level of aggregation two classes of uncertainty can be distinguished: uncertainty due to variability and uncertainty due to limited knowledge.

5.1.1 Uncertainty due to variability

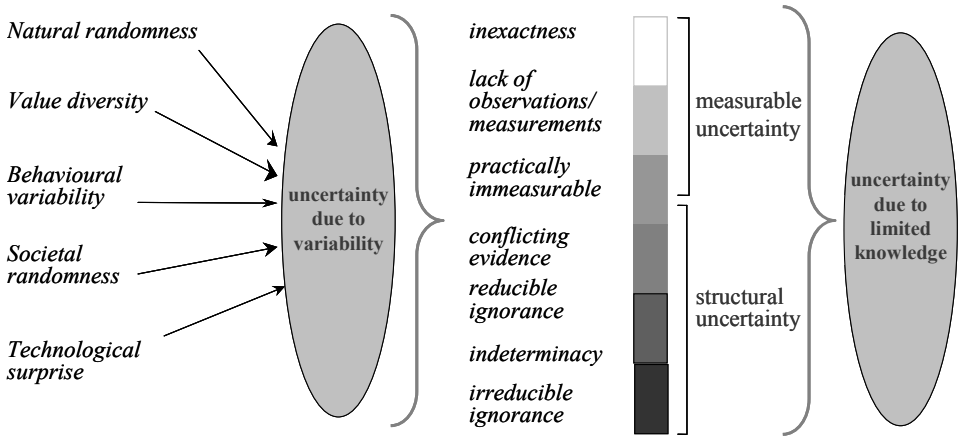
The system or process under consideration may behave in different manners or be evaluated in different ways. The variability is an attribute of reality (an ontological attribute). This type of uncertainty has also been called 'objective uncertainty'.

5.1.2 Due to limited knowledge

This is an attribute of the analyst carrying out the study and his or her state of knowledge (the epistemology in which he or she is situated), also termed 'subjective uncertainty'.

Figure 1 highlights the various sources of variability. These are explained and illustrated by Van Asselt and Rotmans (2002) as '*randomness inherent in nature*' (the non-linear, chaotic and unpredictable character of natural processes also designated 'unobserved seasonal variations'); '*diversity of values*' (differences in people's mental maps and visions of the world, and in their norms and values, as a result of which perceptions and definitions of the problem may diverge); '*human behaviour/behavioural variability*' ('non-rational' behaviour, discrepancies between what people say and what they actually do, or deviations from the patterns of standard behaviour – micro-level of behaviour); '*social, economic and cultural dynamics*' (societal variability, the non-linear, chaotic and unpredictable nature of social processes – macro-level of behaviour, being social and institutional processes the major source of uncertainty resulting from variability): '*technological surprise*' (new discoveries or technological innovations, or the unexpected consequences of technology – collateral effects).

Figure 1 Typology of sources of uncertainty



Source: Van Asselt (2000)

On the other hand, a result of such variability, in conjunction with limitations in the acquisition and measurement of empirical information, displays inherent uncertainty and unpredictability in reality. As such, this contributes to be limitations on knowledge.

The continuum of these limitations thus goes from 'unreliability' to the most fundamental uncertainty, known in the literature as radical, structural or systematic uncertainty. Uncertainties in the category of unreliability are normally measurable or can be calculated, since they are derived from systems or processes that are generally well known. The other end of the continuum, by contrast, implies uncertainties that can at best be roughly estimated. Such radical uncertainty is usually generated by conflicting evidence, ignorance, indeterminacy and variability. These are features characteristic of complex, reflexive systems. As such, a significant part of the uncertainty that arises in analysing this type of system cannot be resolved by more measurements, achieving at most a better understanding of the level of variability and possible states of the systems. On the contrary, the indeterminacy and ignorance inherent to this variability will never disappear. In human behaviour, as in the policies that influence it, uncertainties are produced by the diversity of ethical values and their societal randomness, and these cannot be resolved by means of more measurements.

5.2 The fields of knowledge in uncertainty management, and the concept of 'perspectives'

Any model that seeks to manage uncertainty must incorporate four fundamental dimensions, based on fundamental sources of knowledge: institutional, social, economic and environmental. The move from environmental to institutional knowledge entails an increase in the degree of uncertainty and means that uncertainty due to variability becomes the dominant source.

