Bridging the gap between two analytical frameworks

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Abstract
Research approaches of different disciplines and schools of thought to the same issue can be complementary and illustrative. However, this requires shared meta-level concepts, enhancing the capability of the scholars involved to communicate across the borders. The paper presents a way how to reconcile two established frameworks of analysis for environment-social interactions. The two concepts are vulnerability analysis on the one hand, and DPSIR (Driving forces – Pressures – State – Impacts – Responses) on the other.
Both frameworks integrate social, political, economic and environmental factors, and are thus confronted with the challenge of providing common ground for the different disciplines involved in the analysis; in reality, they experience the cleavage between meanings attached to the same terms by experts with backgrounds in different fields of research. This reduces the comparability of their results within and in particular between the two analytical frameworks.
The paper introduces a method to identify synonymous terms used in different research approaches by systematically structuring sustainability problems based on the distinction of four spheres of sustainability (environmental, economic, social/human and political/societal). This leads to a 4x4 matrix array, in which the diagonal cells relate to a single dimension and the off diagonal cells to “interferences” of two dimensions.
On this basis, a comparison of different research languages is conducted. On the one hand, each D, P, S, I and R category is associated to a cell. On the other, the vulnerability terminology can be addressed either to one cell or to the relation between two of them. As a result, relations between terminologies can be shown, and synonymous terms be identified between different scientific languages.
For instance, ‘biophysical vulnerability’ (the amount of damage produced by a hazard), is a function of ‘Impacts’ and ‘Responses’ in the DPSIR vocabulary. ‘Social vulnerability’ (characteristics of the socio-economic system that favour the damaging action of hazards) is synonymous with social, economic and political ‘driving forces’ (D).
Finally, we exemplify the use of this methodology by applying it to the study of four large-scale environmental risks for biodiversity (biological invasions, climate change, loss of pollinators and environmental chemicals), based on recent research results.

Key words: DPSIR, biophysical vulnerability, social vulnerability, meta-level concepts, ALARM project
1. Introduction

The concept of vulnerability originates in research communities examining risks and hazards, climate impacts and resilience (Turner et al., 2001). Numerous conceptual frameworks have been proposed for examining the vulnerability of biophysical or social systems to harm, induced by both natural and socio-economic forces (Bohle, 2001, Kaspersion et al., 2003, Turner et al., 2003b, Brooks, 2003, Schröter et al., 2004, 2005a, Brooks et al., 2005). Many definitions of core concepts exist, but there is no consensus on their meaning. This diversity, and sometimes the incompatibility among different uses of terms, are largely explained by established discourse frames and patterns characterising the distinct research communities from which the concepts originate. Between them, not only the same term is used with different meanings, but they also have different terms referring to the same object. For instance, depending on the research area, the terms have been applied exclusively to the societal subsystem, to the ecological, natural or biophysical subsystem, or to the coupled socio-ecological / human-environment system (Young et al., 2006, Gallopin, 2006). “Vulnerability”, “adaptation” or “resilience” are used by the life sciences and by social sciences, often with different meanings (Gallopin, 2006). Janssen and Ostrom (2006) give the example of the linguistic confusion in the use of the concepts “socio-ecological systems” (Gallopin et al., 1989, Gallopin, 2006), “social-ecological systems” (Berkes and Folke, 1998), and “coupled human–environment systems” (Turner et al., 2003b, Schröter et al., 2004, Schröter, 2005a). There might be some differences in the meanings of these terms based on disciplinary contextualisation, but all emphasize the importance of including both social and ecological systems as well as their mutual interactions when studying their dynamics.

The abbreviation DPSIR stands for a system analysis view on environmental problems, according to which in the dominant understanding social and economic developments (Driving Forces, D) exert Pressures (P) on the environment and, as a consequence, the State (S) of the environment changes. Finally, this leads to Impacts (I) on human health, society and ecosystems, which may elicit a societal Response (R) that feeds back on Driving Forces, on State or Impacts, through mitigation, adaptation or curative action (Smeets and Weterings, 1999, Gabrielsen and Bosch, 2003). Thus, the DPSIR is defined as “the causal framework for describing the interactions between society and the environment” (EEA, 2006b).

Since 1995, the model has been used widely by the European Environment Agency and by EUROSTAT, for the organization of environmental indicators and statistics (Smeets and Weterings, 1999, Jesinghaus, 1999). Two features of the DPSIR model have contributed to its wide use. First, it structures the indicators in relation to political objectives related to controlling the environmental problem addressed, and second, it focuses on presumed causal relationships, which appeal to policy actors (Smeets and Weterings, 1999, Giupponi, 2005).

However, for analytical purposes, the causal relations assumed cannot express the complexity of the real world (Smeets and Weterings, 1999, Spangenberg et al., 2002, Gobin et al., 2004) and simplicity can be misleading. The relations between the D-P-S-I-R categories may be synergistic (for example, a specific Impact can be caused by a number of State conditions and, indirectly, by Responses to other Impacts; State conditions are influenced by diverse Pressures, each of which can originate from a range of Driving Forces, each causing several Pressures), and these connections cannot be understood when each DPSIR category is addressed separately (Mysiak et al., 2005). Moreover,
many of the relationships between the human system and the environmental system are complex and may be not well understood.

As a result, the interaction of natural and anthropogenic systems is described by a variety of terms (harm, risk, vulnerability, sensitivity, resilience, adaptation, adaptive capacity, adaptation baseline, coping range, pressures, state, impacts), each of them used with different meanings depending on the context and the objectives of the respective study. Although all the epistemologies have been developed for integrated assessments of human-environment interactions, there is a significant lack of convergence between them, and no indication that this gap is being closed. The result is confusion, not only between the researchers from different fields, but even more so for policymakers (Brooks, 2003, Brooks et al., 2005, O’Brien et al., 2005, Gallopin, 2006).

