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Vulnerability: A generally applicable conceptual framework for climate change research

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Abstract

The term 'vulnerability' is used in many different ways by various scholarly communities. The resulting disagreement about the appropriate definition of vulnerability is a frequent cause for misunderstanding in interdisciplinary research on climate change and a challenge for attempts to develop formal models of vulnerability. Earlier attempts at reconciling the various conceptualizations of vulnerability were, at best, partly successful. This paper presents a generally applicable conceptual framework of vulnerability that combines a nomenclature of vulnerable situations and a terminology of vulnerability concepts based on the distinction of four fundamental groups of vulnerability factors. This conceptual framework is applied to characterize the vulnerability concepts employed by the main schools of vulnerability research and to review earlier attempts at classifying vulnerability concepts. None of these one-dimensional classification schemes reflects the diversity of vulnerability concepts identified in this review. The wide range of policy responses available to address the risks from global climate change suggests that climate impact, vulnerability, and adaptation assessments will continue to apply a variety of vulnerability concepts. The framework presented here provides the much-needed conceptual clarity and facilitates bridging the various approaches to researching vulnerability to climate change.

Keywords: Climate change; Conceptual framework; Global environmental change; Integrative research risk assessment; Terminology; Vulnerability

1. Introduction

The ordinary use of the word 'vulnerability' refers to the capacity to be wounded, i.e., the degree to which a system is likely to experience harm due to exposure to a hazard (Turner II et al., 2003). The scientific use of 'vulnerability' has its roots in geography and natural hazards research but this term is now a central concept in a variety of other research contexts such as ecology, public health, poverty and development, secure livelihoods and famine, sustainability science, land change, and climate impacts and adaptation. Vulnerability is conceptualized in very different ways by scholars from different knowledge domains, and even within the same domain. For instance, natural scientists and engineers tend to apply the term in a descriptive manner whereas social scientists tend to use it in the context of a specific explanatory model (O'Brien et al., 2004a; Gow, 2005).

More than 20 years ago, Timmermann (1981) posited that "vulnerability is a term of such broad use as to be almost useless for careful description at the present, except as a rhetorical indicator of areas of greatest concern". Liverman (1990) noted that vulnerability "has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility, and risk". I could easily add exposure, sensitivity, coping capacity, criticality, and robustness to this list. For a recent overview of definitions of 'vulnerability', see Kasperson et al. (2005, Box 14.1). This paper assumes that there is no single 'correct' or 'best' conceptualization of vulnerability that would fit all assessment contexts. Instead, the diversity of

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conceptualizations is seen primarily as a consequence of the term 'vulnerability' being used in different policy contexts, referring to different systems exposed to different hazards.

Vulnerability represents a "conceptual cluster" for integrative human–environment research in the sense of Newell et al. (2005). The existence of competing conceptualizations and terminologies of vulnerability has become particularly problematic in climate change research, which is characterized by intense collaboration between scholars from many different research traditions, including climate science, risk assessment, development, economics, and policy analysis. This collaboration must be based on a consistent terminology that facilitates researchers from different traditions to communicate clearly and transparently despite differences in the conceptual models applied (Laroui and van der Zwaan, 2001). Newell et al. (2005) emphasize that "Team members must be prepared to spend a significant amount of time in *detailed* discussions of the meaning of words" (p. 303, emphasis in the original text), paying particular attention to the "ever present danger, in attempts to develop a shared conceptual framework, [...] of failing to recognise homonyms and the confusion that they cause" because a "common language may still hide divergent assumptions" (Pickett et al., 2005, p. 304).

Let me illustrate the problem by a hypothetical question: "Which of two regions is more vulnerable to climate change and variability: Florida or Tibet?" Different scholars may reasonably provide different answers to this question. Many of them will suggest that Tibet is more vulnerable because it has less resources to cope with whatever threats climate change might bring about, it has less potential to diversify its income base, and it is already stressed by political tensions. Others might highlight Florida's vulnerability, emphasizing its low elevation that makes it highly susceptible to sea-level rise, its current exposure to hurricanes and the severe damages caused by them, and its present climate being rather warm already. Some scholars may refrain from giving an answer unless provided with detailed, preferably probabilistic, scenarios of regional climate change and sea-level rise. Still others might argue that this question is not relevant at all, given the huge differences in climate, topography, and socio-economic conditions between these two regions. I argue that a meaningful consideration of this question requires a clear specification of the applied vulnerability concept, which depends on the context and purpose of the vulnerability assessment.

