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"Indicators of vulnerability and adaptive capacity": Towards a clarification of the science–policy interface

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Abstract: The issue of "measuring" climate change vulnerability and adaptive capacity by means of indicators divides policy and academic communities. While policy increasingly demands such indicators an increasing body of literature criticises them. This misfit results from a twofold confusion. First, there is confusion about what vulnerability indicators are and which arguments are available for building them. Second, there is confusion about the kinds of policy problems to be solved by means of indicators. This paper addresses both sources of confusion. It first develops a rigorous conceptual framework for vulnerability indicators and applies it to review the scientific arguments available for building climate change vulnerability indicators. Then, it opposes this availability with the following six diverse types of problems that vulnerability indicators are meant to address according to the literature: (i) identification of mitigation targets; (ii) identification of vulnerable people, communities, regions, etc.; (iii) raising awareness; (iv) allocation of adaptation funds; (v) monitoring of adaptation policy; and (vi) conducting scientific research. It is found that vulnerability indicators are only appropriate for addressing the second type of problem but only at local scales, when systems can be narrowly defined and inductive arguments can be built. For the other five types of problems, either vulnerability is not the adequate concept or vulnerability indicators are not the adequate methodology. I conclude that both the policy and academic communities should collaboratively attempt to use a more specific terminology for speaking about the problems addressed and the methodologies applied. The one-size-fits-all vulnerability label is not sufficient. Speaking of "measuring" vulnerability is particularly misleading, as this is impossible and raises false expectations.

1. Introduction

Vulnerability is a central concept in climate change research and policy. Article 4.4 of the United Nations Framework Convention on Climate Change (UNFCCC) calls on the developed country Parties to "assist the developing country Parties that are particularly vulnerable to the adverse effects of climate change in meeting costs of adaptation" (United Nations, 1992b). This article has triggered a substantial amount of research that assesses the vulnerability of countries as well as regions, sectors, communities and groups of people.

Recently, policy interest in vulnerability research has increased, because now that climate change impacts are being observed (IPCC, 2007), developing and implementing adaptation policy has become a policy priority. One particular challenge thereby is the design of an international regime that allocates global resources to the most vulnerable countries as suggested by Article 4.4. Information produced by vulnerability assessments is also meant to serve further policy purposes such as raising awareness of climate change and monitoring adaptation policy. Assessing vulnerability thus has moved from being an academic exercise to being a political necessity.

Vulnerability indicators are widely seen as the media of choice for bridging between academic work and political need. Political organisations often recommend the development of indicators and commission teams of consultants and academics to carry out this task. And indeed, indicators, by their very nature, seem to be useful media, because they synthesise complex state-of-affairs such as the vulnerability of regions, households or countries into a single number that can then be easily used by policy.

At the same time, there is an increasing body of literature that criticises many of the attempts that have been made at developing vulnerability indicators as not being scientifically sound or policy relevant (Eriksen and Kelly, 2006; Barnett et al., 2008; Klein, 2009). Similar criticism of indicators can be found in other domains such as human and sustainable development (Gudmundsson, 2003;

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Parris and Kates, 2003; Böhringer and Jochem, 2007). Judging from this literature, indicators seem to be a typical example of failed science–policy communication.

This paper argues that these opposing views result from two sources of conceptual confusion present in the academic and policy communities. First, there is confusion about what indicators are and what they can accomplish in the domain of climate change vulnerability, not the least because vulnerability and related concepts such as adaptive capacity and sensitivity themselves remain vague and inconsistently defined (Adger, 2006; Hinkel, 2008; Ionescu et al., 2009; Wolf et al., 2010). Furthermore, it is not clear what "measuring vulnerability" means and some authors even argue that vulnerability can, in principle, not be measured (Moss et al., 2001; Patt et al., 2008). Finally, the methodologies applied in the development of vulnerability indicators are often not presented transparently (Gallopin, 1997; Eriksen and Kelly, 2006; Klein, 2009).

Second, there is confusion with respect to the purpose of assessing vulnerability in general and indicating vulnerability in particular. Most policy and academic documents in-fact remain silent about the purpose for which the developed vulnerability indicators shall be used. Policy and research questions addressed are generally not stated or only vaguely so. This circumstance is particularly disconcerting because vulnerability assessments are said to be carried out for very different purposes ranging from identifying global mitigation targets to selecting local adaptation measures (Füssel and Klein, 2006; Smit and Wandel, 2006; Patt et al., 2008).

This paper addresses both sources of confusion in order to clarify the science–policy interface in the context of climate change vulnerability. Section 2 reviews the state-of-the-art of climate change vulnerability bringing in findings from recent conceptual work carried out in the context of the ADAM[1] and FAVAIA[2] projects. Section 3 then presents a rigorous conceptual framework of climate change vulnerability indicators and Section 4 applies it to review which deductive, inductive, normative and other arguments are available for developing vulnerability indicators. Next, Section 5 reviews the different purposes of indicating vulnerability and evaluates, for each purpose identified, to what extent vulnerability indicators are the right means for addressing it. Finally, the gap that remains between the intended purposes and what vulnerability indicators can accomplish is discussed in Section 6 and some concluding recommendations are given in Section 7.

2. Vulnerability

The conceptual state-of-the-art of the field of vulnerability to climate change can be described as "Babylonian confusion" (Janssen and Ostrom, 2006). There are many definitions of the term – Thywissen (2006), for example, lists 35 – and there is also a "bewildering array of terms" (Brooks, 2003) that either express similar ideas (*e.g.*, risk, sensitivity and fragility) or inversely similar ideas (*e.g.* resilience, adaptability, adaptive capacity and stability). All of these terms overlap in their meanings, however non-trivially so (Gallopin, 2006; Hinkel, 2008; Wolf et al., 2010). Furthermore, the diversity of definitions is accompanied by a similar diversity of methodologies for assessing vulnerability. Methodologies include participatory, simulation-model-based and indicator-based approaches and are applied to a great diversity of different systems, as well as spatial and temporal scales.