The understanding of the origin and the historical meanings of terms, as well as of their relationships, can reduce the linguistic confusion between different scholar communities and support the collaboration between different traditions of thought. So reaching an agreement on the way the concepts are used would represent an important step forward (Brooks, 2003, Gallopin, 2006, Maxim et al., 2006).

2. Vulnerability

The term **vulnerability** originates in studies of natural hazards and poverty, and may characterize both the biophysical system (i.e. a geographical configuration which for instance favours air pollution) and the social system (an institutional/political configuration favouring e.g. inequalities in the distribution of impacts (Tol et al., 2004)). Brooks shows that social scientists and climate scientists often mean different things when they use the concept of vulnerability. Whereas for social scientists, vulnerability points to the (mainly socio-economic) elements that determine people’s ability to cope with environmental stress. In this case, vulnerability is a **state of the system before the hazard acts**. Climate scientists often view vulnerability in terms of likelihood of occurrence and impacts of a hazard (in this context mostly climate-related events) (Nicholls et al., 1999, Brooks, 2003). In this case, vulnerability is considered as the **likelihood and outcome of the hazard**. This disciplinary divide between the conceptual framings, leading to a range of distinct definitions of vulnerability has been confirmed by a variety of scholars (Brooks, 2003, Adger, 2006, Gallopin, 2006, Smit and Wandel, 2006, Young et al., 2006).

**Likelihood and outcome of the hazard**

The first approach is based on traditional risk analysis, asking for the probability and the size of the damage. In this view, first of all bio-geo-science factors count, as they determine what is the hazard challenging a social system, how frequently does it occur and what are the natural factors influencing its effects (including meteorological, geographical, biological and other factors, e.g. lowlands, small islands, fragile ecosystems, etc.). Then the extent of the possible damage is calculated as the second element of a risk analysis. This approach is also reflected in the definition suggested by the IPCC in 1997, according to which “vulnerability is the extent to which climate change may damage or harm a system” (IPCC, 1997).

The representatives of the “natural hazards” tradition show that the vulnerability of human populations to natural hazards depend on where they reside, and the resources they have to cope. This trend includes human ecology tradition, pointing on the role of the class structure, governance and economic dependency in the differential impact of hazards and the “Pressure and Release” model, which identify two pressures which act synergistically: the physical and biological hazards and the vulnerability, given by the local geography and the social differentiation.

Young et al. (2006) consider that vulnerability refers to situations where neither robustness nor resilience enables a system to survive without structural changes. In such cases, either the system
does adapt structurally or it is driven to extinction. In this sense, vulnerability is understood, again, as a variable characteristic for the relationship between the system and its context.

**State of the system**

For social sciences, the first approach is not satisfactory, for obvious reasons. They stress the factors which turn an external hazard into a catastrophe in the social system as the key elements of vulnerability. For instance, while food scarcity can be triggered by extreme climatic events, such as drought or flood, the emergence of famines in such situations depends on the institutions of society. Wrong policies, even if well intended, can turn a scarcity problem into a famine (Sen 1993).

In this context, the concept of “lack of entitlements”, developed by Amartya Sen in the ‘80s, is a key means to operationalise vulnerability. It focuses on the social realm of institutions, well-being and on class, social status and gender as important variables (Adger, 2006).

The IPCC has broadened the scope of its analysis to incorporate this science line of thought in itrk, and modified its definition of vulnerability to accommodate both concepts. In 2001, it defined vulnerability as “the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate variation to which a system is exposed, its sensitivity, and its adaptive capacity”.

Adger defines vulnerability as “the state of susceptibility to harm from exposure to stresses associated to environmental and social change and from the absence of capacity to adapt” (Adger, 2006, pp. 1). Hence, the concept of vulnerability describes states of susceptibility to harm of social, ecological or socio-ecological systems, i.e. a system characteristic, not an external hazard and its effects.

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**Fig 2. Traditions in vulnerability research and their evolution (reproduced from Adger, 2006)**

The analysis of Turner et al. (2003a) portrays vulnerability as a property of the socio-ecological system, defined as “the degree to which a system, subsystem, or system component is likely to experience harm due to exposure to a hazard, either a perturbation or stress/stressor”. This concept is elaborated based on the criticism of two other models: the risk-hazard (RH) and the pressure-and-release (PAR) models.
The first model assesses the impact of a hazard as a function of exposure to the hazard event and the sensitivity (dose-response). However, this model does not treat the ways in which the system in question amplify or attenuate the impacts of a hazard, it does not make the distinction among exposed subsystems and components that lead to significant variations in the consequences of the hazards and it ignores the role of political economy, especially social structures and institutions, in shaping differential exposure and consequences (Turner et al., 2003b).

In the second model, risk is defined as a function of perturbation, stressor or stress, and the vulnerability of the exposed unit (the conditions that make exposure unsafe). The main criticism to this model is that it does not consider the vulnerability of the biophysical system.

In Turner’s view, vulnerability analysis should lie on three main concepts: entitlements (legal and customary rights), coping capacity (of social, economic and political units) and resilience. The human-environment conditions of the system determine its sensitivity to exposures. These conditions, social and biophysical, influence the existing coping (adaptation) mechanisms, which take effect as the impacts of the exposure are experienced. The adaptation mechanisms determine the resilience of the coupled system (Turner et al., 2003b).

**Synthesis suggestions**

Brooks (2003) suggests a synthesis of both concepts, based on climate change research (which, however, could be generalised). As a conceptual framework that may be applied consistently to studies of vulnerability and adaptation in a wide range of contexts, by researchers with different backgrounds, he suggests distinguishing different kinds of vulnerability, *biophysical, social and inherent*. According to his proposal,

- the *outcome* of the hazard is described as the *biophysical vulnerability*: “Biophysical vulnerability is concerned with the ultimate impacts of a hazard event, and is often viewed in terms of the amount of damage experienced by a system as a result of an encounter with a hazard” (p. 4). This vulnerability is a function of four factors: the nature of the physical hazard, the frequency of occurrence of that hazard, the extent of human exposure to the hazard and the systems’ sensitivity to the impacts of the hazard. Schröter (2005a) places the concept of *ecosystem service* at the core of the vulnerability terminology. In this view, environmental impacts of global change can add to what he calls human vulnerability by altering the supply of ecosystem services (Schröter, 2004, 2005a, Metzger et al., 2006).