This paper presents a conceptual framework and a terminology of vulnerability that enables a concise characterization of any vulnerability concept and of the main differences between different concepts, thereby bridging the gap between various traditions of vulnerability research. This work is modelled to some degree on Grimm and Wissel (1997), who presented "an analysis of terminology and a guide to avoiding confusion" for 'ecological stability'. Necessarily, a generally applicable conceptual framework such as the one presented here cannot cover the full richness of conceptualizations of vulnerability in all fields. Janssen et al. (2006) found 939 references to scientific articles that use 'vulnerability' as a keyword in global change research alone. Furthermore, given the large body of literature already available on this subject, I do not intend to present an exhaustive review of the various schools of vulnerability research or their historical development. For general reviews of the conceptualization of vulnerability, the reader is referred to Timmermann (1981), Liverman (1990), Cutter (1996), Hewitt (1997), Kasperson and Kasperson (2001), UNEP (2002), Ford (2002), Turner II et al. (2003), Cardona (2003), Prowse (2003), and Kasperson et al. (2005). Publications focussing on the conceptualization of vulnerability in climate change research include Adger (1999), Kelly and Adger (2000), Olmos (2001), Downing et al. (2001), Moss et al. (2001), Brooks (2003), Downing and Patwardhan (2004), and O'Brien et al. (2004a).

The primary audience of this paper are scholars engaged in vulnerability assessments involving different research traditions, particularly in the context of climate change and global environmental change. Recently there have been several attempts to develop formal models of vulnerability, both statically (Luers et al., 2003; Luers, 2005; Metzger et al., 2005) and dynamically (Ionescu et al., 2005). The formalization of vulnerability is another context where concise conceptualizations of vulnerability are needed.

The remainder of this paper is organized as follows. Section 2 presents the conceptual framework of vulnerability and the associated terminology. Section 3 applies this framework to discuss the conceptualization of vulnerability in the main schools of vulnerability research, to review earlier attempts at developing classifications of vulnerability, and to analyze the conceptualizations of vulnerability in climate change research. Section 4 concludes this paper.

2. Conceptual framework of vulnerability

2.1. Nomenclature of vulnerable situations

Several authors have emphasized that the term 'vulnerability' can only be used meaningfully with reference to a particular vulnerable situation. Brooks (2003) suggests that one "can only talk meaningfully about the vulnerability of a specified *system* to a specified *hazard* or range of hazards", and to distinguish between *current* and *future* vulnerability. Luers et al. (2003) "argue that vulnerability assessments should shift away from attempting to quantify the vulnerability of a place and focus instead on assessing the vulnerability of selected variables of concern and to specific sets of stressors". Füssel (2004) describes climate-related vulnerability assessments based on the characteristics of the vulnerable *system*, the type and number of *stressors* and their *root causes*, their *effects* on the system, and the *time horizon* of the assessment. Downing and Patwardhan (2004) present a formal nomenclature for the vulnerability of social systems that includes the *threat*, the *region*, the *sector*, the *population group*, the *consequence*, and the *time period*. Metzger et al. (2005) specifies the vulnerability of ecosystems to global change with respect to a particular *ecosystem service*, a *location*, a *scenario of stressors*, and a *time slice*.

The above frameworks largely agree that the following four dimensions are fundamental to describe a vulnerable situation.

System: The system of analysis, such as a coupled human–environment system, a population group, an economic sector, a geographical region, or a natural system. Note that some research traditions restrict the concept of vulnerability to social systems (Downing and Patwardhan, 2004) or coupled human–environment systems (Turner II et al., 2003) whereas others apply it to any system that is potentially threatened by a hazard (McCarthy et al., 2001).

Attribute of concern: The valued attribute(s) of the vulnerable system that is/are threatened by its exposure to a hazard. Examples of attributes of concern include human lives and health, the existence, income and cultural identity of a community, and the biodiversity, carbon sequestration potential and timber productivity of a forest ecosystem.

Hazard: A potentially damaging influence on the system of analysis. United Nations (2004) defines a 'hazard' broadly as "a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation". Hence, a hazard is understood as some influence that may adversely affect a valued attribute of a system. A hazard is generally but not always external to the system under consideration. For instance, a community may also be threatened by hazardous business activities or by unsustainable land management practices within this community. Hazards are often distinguished into discrete hazards, denoted as perturbations, and continuous hazards, denoted as stress or stressor (Turner II et al., 2003).

Temporal reference: The point in time or time period of interest. Specifying a temporal reference is particularly important when the risk to a system is expected to change significantly during the time horizon of a vulnerability assessment, such as for long-term assessments of anthropogenic climate change.

The following nomenclature allows to fully describe a vulnerable situation: *vulnerability of a system's attribute(s) of concern to a hazard* (*in temporal reference*), whereby the temporal reference can alternatively be stated as the first qualifier. Examples for fully qualified descriptions of vulnerability are "vulnerability of the tourism sector in a specific mountain region to climate change over the next 30 years", and "vulnerability of a particular ecosystem's net primary production to wild-fires in 2050". Note that this nomenclature of vulnerability is also applicable to related concepts such as 'adaptive capacity' and 'risk'.