The plurality of definitions of and approaches to assessing vulnerability has led to intensive conceptual work that attempts to clarify concepts and methodologies. Glossaries have been compiled (*e.g.*, ISDR, 2004; IATF/DR, 2006; McCarthy et al., 2001; Thywissen, 2006; Parry et al., 2007), overarching frameworks developed (*e.g.*, Cutter, 1996; Jones, 2001; Brooks, 2003; Turner et al., 2003; Luers, 2005) and different types of approaches have been classified (*e.g.*, Timmerman, 1981; Kates, 1985; Kelly and Adger, 2000; Füssel and Klein, 2006; O'Brien et al., 2007; Füssel, 2007). A general discussion of definitions, methodologies and conceptual frameworks is beyond the scope of this paper. For recent summaries see Adger (2006), Eakin and Luers (2006) and Wolf et al. (2010).

To date, the conceptual work has, however, not resolved the terminological and methodological confusion associated with vulnerability and related concepts. Little agreement has been reached beyond that there are competing conceptualisations of vulnerability and that vulnerability is place-based and context-specific (Cutter et al., 2003).

Recent work carried out in the ADAM and FAVAIA projects addressed the conceptual and methodological confusion more rigorously than previous attempts by applying methods of linguistic analysis and formalisation (Hinkel, 2008; Ionescu et al., 2009; Wolf et al., 2010). The usage of vulnerability and related concepts was analysed in conceptual papers and case studies from the climate change, disaster risk, poverty and food security literature. Common elements that occurred in the usage were abstracted and represented formally. Both theoretical definitions as well as methodologies applied for assessing vulnerability were considered. This work comes to the following conclusions:

1. All definitions and methodologies analysed follow a common form in that vulnerability is *a measure of possible future harm*. The *measure of harm* refers to a value judgement on the "badness" of a state. Commonly used measures of harm are mortality, the number of people affected by floods and loss of ecosystem services. The *possible future* refers to the forward-looking aspect of vulnerability. Not current but future harm is of interest and, importantly, this future harm may or may not happen.
2. Beyond this common form and these two elements little more communality could be found in definitions. Scientific definitions and frameworks are generally not more precise than ordinary language definitions or our intuitive understanding of the concept.
3. Scientific definitions provide little, if any, guidance for designing methodologies for assessing vulnerability. Generally, there is ambiguity in making definitions operational due to the generality and vagueness of the terms involved in the definitions. As a result, methodologies are generally only loosely connected to the theoretical definitions that they make operational.
4. Since scientific definitions do not provide much guidance for assessing vulnerability, guidance must come from the specific case considered. Hence, methodologies for assessing (and indicating) vulnerability must be developed based on the specific research or policy question addressed instead of on general definitions.
5. Finally, due to the normative value judgement involved, making definitions operational, that is designing methodologies for assessing vulnerability, requires normative choice to be made. The meaning of harm needs to be defined for the specific case considered.

The vagueness in definitions and the associated "weak" link between definitions and methodologies can be illustrated with the

[1] Adaptation and Mitigation Strategies: Supporting European climate policy; http://www.adamproject.eu.

[2] Formal Approaches to Vulnerability Assessment that Informs Adaptation; http://www.pik-potsdam.de/favaia.

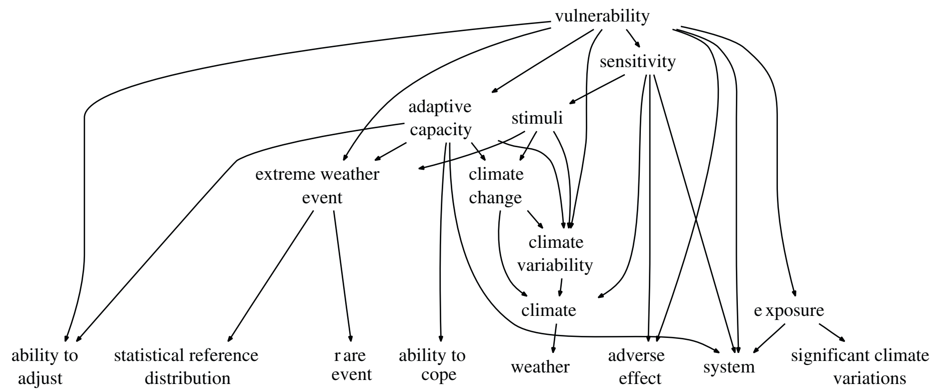

Fig. 1. The relations between the concept of vulnerability and its defining concepts as given in the Working Group 2 glossary of the IPCC Third Assessment Report. The arrows point from the defined concepts to the defining ones.

help of the definition of vulnerability developed within the Working Group II of the Intergovernmental Panel on Climate Change (IPCC), arguably the most authoritative one in the context of climate change. The Third Assessment Report (TAR) of the IPCC defines vulnerability as:

> "the degree to which a system is susceptible to, and 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 change and variation to which a system is exposed, its sensitivity, and its adaptive capacity" (McCarthy et al., 2001, p. 995).

One difficulty in making this definition operational arises from the circumstance that the defining concepts themselves are vague and difficult to make operational. Fig. 1 decomposes the IPCC definition on the basis of the definitions of the defining concepts given in glossary of the TAR (McCarthy et al., 2001, pp. 981–996). The arrows point from the defined concepts to the defining ones. The concepts at the bottom of the figure are those left undefined. In order for the IPCC definition to be clear, the "bottom" concepts would need to be clear, which is, however, not the case. The concepts "ability to adjust" or "ability to cope", for example, are hardly more precise than "vulnerability" itself. Furthermore, many of the defining concepts such as "adverse effect" or "significant climate variations" contain a strong normative or subjective connotation.

A second difficulty lies in the lack of clarity on how the defining concepts are combined, which is best illustrated by the second sentence of the above-cited definition. This sentence has been very influential in the design of methodologies for assessing vulnerability and often only this sentence is cited as being *the* IPCC definition. That the second sentence is, however, not a good definition can be easily illustrated by the attempt to define a car to be a function of tires, engine and coachwork. A "true" definition would have to name the form of the function. This misinterpretation has led to the circumstance that many assessments have focused on assessing the three arguments of this function (*i.e.* exposure, sensitivity and adaptive capacity) separately, paying less or no attention to how to combine these arguments. This combination is, however, essential just as is the way tires, engine and coachwork are combined in order to attain a car.