Vulnerability as a *state of the system*, an internal variable, refers to the *susceptibility to harm*, to the potential for transformation of a system confronted with a hazard. Brooks suggests to subdivide this category according to the kind of system affected:

- *social vulnerability* describes the state of an anthropogenic system before it encounters and independently of a hazard event (Allen, 2003): “Social vulnerability encompasses all those properties of a system independent of the hazard(s) to which it is exposed, that mediate the outcome of a hazard event” (p. 5). It is determined by factors such as poverty and inequality, marginalisation, housing quality, etc. (Adger, 1999) and corresponds to “vulnerability as absence of entitlements” (Adger 2006). However, according to Brooks, it also encompasses the elements of the physical environment, as they relate to human systems, including factors such as topography or groundwater reserves.

- *inherent vulnerability* refers bio-geogenic systems. It is defined as the vulnerability which is “arising purely from the inherent properties of non-human systems or systems for which the term “social” is not appropriate”. Such systems can suffer damages from external hazards, but it remains open how the “amount of damage” is to be measured.
The susceptibility to harm (social vulnerability), once the system is exposed to a hazard, is then the one of the determinants of the biophysical vulnerability as the outcome is produced by the interaction between the social vulnerability and the hazard:

Key factors influencing the outcome, i.e. the biophysical vulnerability, are the hazard to which the system is exposed, its sensitivity (both mentioned by Brooks as functions determining the biophysical vulnerability) and its adaptive capacity (IPCC, 1997, Schröter 2005, Schröter et al. 2005, Adger, 2006), the essence of the social vulnerability. Each of these components enjoyed several definitions, sometimes divergent.

**Biophysical vulnerability: sensitivity and exposure**

The concepts of sensitivity and exposure vary across authors. IPCC defines exposure as “the nature and the degree to which a system is exposed to significant climatic variations” and sensitivity is “the degree to which a system is affected, either adversely or beneficially, by climate-related stimuli” (McCarthy et al., 2001). Adger describes exposure as “the nature and degree to which a system experiences environmental or socio-political stress” (Adger, 2006, pp. 3) and sensitivity as “the degree to which a system is modified or affected by perturbations” (Adger, 2006, pp. 3); Smit and Wandel (2006) and Luers (2005) argue that sensitivity cannot be separated from exposure. For Gallopin sensitivity is “the degree to which the system is modified or affected by an internal or external disturbance or set of disturbances” and an inherent property of a socio-ecological system, existing prior to the perturbation and separate from the exposure (Gallopin, 2006, pp. 295).

Most literature considers exposure as a component of the (biophysical) vulnerability characterising the relationship between the system and the stressor, and consequently as one of the element which determine the outcome of a hazard. Other scholars, focussing on vulnerability as a state of the system, do not include this element among the components of vulnerability. These authors argue that a system can be sensitive to a stressor but is not perturbed as long as it is not exposed to it, in other words it is a “hidden weakness” (Bogardi, 2004, Gallopin, 2006).

**Social vulnerability: adaptive capacity**

The causes of social vulnerability lie in the social system: people can influence their own vulnerability in a complex manner, and – for global changes – this process is mediated by ecosystem services. As for Turner (2003b), the questions addressed by the vulnerability framework are: who and what are vulnerable to the multiple environmental changes underway, and where? How are these changes attenuated or amplified by different human and environmental conditions? What can be done to reduce vulnerability to change? How may more resilient and adaptive communities and societies be built? According to the IPCC, the required adaptive capacity is “the ability of a system to adjust to climate change (including climate variability and extremes) to moderate potential damages, to take advantage of opportunities, or to cope with the consequences” (McCarthy et al., 2001). For Brooks et al. (2005), adaptation does not occur instantaneously, therefore the relationship between adaptive capacity and vulnerability depends crucially on the timescales (short term or long-term adaptation) and hazards with which the observer of the system is subjectively concerned. Also other challenge arise from the tension between “objective” and “perceived” elements of social vulnerability – it can be differently perceived by the vulnerable themselves, and the rest of the population, making it difficult to define a shared metrics measuring and valueing the degree of change produced by a hazard (Kasperson et Kasperson, 2001, Kasperson et al., 2005, Adger, 2006).

The systems’ coping capacity (Turner et al., 2003b) is also called capacity of response (Gallopin, 2006) and adaptive capacity (McCarthy, 2001, Adger, 2006, Smit and Wandel, 2006). For Adger,
adaptive capacity is “the ability of a system to evolve in order to accommodate environmental hazards or policy change and to expand the range of variability with which it can cope” (Adger, 2006, pp. 3). However, Turner et al. (2003b) distinguish capacity to cope or to respond from adaptive capacity, and consider both as components of the resilience of a system. The resilience concept is one of the most used in the analysis of the human-environment relationships (Janssen and Ostrom, 2006), but again with widely differing interpretations regarding both its content and its relation to adaptive capacity. Smit and Wandel (2006) and Gallopin (2006) show that some authors equate adaptive capacity with (social) resilience, some others consider it as a component of resilience and, finally, others consider adaptive capacity as the collective capacity of human actors in a socio-ecological system to manage resilience (Walker et al., 2004). Furthermore, Janssen et al. (2006) show that the knowledge domain “resilience” develops quite separately from the domains “vulnerability” and “adaptation”. Their results show that very few cross-citations exist across “vulnerability/adaptation” papers and “resilience” publications.