In the face of such difficulties, Rotmans and Van Asselt (2001) adopt a 'pluralist' approach to uncertainty management within a previously defined context of integrated models. In this approach, uncertainty is signalled and communicated by means of different interpretations in accordance with different perspectives.

A 'perspective' is defined as a coherent and consistent description of the screen of perception through which (groups of) people interpret or give meaning to the world and its social dimensions, and are guided in their way of acting. A perspective thus comprises both a 'vision of the world' (i.e., how people interpret the world) and a 'style of management' (i.e., how they behave in the face of this vision).

According to this methodology, having characterised the problem under study by determining the sources of knowledge that underlie it, the next task is to select the most notable uncertainties. These can be manifest in the variables of the model and in its structure. In the field of science, protocols and heuristics have been elaborated on to rank uncertainties in terms of their importance (de Marchi et al., 1993; Petersen et al., 2003a, 2003b). In spite of the utility of such ranking procedures, this always implies an exercise of judgement. To achieve a broad analysis of the most important uncertainties, which are frequently due to subjectivity and disagreements among experts, multiple perspectives can be introduced. A pluralist approach means that the effects of the most significant uncertainties selected in a model of integrated assessment are estimated in accordance with a variety of perspectives.

Attempts are frequently made to study reality from a concrete perspective, yet without making this perspective explicit. The pluralist approach seeks to make explicit not one but several perspectives. It makes sense therefore to organise the various perspectives to be considered in a coherent form. This involves establishing a typology that makes it possible to classify the diverse points of view when it comes to evaluating the uncertainties in question. The advocates of the pluralist approach tend to insist on the need to put the perspectives in their cultural and historical context, claiming that people think and behave on the basis of the 'logic of the situation'. For this they turn to cultural theory.

Cultural theory (Douglas and Wildavsky, 1982; Thompson et al., 1990), which was developed by anthropologists and has been widely used in the political sciences and has been a fundamental source of inspiration for the pluralist approach. The typology associated with cultural theory tries to systematise the complex matter of the different cultural perspectives on a general level. In spite of all the academic discussion concerning this typology, what is clear is that Cultural Theory has established dichotomies that have been and continue to be important in social and cultural conceptualisations, as well as dichotomies such as hierarchy versus egalitarianism, private versus public, centralisation versus decentralisation, and individualism versus social solidarity. Moreover, cultural theory has frequently been used as an explanatory or descriptive framework in sociological research (Funtowicz and Ravetz, 1993; O'Riordan et al., 1997) despite some

authors (Van Asselt, 2000) recognising its limitations in reflecting complex social reality. As such, it is deemed the most complete systematisation available for adequately reflecting the pluralism present in systems of social values.

Although it is a schematic approach that simplifies reality, cultural theory provides a framework for classifying the various possible 'perspectives' and in turn using them to interpret the uncertainties in the model in question. This makes it possible to justify and explain different projections of the future, instead of presenting merely maximum, minimum or optimum values.

6 An ESUM

As has been described, the problem of strong sustainability embraces three fundamental aspects: environmental, human-social-institutional and economic. As such, there is a need for an approach that incorporates the interrelatedness of these three components. This section proposes an eco-integrated methodology for the management of structural uncertainty (the ESUM Methodology).

6.1 Essential requirements of the ESUM Methodology

The essential requirements of the methodology are seen to be:

- *Opening of the system of economic reasoning to the biosphere*, i.e., consideration of all the elements and ecosystems present in a territory as economic objects.
- *Territorialisation of the economic system*. As objects differ from one place to another, there is not a global model applicable, but there must be as many models as there are territories. Economic elements acquire their value in the service of the system to which they belong and not independently of this. For this reason, from the moment in which a theoretical model of analysis is proposed, it is vital to have in mind a specific territory.
- *Systemic focus*. This focus attaches importance to the interrelationships between the elements of the system.
- *Interdisciplinarity*. Interdisciplinarity and application of an analytical tool that makes it possible to integrate information from distinct fields of knowledge, from the beginning of the study.
- *Heterogeneous and not necessarily quantifiable units of measurement*. Use of units of measurement that are heterogeneous and not necessarily quantifiable.
- Management of structural uncertainty.