3. Vulnerability indicators

3.1. Measurement and indicators

Measurement is the systematic process of assigning a number to a phenomenon (*i.e.* to some thing we can observe). For example, the phenomenon "heat" can be measured by associating a number called temperature to it. By systematic I mean that the association needs to follow certain rules. Warmer phenomena, for example, should receive a higher number than colder ones. The application of different sets of rules leads to the different measurement scales (*e.g.*, ordinal, interval, and ratio).

Measurement thus is based on the notions of comparative or quantitative concepts, that is concepts that can take on different values. These concepts will be called *variables* (Bernard, 2000). Comparability is key to the notion of vulnerability (Ionescu et al., 2009; Barnett et al., 2008; Wolf et al., 2010). We either compare in time, that is we compare how one entity (*e.g.* a system, region or group of people) changes over time or we compare in space, that is between different geographic or social entities.

How can vulnerability be measured? Strictly speaking it cannot, because vulnerability does not denote an observable phenomenon (Moss et al., 2001; Patt et al., 2008). Vulnerability is a theoretical concept in opposition to, for example, heat or income which are observable ones. This distinction between observable and theoretical concepts has been subject to a lot of debate in philosophy of science (Stegmüller, 1974; Carnap, 1995). The bottom-line is that there is no clear cut and observability is a convention: if the members of a scientific discipline have agreed upon a simple and canonical way of measuring a concept, it is said to be observable. To give an example, there is not much debate about how to measure body height while there is about measuring intelligence or vulnerability.

Since vulnerability is a theoretical concept, it is more accurate to speak about making the concept operational instead of measuring it. Making a theoretical concept operational consists in providing a method (an operation) for mapping it to observable concepts; that method is then called the *operational definition* (Schnell et al., 1999; Bernard, 2000; Copi and Cohen, 2005). In the case of vulnerability, the operational definition is generally called the *methodology* of a vulnerability assessment. I will follow this usage here.

Indicators constitute one approach to making theoretical concepts operational. An *indicator* is a function from observable variables (Gallopin, 1997), called *indicating variables* to theoretical variables. The simplest kind of indicator is a *scalar indicator* which maps one observable variable to one theoretical variable. For example, the presence of a certain lichen specie (observable variable O) is often used to indicate air quality (theoretical variable T):

$$\text{scalar indicator}: O \rightarrow T$$

Note that in the literature, the term indicator is often used for referring only to the indicating variables rather than to the whole function. This usage is, however, misleading, because an observable variable only becomes and indicator when associated (by means of a function) to a further variable, the one to be indicated.

It is also important to note that indicators are "simple" functions. Often they are linear and they should always be monotonously increasing or decreasing. Non-monotonous functions would be misleading; *e.g.* we would not want certain lichen specie to indicate both high and low air quality.

Often, several indicating variables are needed for making a concept operational. A *composite indicator* or an *index* is an indicator that maps (or aggregates) a vector of observable variables to one scalar theoretical variable. The Human Development Index (HDI; UNDP, 1990), for example, maps values of the four observable variables life expectancy, adult literacy, mean years of schooling and income ($O_1, O_2, \ldots, O_n$) to the theoretical variable human development (T):

$$\text{composite indicator}: \begin{pmatrix} O_1 \\ O_2 \\ \vdots \\ O_n \end{pmatrix} \rightarrow T$$

Finally, a *vector-valued indicator* maps a vector of observable variables into a vector of theoretical variables:

$$\text{vector-}v\text{alued indicator}: \begin{pmatrix} O_1 \\ O_2 \\ \vdots \\ O_n \end{pmatrix} \rightarrow \begin{pmatrix} T_1 \\ \vdots \\ T_m \end{pmatrix}$$

Vector valued-indicators are often displayed in form of so-called spider diagrams or radar charts (OECD, 2008), which are diagrams of three or more variables represented on axis starting from one central point. See, for example, the "Water Poverty Index" (Sullivan, 2002) or the "Livelihood Vulnerability Index" (Hahn et al., 2009).

3.2. Two unique challenges involved in developing vulnerability indicators

For the purpose of this paper, I distinguish between three steps involved in the development of vulnerability indicators. For a broader discussion of steps involved in assessing vulnerability see Schröter et al. (2004) or Patt et al. (2008) and in developing indicators see UNEP (2001) and OECD (2008).

The first step is the *definition of what is to be indicated*. In the case of climate change vulnerability indicators, this would be *the vulnerability of an entity to climate change.* A wide array of different entities such as individuals, households, communities, ecosystems, regions, economic sectors and countries are considered. Generally, these entities can be conceptualised as socio-ecological systems (SES; Gallopín, 1991) or coupled human-environmental system (Turner et al., 2003), because vulnerability is determined by the interaction of a social (or human) and an ecological (or environmental) sub-system. Following this literature, I will use the term system as a synonym for entity. Defining the entity thus includes defining the system's boundaries.

The second step is the *selection of the indicating variables*. Technically speaking, this consists in defining the domain of the indicator function. A possible but not necessary next step is the *aggregation of the indicating variables*. This third step consists in defining the indicator function itself.

The development of vulnerability indicators in particular involves two unique challenges. The first challenge lies in the difficulty of exactly defining the vulnerable entity. On the one hand this is due to many assessments being interested in systems with wide system boundaries such as, for example, the vulnerability of a whole country (including its regions, economic sectors and social groups) to all climate related hazards (including both primary and secondary ones) and possibly other hazards. On the other hand, even local assessments targeting individuals or communities need to take into account the wide political, institutional, economic and social context that determines vulnerability, as expressed by the concept of "contextual vulnerability" (O'Brien et al., 2007).

The second unique challenge in developing vulnerability indicators is the forward-looking aspect of vulnerability. As discussed above, vulnerability indicators must indicate a possibility, *i.e.* some state that might or might not come about in the future (see also Patt et al., 2008; Ionescu et al., 2009). The "usual" indicators, however, indicate a state and not the potentiality of a future state. The HDI, for example, indicates the current state of development rather than the possibility of future development.

Due to this forward-looking aspect of vulnerability, developing a vulnerability indicator includes building a predictive model, a task similar to the case of developing a simulation model. In both cases, a function is built that, based on the observed present state, returns information on possible future states. The difference between the two approaches is one of complexity and the treatment of time. In the *indicator-based* approach the function (*i.e.* the indicator) is, by definition, simple (see above) and time-independent (in the sense that it does not contain time as an argument). A vulnerability indicator does not give us information on when in the future harm will occur. In the *simulation-model-based* approach the function (*i.e.* the simulation model) is complex and time-dependent, in the sense that it is a computer program representing a dynamical system that is iterated over time including feedbacks and non-linearity.