Historically, the concept resilience emerged from population ecology and ecosystem management and refers to “the magnitude of disturbance that can be absorbed before a system changes to a radically different state as well as the capacity to self-organise and the capacity for adaptation to emerging circumstances” (Adger, 2006, pp. 2). According to Holling (1973, pp. 17), “resilience determines the persistence of relationships within a system and is a measure of the ability of these systems to absorb changes of state variables, driving variables, and parameters, and still persist”. More recently, the concept was defined by Walker et al. (2004) as “the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same function, structure, identity, and feedbacks – in other words, stay in the same basin of attraction”. For Adger (2000), social resilience is the ability of groups or communities to cope with external stresses and disturbances, as a result of social, political and environmental change. For Gallopin (2006), resilience is related to the ‘capacity of response’ component of vulnerability, and thus it would be more than the flip side of vulnerability, which he names robustness. He concludes that, whereas vulnerability and resilience seem naturally related, their relationship is not at all clear. In any case, however, vulnerability is influenced by the build-up or erosion of the elements of the social-ecological resilience (the ability to absorb the shocks, the autonomy of self-organisation and the ability to adapt both in advance and in reaction to shocks) (Adger, 2006).

The fields of research of vulnerability, resilience and adaptation are confronted with the same challenges (Adger, 2006). We extend the conclusions of this analysis, by showing that the same is also the case for the fields of research having at their core the concept of risk or using the DPSIR logic for the organisation of the environmental information. The aim of such an analysis is to contribute to structuring a common conceptual ground between presently disparate traditions and communities.

3. DPSIR

Different meanings have been given to the concept of Driving Force, depending on “where” the cause of an environmental problem was identified (human and/or natural systems) and the level of the chosen system at which one assumed that it appears. However, most literature sources consider only anthropogenic factors as Driving Forces (Gabrielsen and Bosch, 2003, EEA, 2005b, Giupponi, 2005, Rogers and Greenaway, 2005, Mysiak et al., 2005). For example, the EEA describes Driving Forces as “the social, demographic and economic developments in societies and the corresponding changes in lifestyles, overall levels of consumption and production patterns” (Gabrielsen and Bosch, 2003, pp. 8). The Millennium Ecosystem Assessment (MEA) proposes that drivers can be
both anthropogenic and natural factors “that directly or indirectly causes a change in an ecosystem” (MEA, 2003, pp. 85).

In many studies, Driving Forces are identified to be economic sectors that engender Pressures, such as industry, agriculture and transport. Others describe Driving Forces through mixes of descriptors for the economic sectors, structural features of the economic system, demography and social characteristics (EEA, 2002a), as patterns of resources use, quantities of polluting products and intrinsic properties of such products (EEA, 2000), through societal trends (EEA, 2005a), demography, developments in economic, socio-political, science and technology domains, cultural and religious factors (MEA, 2003).

**Pressures** are anthropogenic factors inducing “unwanted” environmental change (Impacts). According to EEA, they are “developments in release of substances (emissions), physical and biological agents, the use of resources and the use of land by human activities” (Gabrielsen and Bosch, 2003, pp. 8). The definitions of Pressures encountered in literature differ in respect to four points:

1. The object of change: Some definitions focus on the influence of Pressures on the State of the environment, based on the idea that any change in the environment under the influence of the human activity is damaging (Gabrielsen and Bosch 2003). Some other definitions draw a line between changes in the State of the environment that are “acceptable” and changes that are not, based on the underlying concept of ‘carrying capacity’ (IBGE 2000; EEA 2005b). Finally, Pressures may be factors that diminish the benefits that humans get from the environment; in this last case Pressures are defined by making reference directly to the socio-economic Impacts that they produce (Jesinghaus, 1999)

2. The relationship between the Pressure and the change it induces: Some Pressures manifest their effects as soon as they appear (i.e. land use, deforestation), while others materialise with a variable time-lag (i.e. climate change). Some other Pressures may become effective in certain conditions of environmental exposure (Bowen and Riley, 2003, Jesinghaus, 1999). The relationship between Pressures and their effects is expressed in this last case as a probability (i.e. chemical risk).

3. The character of the Pressure: Pressures may refer to emissions (of pollutants, wastes or other disturbances), the use of resources (all use or uses above a threshold), to the intensity or the efficiency of human activities, to changes in lifestyles and activities, or even to general socio-economic features (EUROSTAT 2001; Gabrielsen and Bosch 2003; OECD 2003, EEA, 2006a).

4. The level of detail of the definition: Pressures may be defined either in a very generic manner (Smeets and Weterings, 1999, EEA, 2005c) or, on the contrary, very narrowly, according to the objective of one study (Mourelatou and Smith, 2002).

The definition given by the EEA (Gabrielsen and Bosch, 2003) for Pressures does not specify the conditions in which anthropogenic factors become stressors of the environment. Is it when they exceed a certain threshold? In particular conditions? At certain times? Given the complexity and the non-linear dynamics of the environmental processes involved, and the temporal and spatial variability that characterise the interplay with physico-chemical parameters (climate, soil), the thresholds above which “nature cannot cope anymore” with the consequences of human activity (the so-called ‘carrying capacity’) are actually poorly known and intrinsically “fuzzy” (Muradian, 2001, EEA, 2005b). Also, “cannot cope anymore” is a description of ecosystems responses to

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1 The content of the “acceptability” of the environmental consequences of human activities is a socially defined moving target and can be very different from one stakeholder to another. Declaring that an environmental change is an Impact is the result of complex social interactions between the scientific analysis and stakeholders’ involvement (i.e. Impacts of climate change on human health).
external Pressures which are declared unacceptable, as result of a social discourse. Such “negative” (or “positive”) is a normative statement, based on an anthropogenic value system. “Negative” always implies the questions “for which desiderata?” and “for whom?” Thresholds of social acceptance are fuzzy and can be highly dependent on the particular socio-political context in a given area.