The ESUM incorporates within the guidelines of the social multi-criteria evaluation propounded by Munda (2004) new approaches to the matrix of impacts and its evaluation, as explained below.

6.2 Protocol for ESUM methodology

The protocol for the ESUM Methodology consists of five stages:

6.2.1 Stage 1: knowledge of the socio-economic and ecological system

This knowledge is attained in the two steps:

a analysis, by means of a system of geographical information, of basic territorial variables marking out the biophysical dimension of sustainability

b a historical-institutional analysis (Gallopin and Raskin, 1998) carried out to identify the socio-economic evolution of the territory and its relation with the environmental determinants (i.e., 'driving forces' or the system), which determine the sustainability of the development path.

The main actors involved in the problem and decision-making process are also identified as well as the 'critical uncertainties' resulting from driving forces that will evolve in different ways depending on the dominant 'fundamental dimensions of change' and 'sideswipes' that can impact the system.

6.2.2 Stage 2: participatory processes

Participatory processes add social knowledge to the system and define alternatives and criteria for decisions. To understand this, two techniques of qualitative research are employed:

a in-depth interviews (Rist et al. 2003)

b focal groups (Tábara, 2003).

To fully explore sources of structural uncertainty resulting from social factors requires adequate time for reflection, levels of information and dialogue and discussion to construct knowledge that is relevant to policies. This is something very difficult to achieve by means of codified questionnaires but that is provided by focal groups. Further, this type of experience makes it possible to discuss the final objectives of the evaluation with the criteria defined, their validity and relevance (Tábara, 2003). The technique of life-histories is employed because "as revealed in a comprehensive analysis of the life histories, the dynamics of different forms of knowledge play a fundamental role in the revitalisation of local knowledge" [Rist, (2004), p.26]. This method also grants the interviewees the greatest possible freedom in expressing their opinions, with comments only being made in order to guide the discussion in its subject matter, motivating reflection and drawing contrasts with other opinions (Rist et al., 2003). As such, both focal groups and life-histories as methods prove to be optimal for grasping the diversity of values, the variability of behaviours, and the societal randomness that are fundamental sources of structural uncertainty due to variability.

6.2.3 Stage 3: technical matrix of impacts

In this stage new contributions are made to the method of social multi-criteria evaluation through the use of archetypal scenarios. Structural uncertainty management in this case leads to the construction of four scenarios. Each allows for variability due to the diversity of social values, behaviours, and societal randomness. By evaluating the matrix of impacts, according to the evaluation criteria obtained from the participatory processes, four future-histories are constructed. These perspectives on the future guide the construction of the future scenarios following the prospective scenarios methodology as

proposed by Gallopin and Raskin (1998) and elements from the scenario proposals of Berkhout and Hertin (2002), and Eames and Skea (2003). This use of perspectives is based on cultural theory, which underlies other works that propose the use of prospective scenarios for sustainability analysis. De Vries and Petersen (2008), for example, give a comprehensive overview of prospective scenario contributions to sustainability science, combining value orientations with cognitive maps (the theoretical basis for which can be found in cultural theory) to make up worldviews as the basis for the construction of scenarios. However, the particular claim of our paper is that cultural theory needs to be broadened using concepts from the biology of knowledge proposed by Maturana and Varela (1987).

Maturna and Varela establish the biological and scientific foundations of social phenomenon based on cooperation and harmonious coexistence. This incorporates the acceptance of the 'other' as a legitimate other and human evolution as a natural drift of structural couplings that take place between individuals and their environment. In such natural drift authentic social relations arise. A fundamental guideline in establishing such social relations is the reflexive implication of Maturana's biological approach. Given that the world in which we live as individuals and societies is the product of specific learning and culture, we know that the world constructed within our culture is just one among various alternative worlds. This knowledge entails an ethics where the most essential point is that genuinely grasping the biological and social structure of the human being involves searching for circumstances that allow for an awareness of the situation in question, thus examining it from a more all-embracing viewpoint that incorporates a certain distance. If we know that our world is always a world constructed with others in language, whenever we encounter a contradiction or find ourselves in opposition to another human being, someone with whom *we should like to coexist in harmony*, our attitude cannot consist in simply reaffirming what we see from our own perspective, but rather in realising that our point of view is the product of a structural coupling within an experiential domain that is as valid as our opponent's (though perhaps less desirable to us). The most appropriate course of action in this case will be to look for a more inclusive point of view, an experiential domain where the 'other' has a place, and in which we can construct a world together with him/her.