It is thus important to distinguish between:

1. *Harm indicators*, which are indicators that evaluate a state of an entity based on normative judgements of what constitutes a good or bad state. These indicators do not include the forward-looking aspect.
2. *Vulnerability indicators*, which are indicators of possible future harm. These indicators include both the forward-looking aspect as well as the normative aspect of defining harm.

4. Which arguments are available for developing vulnerability indicators?

In principle, there are three kinds of substantial arguments available for developing vulnerability indicators: (i) *deductive* ones, which are based on existing theory, (ii) *inductive* ones, which are based on data of both the indicating variables as well as observed harm, and (iii) *normative* ones, which are based on value judgements. A fourth kind but *non-substantial* argument is also available, which is based only on data of the indicating variables and thus irrespective of knowledge on vulnerability. Generally, developments of indicators combine the different types of arguments. This section explores which deductive, inductive, normative and non-substantial arguments are available for the case of developing vulnerability and harm indicators and shows, with the help of a couple of examples from the literature, how these arguments are typically combined.

4.1. Deductive arguments

Using deductive arguments in the development of vulnerability indicators means using available scientific knowledge in form of frameworks, theories or models about the vulnerable system of interest in the selection and aggregation of indicating variables. By framework I mean a set of concepts, by theory a set of general relations that hold amongst these concepts and by model a set of more specific relations (Ostrom, 2005). The capability theory of Sen (1983), for example, suggests that the ability to participate in political activities is important for reducing poverty. From this theory one can deduce that variables that measure non-participation in policy may indicate vulnerability to poverty.

What frameworks, theories and models are available for developing climate change vulnerability indicators? For SESs in general there are no theories or models available, but only some general frameworks such as those of Turner et al. (2003) and Ostrom (2009). These framework are abstract and only provide some rough guidance for selecting potential indicating variables but not for aggregating them. Frameworks in general do not provide arguments for aggregation, because they say nothing about the processes through which the different variables interact and may lead to future harm and thus cannot capture the necessary forward looking aspect of vulnerability. A widely used approach therefore is to separate SESs into their social and bio-physical sub-systems.

For the social sub-system, there is no general, let alone global, theory available either, but there are some frameworks that are frequently used. Two prominent examples are the "root causes" of vulnerability put forward by Blaikie (1994) and the eight determinants of adaptive capacity introduced by the IPCC (Smit et al., 2001) and further elaborated by Yohe and Tol (2002) and Adger et al. (2007). Again, these frameworks only help to select indicating variables and not to aggregate them. Furthermore, the deductive arguments for selecting indicating variables built on the available frameworks are rather weak with respect to climate change because they are based on the climate change unspecific idea that the indicating variables indicate the current (positive or negative) potential to encounter or prevent harm in the future. Prominent indicating variables used are GDP and other types of "capitals" such as technology, education and infrastructure. The indicators developed are generally called adaptive capacity or social vulnerability indicators.

At local scales and for specific social systems, there is, of course, the whole of social science research offering a great pool of local and contextualised theories and models. Sen's above-mentioned concept of entitlement, for example, has been widely applied (Bohle et al., 1994; Cutter, 1996; Hewitt, 1997; Kelly and Adger, 2000) and, more recently, the concept of social capital has received attention (Adger, 2003; Pelling and High, 2005). Another example is provided by Hahn et al. (2009), who surveyed 220 households in Mozambique for developing a "Livelihood Vulnerability Index". The indicating variables were selected deductively based on the literature, in particular related to the Sustainable Livelihood Approach (Scoones, 1998). Again, these local level theories only provide arguments for the selection and not the aggregation of indicating variables.

For the bio-physical sub-system there is also no general theory available, but there are specific dynamical (computer) models for some sectors (mostly agriculture, forestry and water) as well as so-called integrated assessment models that include several sectors in a stylised way. These models can, however, not be used for building vulnerability indicators, because they are complex and thus cannot be collapsed into "simple" indicator functions. If those models are used for assessing vulnerability they are applied in combination with harm indicators in the sense of the "classical top-down" simulation-model based approach (Dessai and Hulme, 2004): Possible future states of the vulnerable system are first simulated and then evaluated based on harm indicators. No vulnerability indicators are involved in this approach.

One prominent example of this approach is the project ATEAM (Advanced Terrestrial Ecosystem Analysis and Modelling) that applied a suit of ecosystem and hydrology models together with a harm indicator to assess the vulnerability of European regions relying on ecosystem services (Schröter et al., 2005). Another example is Moss et al. (2001) who used an integrated assessment model and scenarios to produce future evolutions of the state variables of the global SES and then applied harm indicators to each evolution. It must be noted that simulation-model based approaches are sometimes wrongly referred to as vulnerability indicators in the literature. The approach of Moss et al. (2001), for example, is labelled "vulnerability-resilience indicators".

Finally, there is another albeit weak form of deductive argument, which is *expert judgement*. This is actually the only deductive argument applied for the aggregation of indicating variables. Brooks et al. (2005), for example, attempted to aggregate 11 indicating variables by expert judgement via a focus group exercise. A robust result could, however, not be achieved; different experts aggregated differently. The approach of Brooks et al. (2005) will be discussed in more detail in the next section.

In summary, deductive arguments are only available for selecting indicating variables and not for aggregating them. Most approaches in the literature apply this argument as the first step in their methodology. Further examples are given in the next sections.

4.2. Inductive arguments

Using inductive arguments in the development of vulnerability indicators means using data for building statistical models that explain observed harm through some indicating variables. For example, if there is data that shows that heat-wave mortality was highest in low-income neighbourhoods, one can induce that the variable low income may generally indicate vulnerability to heat-waves.

Which statistical models can be developed in the case of climate change vulnerability? Generally, the development of statistical models is only promising if two conditions are met: (i) systems can be narrowly defined in the sense that they can be described using few variables, and (ii) sufficient data is available. Both conditions are, however, rarely met in the case of climate change vulnerability.

The first condition is rarely met because, as pointed out in the last section, the subject matter of climate change vulnerability assessments is usually a complex SES, which cannot, by definition, be described in simple terms with few variables.