Let us now review the Florida–Tibet example from Section 1. The question posed there specified the *system* (the geographical regions Florida and Tibet, respectively) and the *hazard* (climate change and variability). However, the question which of the two regions is more vulnerable to this hazard could not be clearly answered because neither the *attribute*(*s*) *of concern* nor the *temporal reference* were specified. For instance, a vulnerability assessment focussing on human livelihoods as the attribute of concern would probably consider Tibet as more vulnerable because the livelihoods of nomads and subsistence farmers may be threatened by extended droughts. An assessment focussing on economic impacts might consider Florida as more vulnerable, given the substantial concentration of capital along its coastline, which is threatened by hurricanes, storm surges, and sea-level rise. Similarly, an assessment focussing on the late 21st century might regard Tibet as more vulnerable since many Himalayan glaciers that are presently feeding the rivers of this arid region are expected to have disappeared by that time whereas an assessment focussing on current risks might regard Florida as more vulnerable because it already suffers substantial damage from hurricanes.

2.2. Classification scheme for vulnerability factors

A clear description of the vulnerable *situation* is an important first step for avoiding misunderstandings around vulnerability. However, there are also different interpretations of the term 'vulnerability' itself. These different vulnerability *concepts* can be distinguished by the vulnerability *factors* that they consider. (The following discussion uses the term 'vulnerability factor' in a rather broad sense. Readers who wish to hold on to their established conceptualization of 'vulnerability' might think of them as risk factors instead of vulnerability factors.)

Various authors distinguish an 'external' and an 'internal' side of vulnerability to environmental hazards. In most cases, these terms are used to distinguish the external stressors that a system is exposed to from the internal factors that determine their impacts on that system (e.g., Chambers, 1989; Ellis, 2000; Sanchez-Rodriguez, 2002; Pielke and Bravo de Guenni, 2003; Turner II et al., 2003). Sometimes, however, they are used to distinguish 'external' structural socioeconomic factors as investigated by human ecology, political economy, and entitlement theory from 'internal' agency-oriented factors as investigated in access-to-assets models, crisis and conflict theory, and action theory approaches (e.g., Bohle, 2001).

United Nations (2004) distinguish four groups of vulnerability factors that are relevant in the context of disaster reduction: *physical* factors, which describe the exposure of vulnerable elements within a region; *economic* factors, which describe the economic resources of individuals, populations groups, and communities; *social* factors, which describe non-economic factors that determine the well-being of individuals, population groups, and communities, such as the level of education, security, access to basic human rights, and good governance; and *environmental* factors, which describe the state of the environment within a region. All of these factors describe properties of the vulnerable system or community rather than of the external stressors.

Moss et al. (2001) identify three dimensions of vulnerability to climate change. The *physical-environmental* dimension ''accounts for the harm caused by climate''. It refers to the climatic conditions in a region and to the biophysical impacts of climate change, such as changes in agricultural productivity or the distribution of disease vectors. The *socioeconomic* dimension refers to ''a region's capacity to recover from extreme events and adapt to change over the longer term''. The third dimension, *external assistance*, is defined as ''the degree to which a region may be assisted in its attempts to adapt to change through its allies and trading partners, diasporic communities in other regions, and international arrangements to provide aid''. In contrast to United Nations (2004), this conceptualization of vulnerability includes factors outside the vulnerable system, such as characteristics of the stressor and the expected level of external assistance.

Several researchers distinguish biophysical (or natural) vulnerability from social (or socioeconomic) vulnerability. However, there is no agreement on the meaning of these terms. The conceptual framework for coastal vulnerability assessment developed by Klein and Nicholls (1999) sees 'natural vulnerability' as one of the determinants of 'socioeconomic vulnerability'. Cutter (1996), in contrast, regards the 'biophysical' and the 'social' dimension of vulnerability as independent. According to the terminology proposed by Brooks (2003), finally, ''social vulnerability may be viewed as one of the determinants of biophysical vulnerability''.

Each of the conceptual frameworks cited above provides an important classification of factors that determine the vulnerability of a system to a specific hazard. However, these terminologies are clearly incompatible with each other, and none of them is comprehensive enough to consistently integrate the others. The main reason for this confusion is the failure to distinguish between two largely independent dimensions of vulnerability factors: *sphere* (or scale) and *knowledge domain* (see Table 1).

Sphere (*or scale*): Internal (or 'endogenous' or 'in place') vulnerability factors refer to properties of the vulnerable system or community itself, whereas external (or 'exogenous' or 'beyond place') vulnerability factors refer to something outside the vulnerable system. This distinction typically reflects geographical boundaries or the power to influence. Note that the designation of a specific factor as internal or external may depend on the scope of the vulnerability assessment. National policies, for instance, would be regarded as internal in a national assessment but as (largely) external in a local assessment.

Knowledge domain: Socioeconomic vulnerability factors are those that relate to economic resources, the distribution of power, social institutions, cultural practices, and other characteristics of social groups typically investigated by the social sciences and the humanities. Biophysical vulnerability factors, in contrast, are related to system properties investigated by the physical sciences. These two categories can overlap, for instance in the case of built infrastructure.