In other words, what biology shows us, according to Maturana and Varela, is that the uniqueness of humanity, its special endowment, inheres in its occurrence in a social structural coupling where language plays a double role. On the one hand, language plays the role of generating the regularities characteristic of human social structural coupling, including the phenomenon of each individual's personal identity; and on the other hand, a role constituting the recursive dynamic of social structural coupling which produces the reflexivity resulting in the act of adopting a more all-embracing perspective. In essence, the act of going beyond what was previously considered invisible or fixed, and allowing us to see that as humans we only have the World we create with others. This broadening of our reflexive cognitive domain, which always entails novelty of experience, is attainable either by a process of reasoning or, more directly, because of some particular circumstance that induces us to view the other as an equal, coexisting alongside oneself. According to Maturana, this act is the biological foundation of the social phenomenon, for without it there is no socialisation, and without socialisation there is no humanity (Maturana and Varela, 1987).

Such approach involves a natural 'biological ethics' implicit in human systems in which individual wellbeing depends on the wellbeing of the group and on the good

condition of the environment in which they live. Therefore, according to the model put forward by these biologists, the authentic nature of the human being, and driver of evolution, is his consciousness of being part of the human species and of the biosphere. This has resulted in the development of relationships of equality, respect and cooperation with 'others' and 'the other' (any element of the natural environment). The next section explores four future scenarios built on such driving forces.

In the ESUM methodology, the specific degree to which consciousness is developed in the two fields of belonging, the human group, and the biosphere, gives rise to four different driving forces. These driving forces are combined to build four potential future scenarios (Table 1).

Table 1 Four potential future scenarios in ESUM

SCENARIO 1: nurture	Consciousness develops in both fields of belonging (to a human group and the biosphere), cooperation and co evolution with human beings and the biosphere is the dominant social value. Nature is fragile and must be observed and respected in every human activity. Natural capital and manmade capital are not substitutes but complementary.
SCENARIO 2: self-contained	Consciousness develops only in the field of belonging to the biosphere, in a utilitarian way, conserving only what can be enjoyed. Individualism is the predominant social value, so people do not consider economic activity, it must be integrated within the ecosystems. Some natural capital (the one not so appreciated in urban areas as for leisure or by certain economic activities as resource) and manmade capital can be substitutes.
SCENARIO 3: socialised	Consciousness develops only in the field of belonging to a human group. Social cooperation is the dominant social value but nature is just an instrument to obtain resources for social wellbeing. Technology will solve possible problems in the future. Natural capital and manmade capital are substitutes.
SCENARIO 4: self fulfilment	There is no consciousness of belonging to the biosphere or to a human group, Individualism is the predominant social value, when individual wellbeing is obtained, social wellbeing will be obtained too. Technology will solve possible problems in the future. Natural capital and manmade capital are substitutes.

Taking the step of constructing a multi-criteria matrix showing the impacts of the different scenarios for each of the chosen criteria is in itself highly informative and relevant in decision-making. It may prove of great benefit when the various actors involved in the conflict come to discuss the consequences of the decisions that are taken. The idea is to generate a process of cyclical learning that makes it easier to attain greater quality in the decision-making process, bearing in mind the procedural rationality prevalent within the framework of multi-criteria evaluation.

Within this context of rationality, two things need to be highlighted. First, insofar as it is impossible to find an optimal solution that maximises all the criteria (economic, ecological and social), improving the level of information of the actors will make it possible to reach a compromise solution, representing a balance between the distinct evaluation criteria (Munda, 1997). Secondly, during the process of evaluation, new, previously unconsidered criteria may emerge, which may change the perception of the situation under study.