For the EEA, the State is “the quantity and quality of physical phenomena (such as temperature), biological phenomena (such as fish stocks) and chemical phenomena (such as atmospheric CO₂ concentrations) in a certain area.” (Gabrielsen and Bosch, 2003, pp. 8) In the DPSIR literature, the State may refer either to natural systems (Bowen and Riley 2003; Giupponi and Vladimirova 2005) or to both natural and socio-economic systems (Rogers and Greenaway 2005). Depending on the system(s) chosen for description, indicators of State previously developed are different in kind from one study to another. They describe a range of features, from physico-chemical characteristics of ecosystems, quantity and quality of resources or “carrying capacity”, to management of fragile species and ecosystems, living conditions for humans, exposure or the effects of Pressures on humans, or even larger socio-economic issues (Jesinghaus 1999 UNCSD 2001; IAEA and IEA 2001; OECD 2003; EEA 2006a). Some studies adopt the concepts of vulnerability and risk for defining the State and the Impacts. For Fassio et al., the State of the environment is the spatial intrinsic vulnerability spatially combined with Pressures (Fassio et al., 2005) and is expressed as a risk (i.e. of nitrogen leaching). The changes in this risk (State) may determine Impacts (i.e. eutrophication). Giupponi and Vladimirova consider that the State is the environmental vulnerability to a Pressure in a given location (i.e. chemical characteristics of ground-waters) (Giupponi and Vladimirova, 2005), before the Pressure acts. The environmental result of a specific combination of Pressures and State is an Impact (i.e. changes in eutrophication status).

Depending on the discipline and the methodology used, the notion of Impact may focus on completely different target points. In biosciences, an Impact can refer to effects on living beings and non-living compartments (aquatic, terrestrial and atmospheric) (EEA, 2005c, Borja et al., 2005). These changes are often “negative”, in the sense that they affect adversely the functioning of ecosystems relative to their potential performance, under otherwise plausible conditions (Nunes et al., 2003). Examples are genetic, physiologic or behavioral anomalies, modifications in the chemical composition of air or water, changes in the ecosystem's functioning (i.e. primary and secondary productivity) (Edwards, 2002). For defining Impacts, socio-economic sciences focus on effects on the human systems (IBGE, 2000), associated with changes in environmental functions, such as resources provision, water and air quality, soil fertility, physical and mental health, social cohesion (IBGE, 2000, Bowen and Riley, 2003, Gabrielsen and Bosch, 2003, Gobin et al., 2004, EEA, 2005b). The notion of environmental function (or ecosystem service (MEA, 2003)) expresses the perception of human societies that certain categories of the environment are able to accomplish services that contribute to human well-being. This concept was used in biosciences too, for analyzing the consequences of Pressures on the environment (Björklund et al., 1999, Edwards, 2002, Lobo, 2005).

Responses deal with decision making. Depending on the decisional pattern and scale considered relevant, two main groups of definitions of Responses may be identified. One associates Responses uniquely to policy action; the other identifies Responses from different levels of the society, represented both by groups and by individuals, from the government, private or non-governmental sectors. Responses may seek to control Driving Forces or Pressures (prevention, mitigation), to maintain or restore the State of the environment, to help to accommodate to Impacts (adaptation) or even deliberate “do nothing” strategies (Smeets and Weterings, 1999, Gabrielsen and Bosch, 2003, Perrings, 2005). Responses can also be “negative” Driving Forces, if they aim, for instance, at redirecting prevailing trends in consumption and production patterns (Smeets and Weterings, 1999).
The definition used by EEA focuses on the types of measures that can constitute Responses: “Response indicators refer to Responses by groups (and individuals) in society, as well as government attempts to prevent, compensate, ameliorate or adapt to changes in the state of the environment.” (Gabrielsen and Bosch 2003, pp. 8)

In conclusion, the DPSIR scheme can be “turned” and the same phenomenon may be characterised as a Driving Force, Pressure, State or Response (Mysiak et al. 2005). For instance, ‘energy consumption’ has been considered a State indicator (IAEA and IEA 2001), a Driving Force (EEA 2006a), and a Pressure (EUROSTAT 2001), depending on the problem definition and the (disciplinary) approach chosen. These in turn depend on the state of knowledge in the field, the methods and data available, the scale of the study, the disciplinary background, and purposes of the analysis (see figure 2). Due to these factors, the descriptions of systems and of the inter-relationships between the environmental and the human systems can be widely different: “there is no single universally accepted way of formulating the linkages between human and natural systems” (Berkes and Folke 1998). Reducing the complexity is necessary (Fraser 2003), but the methodological background and the terminology shared should be clear.

Section 4 describes a framework complementing and reframing the ‘DPSIR’ model using a complex system methodology based on the distinction between four ‘spheres’ of sustainability (environmental, economic, social and political) and the analysis of their functioning and relationships (Maxim et al. 2006). It presents briefly the definitions given for each of the five D, P, S, I and R concepts, for application in the analysis of relationships between policy, society, economy and biodiversity, and discusses the links between the two frameworks of analysis.

4. Building the bridge

Systems approaches to sustainability highlight the interdependence of three fundamentally different ‘spheres’ of organisation - the economic, social and environmental spheres. This is a neutral but asymmetric interdependence: the Economic is embedded within the Social, and both are embedded within the Biosphere (O’Connor 1994a). To this framework, O’Connor (2006) adds a fourth sphere,
accounting for the functioning of the Political sphere and its role in managing the relationships between the other three dimensions (Figure 3).