With respect to the second condition, it is important to note that data for both the indicating variables as well as for experienced harm is needed. Generally, there is, however, little data on experienced harm. Furthermore, there is only data on harm caused by fast-onset and not slow-onset hazards, since we are just beginning to observe and monitor impacts of slow-onset climate change. The most commonly used harm indicators are economic loss, mortality, people affected, people injured or left homeless (see, *e.g.*, the Emergency Events Database EM-DAT at http://www.emdat.be/). Most data is only available at the national level. Collecting data is of course a possibility but, since it requires a lot of resources, it is only feasible at the local level.

Two largely unsuccessful attempts to inductively build national-level vulnerability indicators are given by Brooks et al. (2005) and Tol and Yohe (2007). Brooks et al. (2005) first used deductive arguments (*i.e.* expert judgement and literature) as well as the non-substantial argument of data availability (discussed further below) to select a short list of 46 potential indicating variables. The list was then reduced inductively. Using mortality as the harm indicator, 11 "key vulnerability indicators" that correlated with mortality at the 10% significance-level were selected. Finally, as mentioned above, it was attempted to aggregate the remaining 11 variables deductively by expert judgement, which however did not deliver a robust result.

Tol and Yohe (2007) follow a similar approach and first deductively selected an initial list of 34 indicating variables based on the above-mentioned eight determinants of adaptive capacity. Six alternative harm indicators such as number of people affected by natural disasters, infant mortality and life expectancy were selected for which data was available in the EM-DAT database. 24 of the 34 indicating variables were found to be statistically not significant. Amongst the statistical significant ones, different ones were found significant for different harm indicators. The authors conclude that the results suggest that there are no universal indicators of vulnerability or adaptive capacity on the national level; mechanisms that cause harm vary from case to case and hazard to hazard.

In summary, induction is feasible when the systems can be narrowly defined by few variables and sufficient data – for both the indicating as well as harm variables – is either already available or can be collected. These conditions are only fulfilled when considering the vulnerability of a specific system to a specific stimulus in a local context.

4.3. Normative arguments

Using normative arguments in the development of indicators means using (individual or collective) value judgements in the selection and aggregation of indicating variables. The indicating variables of the above mentioned HDI, for example, are selected based on the normative argument that human development should be characterised by the three dimensions of longevity, knowledge and income. The indicating variables are then aggregated based on the normative argument that each dimension should be equally important in characterising the state of development (UNDP, 1991, 1993).

The latter, normative argument of *equal weights* is frequently used in aggregation. Aggregating the indicating variables arithmetically based on equal weights implies that the indicating variables are perfect substitutes, which means that a low value in one variable can be compensated by a high value in another (Desai, 1991; Sagar and Najam, 1998; Kaly et al., 1999; Cutter et al., 2003; Hahn et al., 2009). Alternatively, the dimensions could be multiplied, suggesting that a low value in one dimension cannot be fully substituted by a high value in another dimension. The above-mentioned "Livelihood Vulnerability Index" of Hahn et al. (2009), for example, aggregates based on the normative argument of equal weights.

In the context of climate change vulnerability, normative arguments are, however, predominantly applied in the development of harm and not vulnerability indicators, because in the latter case it is difficult to separate the forward-looking aspect of vulnerability from the normative one. Harm indicators, by definition, only deal with the normative aspect of defining what constitutes a good state. In vulnerability assessments, harm indicators are thus generally applied in combination with simulation-models that take care of the forward-looking aspect by projecting possible future states which then are evaluated using harm indicators (*e.g.*, Moss et al., 2001; Schröter et al., 2005).

Defining harm is generally not a straightforward exercise because harm has multiple dimensions between which trade-offs are involved. If we consider a community vulnerable to coastal flooding, for example, important dimensions are, people affected by floods, wetlands lost, damage cost and adaptation cost. Aggregation is further complicated because different stakeholders usually value the dimensions differently.

One way of dealing with these issues is to directly involve stakeholders in the aggregation. The above mentioned ATEAM project, for example, involved stakeholders for weighing the different dimensions of the high-dimensional output of ecosystem and hydrology models, leading to one aggregated number that indicates the "goodness" of each ecosystem service (Schröter et al., 2005). Another way of dealing with this issue is, as some authors argue (*e.g.*, Kelly and Adger, 2000; Hinkel and Klein, 2007, 2009), not to aggregate and to use vector-valued indicators.

4.4. Non-substantial arguments

A couple of further arguments are also applied in the development of vulnerability indicators. These arguments will be called *non-substantial* here, because they are not based on knowledge about vulnerability (as are the deductive and inductive ones) nor on value judgements (as are the normative ones) but only on the structure of the data of the indicating variables. Note that these arguments are different from the inductive ones described above, since the inductive ones also make use of data for harm in the attempt to build a model of the vulnerable system that explains observed harm. On the contrary, non-substantial arguments do not reveal anything about how the indicating variables combine in the process of causing vulnerability.

The argument of *co-variation* or *multi-variation* is frequently used to reduce the number of indicating variables. Principle component analysis (PCA) and similar methods for multivariate data analysis are applied to reduce the number of dimensions (here, the number of indicating variables) needed to describe the state of the system whose vulnerability is to be indicated. It is important to note that multivariate analysis does, however, not reveal anything about the influence of the indicating variables on the theoretical variable (here, vulnerability) to be indicated (OECD, 2008).

A prominent example using this argument is the "Social Vulnerability Index" developed by Cutter et al. (2003) for the 3141 counties of the United States. The authors first selected more than 250 variables deductively based on literature. This list was then narrowed down to 42 variables by getting rid of redundant variables through multicollinearity analysis. Finally, PCA was applied and 11 components explaining 76.4 percent of the variance were identified.

A further argument used in the aggregation is the one of *robustness*, which refers to an index being robust against the usage of alternative methods of aggregation. Robustness is tested by applying alternative methods of aggregation to the data of indicating variables and evaluating the resulting rankings. For the HDI index, *e.g.*, it was shown that the index is not very sensitive with respect to aggregating geometrically or arithmetically (UNDP, 1993).

Finally, the argument of *data availability* plays a major role in the development of indicators in general and vulnerability indicators in particular. Niemeijer (2002) uses this argument for differentiating between deductive approaches for which "data availability is the central criterion" and those for which it is not, calling the former *data-driven* and the later *theory-driven* approaches.