Table 1
Examples for each of the four categories of vulnerability factors classified according to the dimensions sphere and knowledge domain

	Domain	
Sphere	Socioeconomic	Biophysical
Internal	Household income, social networks, access to information	Topography, environmental conditions, land cover
External	National policies, international aid, economic globalization	Severe storms, earthquakes, sea-level change

Table 1 illustrates the independence of the dimensions 'sphere' and 'knowledge domain' by providing examples for each of the four categories of vulnerability factors implicitly defined by them. Taken together, these four categories constitute the vulnerability profile of a particular system or community to a specific hazard at a given point in time.

The classification scheme for vulnerability factors presented in Table 1 constitutes the *minimal* structure for describing the multitude of vulnerability concepts in the literature. Obviously, each of these categories can be broken down further in order to more accurately describe the factors that are relevant in a specific assessment context. Internal social vulnerability factors, for instance, may be further distinguished between generic factors and factors that are specific for a particular hazard (Brooks, 2003). Furthermore, many factors are changing over time. In the ecological tradition of vulnerability research, for instance, 'sensitivity' denotes the degree to which a system is instantly effected by a perturbation whereas 'resilience' focusses on the ability of the system to maintain its basic functions and return to the original state after a perturbation.

The classification of vulnerability factors presented in Table 1 is largely compatible with the components of the integrated vulnerability framework proposed in Turner II et al. (2003), whereby 'internal socioeconomic vulnerability' corresponds to 'resilience', 'internal biophysical vulnerability' corresponds to 'sensitivity', 'external socioeconomic vulnerability' corresponds to 'human conditions/influences', and 'external biophysical vulnerability' corresponds to 'environmental conditions/influences'. The four elements of risk identified by Hewitt (1997, Chapter 1) are related to the four groups of vulnerability factors as follows: 'internal socioeconomic vulnerability' corresponds to 'vulnerability and adaptation' as well as 'human coping and adjustments', 'internal biophysical vulnerability' corresponds to 'intervening conditions of danger', and 'external biophysical vulnerability' corresponds to 'hazard'. The well-established terms applied in the various schools of vulnerability research are very useful in a context where their meaning is clear. The systematic terms suggested in this paper are not intended to replace them but to allow the consistent description of any vulnerability concept without having to recur to the terminology of a particular school of vulnerability research.

Vulnerability can principally be reduced by targeting any group of vulnerability factors. However, not all factors are amenable to policy interventions in all situations. Classical hazards assessments, for instance, have generally regarded 'natural' hazards as exogenous to the vulnerability assessment. This perspective, however, has become increasingly inaccurate given the widespread effects of human activities on environmental hazards such as river flow, local temperatures, and even global climate.

Coming back to the Florida–Tibet example, a crude analysis suggests that Tibet may be more vulnerable in terms of internal socioeconomic factors (response capacity; e.g., average household income) and external socioeconomic factors (e.g., national economic policies) whereas Florida may be more vulnerable in terms of internal biophysical factors (sensitivity; e.g., coastal topography) and external biophysical factors (exposure; e.g., tropical storms).

2.3. *Terminology of vulnerability concepts*

I propose the following terminology to consistently describe any vulnerability concept, based on the four groups of vulnerability factors identified in Section 2.2. Vulnerability concepts comprising only *one* group of factors are denoted by qualifying the sphere and the domain (e.g., 'internal socioeconomic vulnerability'). The qualifier 'cross-scale' is used for combinations of internal and external factors, and 'integrated' for combinations of socioeconomic and biophysical factors. These qualifiers allow to uniquely denote vulnerability concepts combining *two* groups of factors from the same sphere or the same domain (e.g., 'cross-scale socioeconomic vulnerability') or all *four* groups ('cross-scale integrated vulnerability'). The pertinent literature contains two vulnerability concepts that combine *three* groups of factors (see Section 3.2). In the absence of a more concise term, these concepts are denoted as 'cross-scale socioeconomic vulnerability *cum* sensitivity' and 'internal integrated vulnerability *cum* exposure'.

An important limitation of the terminology of vulnerability concepts described so far is its indifference with respect to time. For instance, the 'internal socioeconomic capacity' (or 'response capacity') of a community to climate change comprises its 'coping capacity' (i.e., its ability to cope with short-term weather variations) as well as its 'adaptive capacity' (i.e., its ability to adapt to long-term climate change). Discussions about vulnerability concepts that do not refer to a particular vulnerable situation should therefore specify the temporal reference in addition to the sphere and knowledge domain. In addition to the obvious terms 'current' and 'future', the term 'dynamic' is used for vulnerability concepts that refer to the present *as well as* the future.