Ensuring a respect for conditions of natural and social system viability, upon which long run economic activity depends, appears as a key precept for sustainability policy, as least as much the currently dominating policy of improving the conditions for the economic system, and none can be done at the expense of the other if long-term viability is to be achieved (O’Connor 1994b; 1994c; Spangenberg 2002; Spangenberg et al. 2002). Governance for sustainability therefore centres on the regulation of the economic sphere in relation to the two other spheres, in order to assure the simultaneous respect for quality/performance goals pertaining to each of the three spheres and the respect for one sphere in relation to another. As highlighted by O’Connor (in Maxim et al. 2006) and Spangenberg (2005a), for analytical purposes, it is convenient to highlight as complementary: (1) descriptions centred on the internal functioning of each sphere having a degree of autonomy relative to the other spheres; and (2) descriptions of the interactions between spheres. The pair-wise interface aspects can be characterised through investigation of the “demands” and “supply” of each sphere relative to the others. Analyses in functional terms may focus on the roles, services or behaviour that is expected of, or sought by one sphere from each of the other spheres, in order to permit its system viability (O’Connor in Maxim et al. 2006; Spangenberg 2005b).

In terms of systems analysis, each dimension represents a class of complex, non-linear, evolving systems. In reality, many issues involve “cumulative causation” with the interference of all four dimensions. Restriction to a pair-wise analysis of interfaces is artificial in a fundamental sense (i.e. the Economic and Political are inseparable from the Social, and the Economic cannot exist without the Environmental), but is a highly didactic and productive approach, allowing management to focus on mutually reinforcing processes (Spangenberg et al., 2002). Based on this approach to sustainability (described in detail in Maxim et al., 2006) and in order to offer a definition based on a solid and clear methodological background for the use of DPSIR logic, we associate one category of the DPSIR framework to each of the cross-cuttings between the four ‘spheres’ (Table 1).

Based on the conceptual background developed by Brooks (2003), which seemed to us the most appropriate for framing the DPSIR – four spheres - vulnerability integrated analysis of biodiversity, we propose to localise vulnerability within each system (ecological and socio-economic), and/or in their relationships.
<table>
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<td>THE SOCIAL SPHERE</td>
<td>Industries and Lifestyles</td>
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<td>DRIVING FORCE</td>
<td>Socio-economic “STRESSOR” (Social Vulnerability)</td>
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| ECONOMIC | | |
|----------|----------|---------------|-----------|
| MANAGEMENT PRACTICES | Sustaining what and for whom? Employment, Work conditions, Distributional issues related to “environmental justice” conflicts | THE ECONOMIC SPHERE | |
| DRIVING FORCE | Socio-economic “STRESSOR” (Social Vulnerability) | Performance, Products and Output | |
| PRESSURES ON BIODIVERSITY | Physical, chemical or biological “STRESSOR” IMPACTS on ENVIRONMENTAL FUNCTIONS “SOURCE”, “SINK”, “SITE” and “SCENERY” | THE ENVIRONMENTAL SPHERE | |
| IMPACTS on ENVIRONMENTAL FUNCTIONS | “IMPACTS” (Biophysical vulnerability) | STATE CHANGES OF STATE | |
| THE ENVIRONMENTAL SPHERE | | | |
| STATE | CHANGES OF STATE | | |
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<th>POLITICAL</th>
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<tr>
<td>SOCIAL POLICY: Public awareness and participation, Policies for an ageing society</td>
<td>ECONOMIC POLICY: Shaping the rules and limits of markets</td>
<td>ENVIRONMENTAL POLICY: Definition of risks in the environmental regulation</td>
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<td>RESPONSE “ADAPTATION”</td>
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4.1. Driving Forces and Pressures

Our definition of Pressures, resulting from the adaptation of the last EEA definition (Gabrielsen and Bosch, 2003) to the above systems considerations, considers that Pressures are consequences of
human activities (i.e. release of chemicals, physical and biological agents, extraction and use of resources, patterns of land use, creation of invasion corridors) which have the potential to cause or contribute to adverse effects (Impacts). The potential of a Pressure (in the DPSIR language) to cause an Impact is called hazard (in risk analysis language). For instance, introduced species (Pressure) may present characteristics (i.e. high adaptability) which have the potential to produce ecosystem disturbance (Impacts), which indirectly may lead to income losses (Impacts).

Driving Forces belong to the “whole” context (social, economic, political) that defines an environmental problem. It may be an element belonging to one of the four systems or to the relationships between them which is having a role of influence on the structure, the functioning or on the patterns of interaction between them for the given case (i.e. institutional arrangements, economic trends, social values, consumption patterns). That is, features contributing to the dynamics of their change by triggering Pressures: Driving Forces are changes in the social, economic and institutional systems (and/or their relationships) which are triggering, directly and indirectly, Pressures (in our example, on biodiversity). Natural factors (i.e. volcanoes, natural emissions of chemicals) are not included among Driving Forces. Even if natural and anthropogenic factors are interrelated, the drivers of main risks for the biosphere are human-made. The socio-economic dynamics itself generates risks for society and the economy and nature degradation is the carrier for feed-backs of human action on humans (Beck 1986). Therefore, the Driving Forces are pointing to the elements determinant for the current “crisis of control” (O’Connor 1994a). Once acknowledged, their management could allow to the society to control itself better if imperfectly through governance (Spangenberg 2006).

Confronting these definitions with the terminology used in the “vulnerability” language, one can highlight the partial synonymy between Pressures or Driving forces and the terms “shocks”, “disturbances”, “stresses” or “perturbations”. These are used for naming exogenous factors (i.e., climate changes or market fluctuations) that have the potential to create an adverse impact on the system under observation (Turner et al. 2003b, Luers 2005). In this research tradition, multiple global change stressors are socio-economic changes, climate change or land use change (Turner et al., 2001, Schröter et al, 2004). For Turner et al. (2003b), hazards are defined as “threats to a system, comprised of perturbations and stress (and stressors), and the consequences they produce”. A perturbation is “a major spike in pressure (e.g. a tidal wave or hurricane) beyond the normal range of variability in which the system operates”. Stress is a “continuous or slowly increasing pressure (e.g. soil degradation), commonly within the range of normal variability” (Turner et al., 2003b, pp. 8074). Perturbations often originate outside the system, and stress within the system.