5. Fit for purpose

5.1. Purposes of assessing vulnerability

Up to this point, the development of vulnerability indicators was discussed without reference to the problems that these indicators are meant to solve. Indicators serve, just as any other method, the purpose of solving a problem, or more specifically, of addressing a policy or research question. Hence, the potential of indicators can only be discussed adequately in the light of these problems. This section therefore briefly reviews what is said in the literature about the purposes of developing indicators and assessing vulnerability.

On the most general level, the purpose of indicators is to describe the state of affairs of a complex system in simple terms (Hammond et al., 1995; Niemeijer, 2002; Barnett et al., 2008). For example, we use indicators of biodiversity to describe the state of complex ecosystems or indicators of human development to describe the state of complex socio-economic systems. Since indicators reduce complexity, they are, by their very nature, useful to communicate complex issues from science to policy or the general public. Indicators are often particularly designed for policy making or monitoring the performance of policy measures (Hammond et al., 1995; Gudmundsson, 2003; Niemeijer and de Groot, 2008; Barnett et al., 2008). Many policy documents, in fact, directly suggest the development of indicators. A prominent example is the Agenda 21 stating that ''indicators of sustainable development need to be developed to provide a solid basis for decision making'' (United Nations, 1992a, Chapter 40.4).

The role of indicators in policy making,however, has been subject to a lot of critique. Evaluations of indicators in the domains of sustainability, environment and vulnerability conclude that most methodologies applied are not scientifically sound (Parris and Kates, 2003; Eriksen and Kelly, 2006; Barnett et al., 2008) and may actually mislead policy (Böhringer and Jochem, 2007). Indicators are often only used ''symbolically'' for legitimising decisions that would have been taken anyway or the absence of indicators may be used for justifying inaction (Gudmundsson, 2003).

The purpose of vulnerability assessments is, on the most general level, to inform decision making (Schröter et al., 2004; Patt et al., 2008). The term assessment is thereby used in opposition to research to express that problem-solving is driven by the purpose ''to inform policy and decision-making, rather than to advance knowledge for its intrinsic value'' (Weyant et al., 1996, p. 374).

Turning to policy documents, little can, however, be learnt about the specific purposes for which vulnerability indicators are meant to be used. The current Impact Assessment accompanying the European Commission's White Paper on Adaptation, for example, contains a section labelled ''The need for indicators of vulnerability'' (European Commission, 2009, pp. 15–19). In this section, however, nothing more is said beyond that vulnerability indicators are needed ''to help preparing EU-wide adaptation policy'' (p. 18).

A similar lack of specificity is found in the United Nation's Barbados Programme of Action (BPOA; United Nations, 1994), which calls for ''the development of vulnerability indices and other indicators that reflect the status of Small Island Developing States'' (paragraph 113 on p. 44). The remainder of the document remains, however, silent about the purpose for which these indicators shall be used. The only policy documents that are, to my knowledge, more explicit on purposes are the proposals to use vulnerability indicators as a tool for allocating adaptation funds to ''particularly vulnerable countries'' in the context of the UNFCCC (Klein, 2009).

In the academic literature, a similar lack of specificity about the purposes of assessing vulnerability can be observed. Vulnerability assessment case studies generally say little or nothing on the policy or research questions that they address beyond calling themselves ''vulnerability assessments'' in the first place (Hinkel, 2008; Wolf et al., 2010). Only the conceptual literature is more explicit and makes a few general distinctions (Füssel and Klein, 2006; Smit and Wandel, 2006; Patt et al., 2008). Drawing on this literature, the following six purposes for assessing vulnerability can be identified: (i) to identify mitigation targets; (ii) to identify particularly vulnerable people, regions or sectors; (iii) to raise awareness of climate change; (iv) to allocate adaptation funds to particular vulnerable regions, sectors or groups of people; (v) to monitor the performance of adaptation policy; and (vi) to conduct scientific research. The next section discusses to what extent vulnerability indicators can meet these purposes.

5.2. Are vulnerability indicators fit for purpose?

5.2.1. Are vulnerability indicators the right means to identify mitigation targets?

Clearly, the answer is no. Identifying mitigation targets is a question of global scope and, as shown in Section 4, no general deductive or inductive arguments are available for developing vulnerability indicators at this scale. The identification of mitigation targets is a matter of developing and applying earth system and global integrated assessment models. These models are complex and cannot be collapsed into a simple indicator function. Instead, these models are applied to project possible future impacts of given mitigation targets. Normative trade-offs between the many dimensions of the projected impacts are important, but addressing these is a matter of developing harm and not vulnerability indicators.

5.2.2. Are vulnerability indicators the right means to identify particularly vulnerable people, regions or sectors?

At local scales and when systems can be narrowly defined by few variables, the answer is yes. Only under these conditions can inductive arguments be build based on data of observed harm in order to find out which people or communities are most vulnerable.

At larger scales, the answer is no. Induction has not revealed much so far and is not likely to do so in the future, due to the complexity of systems involved, the many variables needed to describe them and the little data available. The only deductive arguments available at larger scales are those based on general vulnerability frameworks which, however, only help to select indicating variables and not to aggregate them into an index. Hence, simulation-model based approaches are, as stated above, the only available methodologies for assessing vulnerability at larger scales. Collapsing these complex models into simple indicator functions, however, would mean that one disregards the more advanced knowledge available in form of these models.

5.2.3. Are vulnerability indicators the right means to raise awareness of climate change?

The direct answer is no, because the problem of raising awareness of uncertain climate change is primarily a problem of risk communication. Risk communication is a social and institutional process (Renn, 2008), which (tautologically) must be addressed by risk communication methods. The information used is only one of many factors that play a role in this process and often other factors such as the charisma of the communicator or the stakeholders' personal experience with climate-related extreme events are more important than the information itself (Hinkel et al., 2009).

Furthermore, what kind of information is useful in the risk communication process is subject to ongoing research and there are no general answers (see, *e.g.*, Bostrom et al., 1994; Patt et al., 2005). What can be said at the general level is that information is only considered useful by stakeholders if it is relevant to their needs (Cash et al., 2003). Given the vagueness of the concept of vulnerability and the rather complex idea it expresses (*i.e.* possible future harm) it seems that simpler concepts such as climate change itself (*e.g.*, increase of average temperature) or experienced harm (*e.g.*, the number of people that died during a heat wave) are likely to be more relevant in the risk communication process. One interesting insight gained from the final stakeholder workshop of the above-mentioned ATEAM project is that stakeholders were not interested in the developed adaptive capacity indicator, because they felt that they could better judge for themselves on their ability to respond (Schröter et al., 2004).