The combination of the nomenclature of vulnerable situations from Section 2.1 and the terminology of vulnerability concepts presented here provides a generally applicable conceptual framework of vulnerability, spanned by the following six dimensions:

- Temporal reference: current vs. future vs. dynamic.
- Sphere: internal vs. external vs. cross-scale.
- Knowledge domain: socioeconomic vs. biophysical vs. integrated.
- Vulnerable system.
- Attribute of concern.
- Hazard.

An example for a fully qualified characterization of vulnerability according to this framework is 'current internal socioeconomic vulnerability of the livelihood of Tibetan subsistence farmers to drought'. Since statements about vulnerability involving all six dimensions are rather cumbersome, in practice one will only specify those attributes that are not clear from the context. The Florida–Tibet example has shown, however, that each dimension may be relevant for clarifying what is meant by 'vulnerability' in a particular context.

The conceptual framework of vulnerability presented here can be applied in various ways. First of all, it allows to communicate clearly which interpretation of vulnerability is used in a specific assessment. Second, it facilitates the discussion how and why different vulnerability concepts differ from each other. Third, it provides a framework for reviewing existing terminologies and classifications of vulnerability. Examples for all these applications are provided in the next section.

3. Application of the conceptual framework

3.1. *Classical approaches to vulnerability research*

The conceptualization of vulnerability varies significantly across research domains, and it has evolved over time. For instance, the theoretical evolution of hazards research is generally characterized by the following stages: (1) pure determinism, assuming that nature causes hazards; (2) a mechanistic engineering approach, emphasizing that technology can be used to reduce vulnerability and losses; (3) the human ecology approach, arguing that human behavior and perceptions were important; and (4) the political economy approach, arguing that structure not nature, technology, or agency creates vulnerability. For a more detailed review of the evolution of conceptual approaches to vulnerability research, the reader is referred to Kasperson et al. (2005).

Table 2
Correspondence between the conceptualization of vulnerability according to several major approaches to vulnerability research (left-most column), the vulnerability factors included (central columns), and the denotation according to the terminology presented in Section 2.3 (right-most column)

Approach	Vulnerability factors				Denotation
	IS	IB	ES	EB	
Risk-hazard	–	X	–	–	Internal biophysical vulnerability
Political economy	X	–	?	–	Cross-scale socioeconomic vulnerability
Pressure-and-release	X	X	–	–	Internal integrated vulnerability
Integrated (e.g., hazard-of-place)	X	X	X	X	Cross-scale integrated vulnerability
Resilience	X	X	?	?	Cross-scale (?) integrated vulnerability

A question mark indicates that it is not clear whether a particular vulnerability factor is included in the respective conceptualization of vulnerability. Abbreviations: IS, internal socioeconomic; IB, internal biophysical; ES, external socioeconomic; EB, external biophysical.

Table 2 shows the conceptualization of vulnerability according to the main approaches to vulnerability research presented in this subsection and indicates which of the four groups of vulnerability factors are typically included. The two 'classical' approaches to vulnerability research: the risk-hazard approach and the political economy approach, largely correspond to the 'geocentric' and 'anthropocentric' approaches to the study of criticality identified by Kasperson et al. (1995), and to the 'direct' and 'adjoint' approaches to assessing climate impacts distinguished by Parry et al. (1988).

3.1.1. *Risk-hazard approach*

The risk-hazard approach is useful for assessing the risks to certain valued elements ('exposure units') that arise from their exposure to hazards of a particular type and magnitude (Burton et al., 1978; Kates, 1985). This approach is most widely applied by engineers and economists in the technical literature on disasters, and a similar concept is used in epidemiology (Downing and Patwardhan, 2004, Annex A.3.1). The respective vulnerability definition refers primarily to physical systems, including built infrastructure, and it is descriptive rather than explanatory. The risk-hazard approach is more difficult to apply to people whose exposure to hazards largely depends on their behavior, as determined by socioeconomic factors. For that reason, the vulnerability of people has sometimes been treated simply as "exposure to hazards" (Hewitt, 1997, p. 27) or "being in the wrong place at the wrong time" (Liverman, 1990). Traditionally, the risk-hazard framework assumes that hazard events are rare, and that the hazard is known and stationary (Downing et al., 1999), although it has been applied to a wider range of hazards recently.

A key aspect of the risk-hazard approach is the clear distinction between two factors that determine the risk to a particular system: the 'hazard', which is "a potentially damaging physical event, phenomenon or human activity [that] is characterized by its location, intensity, frequency and probability", and the 'vulnerability', which denotes the "relationship between the severity of hazard and the degree of damage caused" (UN DHA, 1993; Coburn et al., 1994; United Nations, 2004). The vulnerability relationship is variably denoted as 'hazard-loss relationship' in natural hazards research, 'dose-response relationship' or 'exposure-effect relationship' in epidemiology, and 'damage function' in macroeconomics. Similar to 'vulnerability', the term 'risk' is also interpreted in different ways (see, e.g., Coburn et al., 1994; Adams, 1995; Cardona, 2003; Kelman, 2003). The use of the term in this paper always refers to the concept denoted as 'outcome risk' by Sarewitz et al. (2003). Two general definitions for (outcome) risk are "expected losses […] due to a particular hazard for a given area and reference period" (Adams, 1995) and "expected losses […] resulting from interactions between natural or human-induced hazards and vulnerable conditions" (United Nations, 2004). The vulnerability concept applied in the risk-hazard framework is characterized as 'internal biophysical vulnerability' according to the terminology from Section 2. The terms 'sensitivity' and 'susceptibility' are also used to denote this concept.