These stresses are characterised by magnitude, frequency, duration and areal extent of the hazard (Brooks 2003). However, the terms “stress” and “perturbation”, as defined by Turner do not distinguish natural and socio-economic sources of these stresses for the environment. In this respect, the “four spheres DPSIR framework” is an important step forward in the analysis of a given environmental problem, by its ability to identify the role of forces which are different in nature (natural and respectively social, economic and institutional) on the system chosen for the analysis. In order to correlate the two models, we distinguish “stressors” reflecting the consequences of economic activity for the environmental sphere (i.e. such as chemical emissions or climate changes), included in “Pressures” category, and “stressors” reflecting the latent potential of social, economic or institutional features to develop these Pressures, which we suggest to include in the “Driving forces” category. We consider that biophysical vulnerability (i.e. the outcome) is driven by inadvertent or deliberate human action. In this respect, social and economic forces can create a state

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2 For further clarification on our use of this term, see further, Section 4.3.
3 The definitions and examples are the results of socio-economic case studies conducted as part of the EU FP6 Integrated Project ALARM Assessing Large-scale environmental Risks for biodiversity with tested Methods funded by the EU Commission’s DG RES
of social vulnerability to environmental disturbance (Fraser, 2003). In other words, the “social vulnerability” embodies latent or active Driving Forces for Pressures on the environment (it can be triggered by structural or functional characteristics of the social, economic, institutional systems, or of their relationships).

For example, an “environmental problem” can result from the relationships between stakeholders (power balance), from the inefficiency of institutional arrangements in implementing an established regulation, from social inequality (dumping waste in poor areas may be cheap) or from the inadequacy of policy actions for a given social context. The examination of human motivations, behaviors and attitudes that induce, are affected by or respond to the change in the environmental conditions is highly relevant for understanding Driving Forces, and needs the analysis of social mechanisms relevant for the issue under study (O’Connor 1994b; IBGE 2000 Spangenberg et al. 2002 Bowen and Riley, 2003). A description of an environmental issue that ignores employment, environmental sensibility or the relative distribution of Impacts between social groups and economic players essentially assumes that any Response may disregard such aspects (Maxim et al., 2006).

4.2. State

Biophysical systems structures (e.g. species or genetic diversity) and life support functions (e.g. nutrient cycles), which have not a direct meaning for the social systems but whose changes may indirectly lead to Impacts on humans, are hardly addressed in vulnerability literature due to the traditional focus on human system in this research field. One of the few references is Brooks (2003) and his category of “inherent vulnerability”, as described above.

Maxim and al. (2006) relate the state (of environmental systems in general and of biodiversity in particular) to the adverse effects (Impacts) resulting from exposure to Pressures. Thus the State (e.g. of biodiversity) is reflecting the vulnerability to a Pressure in a given location (Giupponi and Vladimirova, 2005). However, because of the complexity of natural systems and the limited knowledge of them, there is not one measurement scale and unit but a range of them from which a choice must be made in each case. In particular, as there is no agreed definition for the State of biodiversity and not “all” biodiversity can be measured (Maxim et al., 2006), we use vulnerability as a “metrics” for indicating the “biodiversity to measure” at the chosen scale of analysis:

*The State of biodiversity is the quantity of biological features (measured within species, between species and between ecosystems), of physical and chemical features of ecosystems, and/or of environmental functions, vulnerable to (a) Pressure(s), in a certain area.*

4.3. Impacts

The concept of Impact is present both in the DPSIR and in the vulnerability vocabulary, with mainly the same meaning. For Brooks (2003), Impacts of climate change (lives loss, people affected, economic losses) are an outcome of a hazard, mediated by the properties of the human system that is exposed to and affected by a hazard. Thus Impact is defined as an outcome, and similar to biophysical vulnerability it is a function of sensitivity, adaptation and exposure (Turner, 2003b, Schröter et al., 2004, 2005b, Schröter, 2005, Adger, 2006). Thus biophysical vulnerability is a function of potential impacts and adaptive capacity (Metzger et al., 2005). In ‘DPSIR’ terms, biophysical vulnerability is a function of Impacts and Responses:

\[ V_{(\text{Biophysical})} = f (\text{Impacts, Responses}). \]

Depending on the time scale related to an observed Impact and its severity, a system can be called (biophysically) vulnerable or not. For example, Gallopin (2006) considers that perturbation limited to the generation of trivial and ephemeral changes can hardly be called “damage”, and therefore the
system cannot be called vulnerable to these hazards. Anyway, he concludes that it is not always clear what is meant by the term “damage”. For Turner et al. (2001), stresses or perturbations that exceed the systems’ ability to cope and respond lead to impacts that can, in turn, affect resources and mechanisms for further coping. When impacts are “sufficiently” significant, they may trigger “more fundamental” changes in the system, described as adaptations. However, Turner et al. do not specify which the thresholds above which a system cannot cope anymore are, neither those above which impacts become significant or adaptation mechanisms appear. Luers (2005) shows that for individual variables (e.g. agricultural yield), a threshold of damage can be established. Such thresholds, even in relatively well-understood ecological subsystems of a socio-ecological system, are difficult to discern (Muradian, 2001). Another main challenge for the measurement of impacts is the next step: it inevitably requires determining thresholds of acceptability, for losses e.g. of species, but also of environmental functions.