5.2.4. Are vulnerability indicators the right means to allocate adaptation funds to particular vulnerable people, regions or sectors?

Again, it must be emphasised that adaptation funds allocation is a much wider problem than the one of designing an allocation algorithm. The primary problem is not one of science developing this algorithm but one of stakeholders creating an appropriate institution for the allocation. What kind of institution is appropriate and whether a vulnerability indicator may serve as allocation algorithm thereby are questions that cannot be answered in the general.

If we consider, for example, the global problem of allocating adaptation funds in the context of the UNFCCC to the ''most vulnerable'' countries, the answer is no, indicators are not the right means of doing so. As stated earlier, there are no inductive arguments available at this scale and the available deductive arguments based on frameworks only help to select indicating variables and not to aggregate them. Given the plurality of existing frameworks and possible interpretations thereof, even the selection of indicating variables would, however, be contestable from a scientific point of view. It is thus more than likely that any indicator developed would be attacked by those Parties that are not happy with their vulnerability score attained under the particular indicator. Hence, the problem of global adaptation funds allocation under the UNFCCC is one of negotiating a normative agreement amongst the Parties of the Convention (see also, Klein, 2009). Hiding this problem of negotiation behind the label ''developing vulnerability indicators'' is misleading because it raises the false hope that research could potentially solve the problem which in turn may only delay the negotiation.

If we consider the allocation of adaptation funds on a national level, I would also answer no. As argued above, there is already more advanced knowledge available on the climate issues a country is facing (*e.g.*, through simulation-model based assessments, community-based vulnerability assessments or the National Adaptation Programmes of Actions). Vulnerability indicators would not reveal more but rather disguise what is known. Countries should address the known issues by negotiating national priorities and developing issue-specific programmes and projects.

5.2.5. Are vulnerability indicators the right means to monitor adaptation policy?

The preliminary answer is no; but again, more specificity is needed. Adaptation is, similarly to vulnerability, a vague and general concept. In most instances, adaptation remains a matter of social learning involving many decision makers on different scales with differing perceptions (Hinkel et al., 2009). Before indicators can be developed, clarity is needed on the specific purpose of an adaptation policy. Indicators cannot be developed for adaptation policy in general. The relevant policy fields need to be identified and policy goals and targets need to be set.

If goals and targets have been set, the subsequent problem of monitoring adaptation policy performance may be addressed. The indicators used for this purpose, would, however, be harm and not vulnerability indicators. The successful outcome of adaptation policy is that less harm is observed in the future, which is why harm indicators are often called *outcome indicators* in this context. Since the outcomes of adaptation policy can, in most cases, only be observed in the far future, it has been suggested that *process indicators* shall be used to monitor the process of adaptation itself. The indicators used for this purpose would also not indicate vulnerability but rather the institutional stages of the adaptation process (*e.g.*, whether a heatwave emergency management plan has been put in place or not).

5.2.6. Are vulnerability indicators the right means to conduct scientific research?

In my opinion, the answer is no. Since research is an enquiry process directed towards answering open questions, its success depends on the clarity of the research questions formulated. Labelling research ''assessing vulnerability'' or ''developing vulnerability indicators'' is, given the plurality of scales, systems and questions involved, too unspecific and disguises what is actually done. This lack of specificity is, in my opinion, to a large extent responsible for the Babylonian confusion around the concept of vulnerability that prevails in the scientific community.

This confusion can only be alleviated by the usage of more specific labels. The above mentioned example of developing a heatwave vulnerability index, for example, could more adequately be labelled by the research question underlying it, that is: Which social factors can explain heatwave mortality? To give another example, the above mentioned work by Brooks et al. (2005) is titled ''The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation''. A more specific title such as ''Can mortality due to climate-related disasters be explained by national-level socio-economic variables?'' would represent the papers content more accurately and would thus improve the sharpness of scientific communication, a step necessary for advancing the field of climate change impacts and adaptation beyond the Babylonian confusion.

6. Discussion

In 5 of the 6 problems that vulnerability assessments are meant to address according to the literature, it is found that vulnerability indicators are not appropriate methodologies. A first eye-catching reason why they are not appropriate is that the primary problems faced are not ones of assessing vulnerability. In those cases, the term vulnerability is used as an unspecific proxy for addressing much wider research and policy questions such as communicating risk or negotiating normative agreements, without, however, calling these by their proper names.

This circumstance is, in my opinion, the legacy of the early IPCC work which focused on mitigation and global impact assessment. In this context, few, well-formulated or at least implicitly clear research questions were addressed such as: How dangerous are the impacts of climate change and certain mitigation targets? The usage of the three components of the IPCC definition for assessing vulnerability made sense in that they follow the global, top-down line of thought: First, climate models are run to assess the exposure, then damage functions or impact models are applied to assess the sensitivity of the exposed entities and finally the potential impacts thus attained are ''corrected'' by assessing adaptive capacity.

In the meantime, a stronger focus on adaptation has emerged and a much wider array of questions on all scales are being addressed. This shift in focus has, however, been insufficiently reflected in the terminology used. The decomposition of vulnerability into the components exposure, sensitivity and adaptive capacity is not necessarily adequate for the much wider array of questions addressed today and should certainly not be taken as a blue-print for assessing or indicating vulnerability. The differences between these components are increasingly blurred the more one moves away from the global, top-down and model-based assessments. This is illustrated by the difficulties that many indicator-based assessments have in trying to decide to which of these three components indicating variables should be attributed to. Brooks et al. (2005), for example, report that experts in a focus group asked to attribute lists of indicating variables to either vulnerability or adaptive capacity were largely undecided.

The first necessary step in clarifying the science–policy interface therefore is to be more explicit and specific about the problems addressed. The one-size-fits-all label ‘‘assessing vulnerability’’ is not sufficient. A terminology must be applied that goes beyond the concepts used in the IPCC definition and that is specific enough to convey the diversity of problems addressed and methods applied. Interestingly enough, a recent review of sustainable development indicators comes to similar conclusions (Parris and Kates, 2003).