6.2.4 Stage 4: new participatory processes of evaluation

After developing the technical matrix of impacts, a new participatory process of evaluation is developed. The first step is to test and ratify the choice of evaluation criteria made on the basis of the broad range of criteria proposed by the agents. The second step is to validate the coherence of the scenarios and their respective narratives. This validation gives feedback to rewrite the narratives if necessary, and start a second iterative validation process, resulting in a reasonable agreement about the coherence of scenarios and narratives. The third step, on the basis of the qualitative and quantitative information provided by the technical matrix, is to ask the main actors for their own evaluation and overall preference with respect to the four proposed scenarios.

6.2.5 Stage 5: conclusions for decision-making

Finally, on the basis of the technical matrix and the evaluations made by the participative agents, conclusions are reached for public decision-making about procedures with the best possibilities for the sustainability of the territory under study. This stage identifies the opportunities and obstacles to achieving them that currently exist in society, making ESUM a useful and appropriate tool for policy making. Each scenario constructed on the basis of a different development of human consciousness describes a mode of development that is closer to or further from procedures of sustainability according to the criteria established in the participatory processes. The development of human consciousness coevolving with the way humans decide to coexist with others and the environment, is thus at the heart of the sustainability of human systems. The next section concludes our paper.

7 Conclusions and epistemological implications

The ESUM methodology implicitly brings together the following epistemological factors as essential for dealing with the three aspects of sustainability of a system incorporating human beings: namely, complex, reflexive and emergent properties. These are:

- *The territorialisation of the economic system:* territorialisation is achieved by defining the study area and using a system of geographical information to analyse the key natural resources, and their interrelationships. They must be analysed both as economic resources and restrictions upon economic activity. This conception of natural resources entails the opening of the system of economic reasoning to the biosphere and the acquisition of value on the part of economic elements in the context of the system to which they belong.
- *The systemic approach is reflected in consideration of the interrelationship of biophysical, social and economic variables in the proposal of the future scenarios*.
- *A democratisation of knowledge:* this takes place through the participatory processes. These bring together the visions of development desired by the agents and the criteria of assessment. The alternatives and criteria are agreed upon by the agents involved in the decision-making process.

- *Structural uncertainty management:* the proposal of scenarios within a participatory framework means that critical and structural uncertainties are dealt with by developing different solutions to these uncertainties depending on the perspective adopted.
- *There is an interdisciplinary approach:* such an approach is among the agents consulted, and experts in various subjects related to the critical uncertainties and evaluation criteria.
- *Social Incommensurability:* heterogeneity and incommensurability are taken into account by having distinct evaluation criteria that further bring together different social sensibilities ('social incommensurability'). This means a starting point is to stand in the other's shoes in any social process, to decide about matters that affect the sustainability of the system. It also implies to start adopting the biological ethics proposed by Maturana and Varela, since by considering the other social sensibilities as equally legitimate, we are constructing a consensus in which cooperation with others can take place. This way can more easily avoid the power struggles in decision processes which do not lead to the most efficient solution for resources management, nor to a fair solution.
- *Integration of information:* information from three dimensions of the problem (economic, social and environmental) is integrated throughout the modelling process. This starts from the territorialisation of the economic system by means of a geographical information system (GIS), making it possible to superimpose on the territory the relevant information from the different areas, and goes through to the validation of the qualitative aggregation criteria, including the knowledge of the various agents by means of participatory consultation.

The implications of this methodology for research in sustainability are interesting and significant. Adopting a different approach from the dominant classical economic perspective, to understanding the economic system and sustainability allows appreciation of aspects fundamental to 'strong' sustainability, i.e., human consciousness. In this paper, human consciousness from the point of view of the biology of knowledge as stated by Maturana and Varela (1987), this means an ethical approach to sustainability that conditions the whole evolution of the system through sustainable or not sustainable paths, to the way humans decide to coexist between them and with the environment. This provides a deeper and more balanced approach to sustainability rather than purely the economic progress or degree of technology applied to manage environmental problems. So, while economic and technology aspects are necessary, they will be useless as tools in any decision making process pursuing sustainability if not embedded in an ethical base of human consciousness and interconnectedness, i.e., tightly joint and dependent on the others and the natural environment.

In conclusion, while our paper makes a significant contribution to thinking about sustainability, we also recognise the need to test and put into practise principles we have proposed. As such, further research is currently underway which implements the ESUM framework and will allow a degree of testing and synthesis. We hope to publish these results shortly.

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