3.1.2. *Political economy approach*

The political economy approach focuses the analysis on people, asking who is most vulnerable, and why. In this tradition, Adger and Kelly (1999) define vulnerability as "the state of individuals, groups or communities in terms of their ability to cope with and adapt to any external stress placed on their livelihoods and well-being. […] It is determined by the availability of resources and, crucially, by the entitlement of individuals and groups to call on these resources."

The political economy approach prevails in the poverty and development literature. Vulnerability refers exclusively to people, and it is based on an explanatory model of socioeconomic vulnerability to multiple stresses. In the terminology from Section 2, this vulnerability concept is characterized as 'internal social vulnerability' or 'cross-scale social vulnerability'. The terms 'response capacity', 'coping capacity', and 'resilience' are also used to denote this concept.

3.1.3. Pressure-and-release model

The disaster pressure-and-release (PAR) model takes its starting point from the risk-hazard framework, defining risk as the product of hazard and vulnerability (Blaikie et al., 1994; Wisner et al., 2004). It then presents an explanatory model of vulnerability that involves global root causes, regional pressures, and local vulnerable conditions, without explicitly defining the term 'vulnerability'. The PAR model has similarities with hierarchical models used in epidemiology, such as the hierarchy of causes (MacMahon et al., 1960), the pressure-state-response (PSR) model (OECD, 1993), and the driving force-pressure-state-effect-action (DPSEA) framework (Kjellström and Corvalan, 1995).

3.1.4. Integrated approaches

The risk-hazard approach and the political economy approach have been combined and extended in various integrated approaches, most notably the hazard-of-place model (Cutter, 1993, 1996; Cutter et al., 2000; Cutter, 2003) and the coupled vulnerability framework (Turner II et al., 2003). Integrated approaches to vulnerability research have their roots in "geography as human ecology" (Barrows, 1923). One of their key features is the combination of 'internal' factors of a vulnerable system with its exposure to 'external' hazards. In this tradition, Cutter (1993) defines vulnerability as "the likelihood that an individual or group will be exposed to and adversely affected by a hazard. It is the interaction of the hazards of place […] with the social profile of communities." In the context of health risks from extreme weather events, the National Research Council (2001) defines vulnerability as the "extent to which a population is liable to be harmed by a hazard event. Depends on the populations's exposure to the hazard and its capacity to adapt or otherwise mitigate adverse impacts." In the context of food insecurity, the World Food Programme (2004) "sees vulnerability as being composed of two principal components, namely: (i) risk of exposure to different types of shocks or disaster event […] (ii) ability of the population to cope with different types of shock or disaster event." Turner II et al. (2003) suggest a place-based conceptualization of vulnerability that comprises exposure, sensitivity, and resilience, without giving a formal definition.

Integrated definitions of vulnerability are widely used in the context of global environmental change and climate change (see Section 3.3) with reference to regions, communities, or other social units. Another important application is in vulnerability (or risk) mapping, which is a multidisciplinary approach for identifying particularly vulnerable (or critical) regions (see e.g., O'Brien et al., 2004b; Metzger et al., 2005). Integrated vulnerability assessments have traditionally focussed on physical stressors, such as natural hazards or climate change. Some recent efforts, such as the 'double exposure' project (O'Brien and Leichenko, 2000; O'Brien et al., 2004b), have assessed the combined effects of biophysical and socio-economic stressors.

3.1.5. Resilience approach

Another tradition of vulnerability research has its roots in ecology. This community, which focusses on the concept of 'resilience', is currently not strongly involved in global change and climate change research (Janssen et al., 2006). The glossary of the Resilience Alliance (⟨http://resalliance.org⟩) defines vulnerability as follows

> "The propensity of social and ecological systems to suffer harm from exposure to external stresses and shocks. It involves exposure to events and stresses, sensitivity to such exposures (which may result in adverse effects and consequences), and resilience owing to adaptive capacity measures to anticipate and reduce future harm.
> The antonym of resilience is often denoted vulnerability. Coping capacity is important, at all stages, to alter these major dimensions."