O’Connor distinguishes two categories of environmental functions: “functions OF” (the environment) and “functions FOR” (humans). The “functions OF” are the basic processes and cycles in the internal functioning of ecosystems systems, which are responsible for sustaining their resilience. The “functions FOR” are those which provide human welfare (Noël and O’Connor 1998; Ekins et al. 2003). Once the structure of the ecosystem modified, its functioning is also changing; therefore changes of State may determine undesirable changes in the environmental functions “OF” the ecosystem. As the “functions OF” the environment are the basis for the “functions FOR” humans, the change in the functioning of the ecosystem affects the environmental functions “FOR” that it is able to provide to socio-economic system. In line with this approach and with the EEA (EEA 2005a; 2005b), we also use the concept of environmental function for defining Impacts: they are changes in the environmental functions, affecting (negatively) the social, economic and environmental dimensions, and which are caused by changes in the State (of biodiversity).

4.4. Responses

Given that the main purpose for using DPSIR is to organise information in order to communicate it to policy-makers, we define a Response as a policy action, initiated by institutions or groups (politicians, managers, consensus groups) which is directly or indirectly triggered by [the societal perception of] Impacts and which attempts to prevent, eliminate, compensate, reduce or adapt to them and their consequences.

Essentially, a preventive policy will target the reduction of Pressures and therefore will address in the first place Driving Forces (i.e. changing behaviour or production patterns, mitigation); this approach is the most adequate for biodiversity management (Spangenberg 2006). A curative policy (end-of-pipe) will only try to diminish the damages on the environment by adaptation, either through running technical solutions such as restoration, cleaning and global monitoring of the environment in regard to quality norms (action on State), or through protection of the Impacted social groups (action on Impacts) (IBGE 2000; Mysiak et al. 2005). In some cases, deliberate “do nothing” strategies are also a Response. In analytical terms, Responses target the only political level, while adaptation (one element of vulnerability) includes more than political responses, dealing with all levels of the social, economic and institutional changes which aim at diminishing vulnerability.

For Brooks (2003), adaptation is the “adjustments in a system’s behaviour and characteristics that enhance its ability to cope with external stresses” (Brooks, 2003, pp. 8). The effect of adaptation is to reduce social vulnerability, which depends critically on the context: whether or not this translates into a reduction in biophysical vulnerability will depend on the nature and the evolution of the hazard, and on the nature of the system. In other words, a system can be vulnerable to certain disturbances and not to others, or it can be vulnerable to a hazard at a certain moment in time, or a
certain scale, and not to another. Furthermore, both hazards and their effects have a multi-scale nature, and human-environment systems are simultaneously exposed to multiple, interacting hazards (Brooks et al., 2005, Gallopin, 2006). Adaptive capacity is associated predominantly with governance, civil and political rights and literacy. Theories of adaptive capacity cannot neglect power and conflict. In a society, whether or not adaptive capacity is realised is sometimes viewed as dependent on political will, which should be subject to investigation if we are to understand the adaptation process.

In the present paper, adaptation capacity and social vulnerability are, both, descriptors of the state of the socio-economic system, of its potential to deal with hazards, which include Driving Forces for existing or potential Impacts. As underlined by Brooks (2003), there is currently a tendency for vulnerability to be addressed solely in terms of the characteristics and behaviour of vulnerable populations - with little regard to the wider economic and geopolitical context that often causes or exacerbates poverty and vulnerability (O’Brien and Leichenko, 2000; Pelling and Uitto, 2001; Singh, 2002). Brooks associates this approach, inspired by Sen’s idea of “capacity building”, to the desire of researchers and policy makers to avoid challenging the powerful political and economic vested interests that determine the nature of the adaptation context, and to the view that it is either undesirable or impossible to question the fundamental geopolitical and economic contexts within which adaptation must be carried out. Hence, the concepts of adaptive capacity and capacity building could be employed in the same manner as the concept of social capital has been employed by bodies such as the World Bank, as a justification for inaction regarding the large-scale structural causes of vulnerability, by emphasizing micro-scale processes as the key to sustainable development. Both micro-scale and macro-scale analyses are needed for a comprehensive view of vulnerability and adaptation opportunities.

5. Discussion and conclusions

One of the key advantages of the “four spheres DPSIR framework” relates to the differentiation between structural features of the systems analysed and the relationship between sub-systems different in nature (environmental, social, economic and political), and for which different disciplinary backgrounds are needed for understanding their contribution to the issue addressed. This allows the identification of the role of each discipline and clarifies the different meanings of the “vulnerability”. Hence, the “four spheres” may be considered as sub-systems of the human-environment meta-system. Vulnerability can characterize either each of these sub-systems or their relationships. In this manner, we can grasp both natures of the vulnerability previously highlighted in literature – as characteristic for the state of the system and for its relationship with the hazard.

A second innovative aspect brought by this model, comparing to the “vulnerability” framework, is related to its ability to account for forces acting at different scales. In this respect, for each of the four dimensions of sustainability highlighted above, the scale specificity of phenomena can be addressed. For example along the economic dimension, the change of scale can be highlighted from the "local" economic activity, such as a production unit or a household, to the more aggregated systems representations of economic activity such as industrial sector outputs, national income, employment; along the institutional dimension, from the local, regional, national to European and international political arrangements; along the environmental dimension, from the site or species level to ecosystem or landscape level; along the social dimension, from the individual and the local community cultural values to the European lifestyles (O’Connor J. 2004). Climate change acts simultaneously, at global level, with other pressures, and tools for accounting on synergistic or antagonistic effects of different stressors, acting at multiple scales, are needed. Integration might be needed between climate change and other Pressures. Therefore, methodological framing proposed
here allows the enlargement of the analysis in terms of vulnerability to larger issues than climate change.

Quantification of either biophysical or social vulnerability (Pressures and Driving forces), as well as of State or Impacts, cannot avoid establishing thresholds of acceptability of loss of environmental functions, damage or social disruption. The present paper addresses one of the main challenges for both the “four spheres DPSIR model” and for the vulnerability research, which is to develop a unified conceptual framework and robust measures (Brooks, 2003, Adger, 2006).

References


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