A second reason why vulnerability indicators are not appropriate for addressing some of the policy problems named above is the lack of deductive arguments for aggregating indicating variables and the lack of inductive arguments at larger scales. This paper thus confirms findings of previous studies (*e.g.* Barnett et al., 2008) that indicator-based approaches are only appropriate at local scales and when systems can be narrowly defined. Only then is it possible to describe entities by few variables and thus to develop an inductive argument. Furthermore, local indicators cannot be generalised, because vulnerability is context specific (O’Brien et al., 2007) and factors that create adaptive capacity are different for different climate stimuli (Tol and Yohe, 2007).

Even at local scales two dilemmas remain. The first one pertains to indicators in general. One one hand, we use indicators because issues are complex and indicators reduce this complexity by describing complex systems in simple terms, at best in terms of single numbers. On the other hand, the very meaning of complexity is non-reducibility (Waldrop, 1992). For complex systems, theories and models are often scarce, uncertain or non-linear. Indicators, however, are simple, mostly linear models. Indicators can therefore, by their very nature, not capture surprise, which is particularly disconcerting in the domain of climate change, because non-linearity, thresholds or so-called ‘‘tipping points’’ are essential features of the climate problem (*e.g.*, Lenton et al., 2008).

A second dilemma pertains to climate change vulnerability, in particular. As shown here, indicators are best applicable when systems can be well and narrowly defined. The systems considered in the context of climate change vulnerability are, however, generally not of this kind. System boundaries are often difficult to establish and need to be continuously redefined during the course of an assessment (Eriksen and Kelly, 2006; O’Brien et al., 2007). The problem of assessing vulnerability is a so-called ‘‘wicked problem’’ (Rittel and Webber, 1973), because there is ambiguity on what exactly the problem to be solved is and no canonical solution exists.

In face of these dilemmas, I recommend that if vulnerability indicators are to be developed, they should only serve as high-level entry points to further more detailed information behind. Since indicators reduce complexity, they can be interpreted in a variety of different ways and background information is necessary to prevent misinterpretation. The different types of arguments used in developing indicators should be made transparent. In particular, normative arguments should be made explicit and be based on the preferences of relevant stakeholders. Finally, due to the inherent ‘‘wickedness’’ of the task, any vulnerability indicator would need to be updated regularly, based on new research findings.

7. Conclusion

This paper first developed a rigorous conceptual framework for speaking about vulnerability indicators. A vulnerability indicator indicates possible future harm and is a function which maps observable or indicating variables to theoretical variables denoting vulnerability. Since vulnerability refers to future and not present harm, this function must include a predictive model. In contrast to simulation-models, the indicator model is simple (often linear) and not explicit in time. Vulnerability indicators must also be distinguished from harm indicators which do not include this forward looking aspect but only aggregate the multiple dimensions of an entity’s state based on value judgements.

The framework was then applied to analyse which scientific arguments are available for developing vulnerability and harm indicators. In principle, four kinds of arguments are made: (i) deductive ones based on theory, (ii) inductive ones based on data for both harm and indicating variables, (iii) normative ones based on value judgements, and (iv) non-substantial ones based on data for only the indicating variables. Developments of indicators usually combine these four types of arguments.

It was found that deductive arguments are only available for selecting indicating variables and not for aggregating them. Inductive arguments are only available at local scales when systems can be well and narrowly defined by few variables. At larger scales, inductive arguments can generally not be built because the systems considered are complex socio-ecological systems which cannot be described by few variables and for which little data is available. If vulnerability is assessed at larger scales, this is a matter of first applying simulation-models to project future states of the vulnerable system and then applying harm indicators to evaluate these states. Confusion arises because these approaches are sometimes wrongly called vulnerability indicators in the literature. Normative arguments are generally only applied in the development of harm and not vulnerability indicators. Non-substantial arguments are frequently applied in the aggregation. These arguments, however, do not reveal anything about the processes that cause vulnerability but only summarise the information contained in the data of the indicating variables.

Finally, this availability was opposed with the types of problems vulnerability indicators are meant to address. In the literature, vulnerability assessments are said to be carried out for the following six purposes: (i) to identify mitigation targets; (ii) to identify vulnerable entities; (iii) to raise awareness; (iv) to allocate adaptation funds; (v) to monitor adaptation policy; and (vi) to conduct scientific research. It was found that vulnerability indicators are not the appropriate methodology for 5 of these 6 purposes. Vulnerability indicators may be appropriate to identify vulnerable people, regions or sectors at local scales when systems can be narrowly defined and hence deductive arguments are available for selecting indicating variables and inductive ones for aggregating them. For the other purposes, either vulnerability is not the adequate concept or, in the cases that it is, indicator-based approaches are not the appropriate methodology.

The general conclusion that can be drawn from the work presented is that both the policy and academic communities should collaboratively aim to make the problems addressed and the methodologies applied in the context of climate change vulnerability and adaptation more explicit. To this end, a more specific terminology needs to replace the vague and unspecific terminology used in the context of the IPCC definition of vulnerability. The-one-size-fits-all label ‘‘vulnerability’’ is not suitable, because it disguises the wealth of different types of problems addressed and methods applied. The conceptual work on vulnerability, in particular the quest for a universal definition of vulnerability and associated concepts, should be given up in favour of using the existing terminology of the social sciences (and extending it where needed) to describe problems and methods as specifically as possible.

More specificity is also needed for speaking about vulnerability indicators in particular. Speaking of ‘‘measuring vulnerability’’ should be avoided, as this is impossible and raises false expectations. More caution should be taken not to call impact or harm indicators vulnerability indicators. The different types of arguments involved in assessing vulnerability should be made explicit and cleanly separated from each other. In particular, normative arguments should be separated from inductive and deductive ones. The framework developed in this paper provides a more differentiated terminology that can be be applied towards these ends.

Whether, and what kind of, indicators are useful for climate change adaptation policy remain open questions. Before these questions can be addressed, work is needed to spell out the climate relevant policy fields and to define goals and targets. Problems should thereby be defined as narrowly as possible, for the reasons named above. Given the novelty of the issues there is a need to experiment and learn. Policy goals, targets and indicators need to be evaluated and refined frequently.

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