The two paragraphs in this definition seem to be incompatible with each other. The first one defines vulnerability based on three factors, one of them being resilience, in a way that closely corresponds to the integrated approaches described above. The second paragraph, in contrast, describes vulnerability as the "antonym of resilience", thereby suggesting that it is comprised of internal factors only. An important feature of the resilience approach not depicted in Table 2 is its consideration of the dynamic aspects of vulnerability, as resilience denotes the ability of a system to return to an earlier (meta-)stable state after a perturbation.

3.1.6. Other conceptualizations of vulnerability

Some authors have used the term 'vulnerability' largely synonymous to (risk of) 'exposure'. Examples include "Human vulnerability to severe storms continues to rise because of the progressive occupation of hazardous areas" (Smith, 1996, p. 210) and "An estimated 75 million people [in Bangladesh] are vulnerable to arsenic poisoning" (UNEP, 2002, p. viii). This interpretation is not included in Table 2 because it is not reflected in formal definitions of vulnerability.

3.2. Earlier classifications of vulnerability

Table 3 presents the vulnerability concepts identified in the various classification schemes presented in Section 2.2 and the vulnerability factors that they include. The most interesting observations are as follows:

- In total eight different vulnerability concepts can be distinguished (1–8).
- The qualifier 'social'/'socioeconomic' is used for four different concepts (1, 4, 6, 8).
- The qualifier 'biophysical'/'natural' is used for three different concepts (5, 6, 7).
- The qualifiers 'socioeconomic' as well as 'biophysical' are used to denote 'cross-scale integrated vulnerability' (6).

Table 3
Correspondence between the vulnerability concepts distinguished in several earlier classification schemes (left-most column), the vulnerability factors covered by the respective concept (central columns), and the denotation according to the terminology presented in this paper (second right-most column)

Classification scheme	Vulnerability factors				Denotation	No.
	IS	IB	ES	EB		
Bohle (2001)						
Internal	X	–	–	–	Internal socioeconomic vulnerability	1
External	–	–	X	–	External socioeconomic vulnerability	2
Sanchez-Rodriguez (2002)						
Internal	X	–	–	–	Internal socioeconomic vulnerability	1
External	–	–	–	X	External biophysical vulnerability	3
Cutter (1996)						
Social	X	–	X	–	Cross-scale socioeconomic vulnerability	4
Biophysical	–	X	–	X	Cross-scale biophysical vulnerability	5
Klein and Nicholls (1999)						
Socioeconomic	X	X	?	X	Cross-scale integrated vulnerability	6
Natural	–	X	–	–	Internal biophysical vulnerability	7
Moss et al. (2001)						
Socioeconomic	X	–	–	–	Internal socioeconomic vulnerability	1
"External assistance"	–	–	X	–	External socioeconomic vulnerability	2
Physical-environment	–	X	–	X	Cross-scale biophysical vulnerability	5
Brooks (2003)						
Social	X	X	?	–	Cross-scale socioeconomic vulnerability cum sensitivity	8
Biophysical	X	X	?	X	Cross-scale integrated vulnerability	6
United Nations (2004)						
Social and economic	X	–	–	–	Internal socioeconomic vulnerability	1
Physical and environment	–	X	–	–	Internal biophysical vulnerability	7

The right-most column enumerates the different vulnerability concepts. See the legend of Table 2 for further explanations.

- Some classification schemes are exclusive (i.e., a particular vulnerability factor occurs in only one of the categories), whereas others are inclusive (i.e., one category includes all vulnerability factors from the other category).
- It is not always clear whether 'external socioeconomic factors' are included in a particular conceptualization.

Obviously, none of the one-dimensional classification schemes from the literature is able to consistently distinguish the eight vulnerability concepts identified in Table 3. This observation supports the claim that the slightly more complex framework presented here is necessary for characterizing the multitude of interpretations of vulnerability in the literature.

Noting the considerable confusion around the meaning of the term 'vulnerability', in particular in the climate change context, Brooks (2003) intends "*to present a tentative conceptual framework for studies of vulnerability and adaptation to climate variability and change, generally applicable to a wide range of contexts, systems and hazards.* [...] *The IPCC definition of vulnerability is discussed within this concept, which helps us to reconcile apparently contradictory definitions of vulnerability*". The core of this framework is the distinction between two interpretations of vulnerability in climate change research. These two interpretations are denoted as 'social vulnerability' and 'biophysical vulnerability', whereby "*social vulnerability* [...] *describe*[*s*] *all the factors that determine the outcome of a hazard event of a given nature and severity*" (p. 5) *whereas* "*biophysical vulnerability* [*is*] *a function of hazard, exposure, and sensitivity*" (p. 4) that "*has much in common with the concept of risk as elaborated in the natural hazards literature*" (p. 6). Hence, the main difference between these two concepts is that biophysical vulnerability does include characteristics of the hazard whereas social vulnerability does not. Table 3 shows that the use of these terms by Brooks (2003) contrads earlier definitions, thus increasing rather than decreasing the confusion around different interpretations of vulnerability.

3.3. Vulnerability to climate change

The fundamental policy options for limiting the adverse impacts of anthropogenic climate change are *mitigation* of climate change, which refers to confining global climate change by reducing the emissions of greenhouse gases or enhancing their sinks, and *adaptation* to climate change, which moderates the adverse effects of climate change through a wide range of actions that are targeted at the vulnerable system or population. A third policy option, which has attracted limited interest so far is *compensation* for climate impacts, typically conceived as transfer payments (or other assistance) from those countries who disproportionately contributed to climate change to those who disproportionately suffer from it (e.g., Paavola and

Adger, 2002). All three response options rely on information about the vulnerability of key systems to climate change but their specific information needs differ significantly. Mitigation and compensation need to distinguish the incremental impacts of anthropogenic climate change from the impacts of natural climate variability since they are primarily concerned with the former; this distinction is less relevant for adaptation. While aggregated estimates of climate impacts can be very useful for mitigation policy (and to some degree for compensation policy), adaptation actors typically require information that is more disaggregated spatially and temporally. For a more extensive discussion of the evolution of climate change vulnerability assessments, see Füssel and Klein (2006).

The main traditions of vulnerability research discussed in Section 3.1 vary in their ability to provide useful information for these three policy contexts. The risk-hazard approach is most appropriate to inform mitigation and compensation policy whereas the political economy approach is better suited to informat the design of adaptation policies. However, both approaches need to be extended to account for the large-scale and long-term nature of anthropogenic climate change. Integrated frameworks, as the most general category, are capable of providing information for all climate policy options. The pressure-and-release model and the resilience approach have not been widely applied in the climate change context.

Reviews of the interpretation of 'vulnerability' in climate change research have generally identified two different vulnerability concepts. Most importantly, O'Brien et al. (2004a) distinguish between an 'end-point' and a 'starting-point' interpretation of vulnerability. The two roles of vulnerability research underlying these interpretations of vulnerability largely correspond with the two types of adaptation research distinguished by Smit et al. (1999) and by Burton et al. (2002). Table 4 summarizes the main differences between these two interpretations of vulnerability. Vulnerability according to the end-point interpretation represents the (expected) net impacts of a given level of global climate change, taking into account feasible adaptations. This interpretation is most relevant in the context of mitigation and compensation policy, for the prioritization of international assistance, and for technical adaptations. It is based on the integrated framework or the risk-hazard framework of vulnerability research (see the discussion below). Vulnerability according to the starting-point interpretation focusses on reducing internal socioeconomic vulnerability to any climatic hazards. This interpretation addresses primarily the needs of adaptation policy and of broader social development. It is largely consistent with the political economy approach.

Table 4 postulates that the end-point interpretation of vulnerability in climate change research can be based on the risk-hazard approach. The risk-hazard approach has

Table 4
Two interpretations of vulnerability in climate change research (partly based on O'Brien et al., 2004a; Smit et al., 1999; Burton et al., 2002; Füssel and Klein, 2006)

	End-point interpretation	Starting-point interpretation
Root problem	Climate change	Social vulnerability
Policy context	Climate change mitigation, compensation, technical adaptation	Social adaptation, sustainable development
Illustrative policy question	What are the benefits of climate change mitigation?	How can the vulnerability of societies to climatic hazards be reduced?
Illustrative research question	What are the expected net impacts of climate change in different regions?	Why are some groups more affected by climatic hazards than others?
Vulnerability and adaptive capacity	Adaptive capacity determines vulnerability	Vulnerability determines adaptive capacity
Reference for adaptive capacity	Adaptation to future climate change	Adaptation to current climate variability
Starting point of analysis	Scenarios of future climate hazards	Current vulnerability to climatic stimuli
Analytical function	Descriptive, positivist	Explanatory, normative
Main discipline	Natural sciences	Social sciences
Meaning of 'vulnerability'	Expected net damage for a given level of global climate change	Susceptibility to climate change and variability as determined by socioeconomic factors
Qualification according to the terminology from Section 2	Dynamic cross-scale integrated vulnerability [of a particular system] to global climate change	Current internal socioeconomic vulnerability [of a particular social unit] to all climatic stressors
Vulnerability approach	Integrated, risk-hazard	Political economy
Reference	McCarthy et al. (2001)	Adger (1999)

been widely applied in risk assessments to estimate the expected damages caused by various kinds of hazards, including climatic hazards. Standard applications of disaster risk assessment (DRA) are ‘‘primarily concerned with short-term (discrete) natural hazards, assuming known hazards and present (fixed) vulnerability’’ (Downing et al., 1999). In contrast, key characteristics of anthropogenic climate change are that it is long-term and dynamical, it is global but spatially heterogeneous, it involves multiple climatic hazards associated with large uncertainties, and it is attributable to human action. These differences are summarized in Table 5. In a nutshell, the hazard and risk events considered in DRA are limited in time and space and rather well-known whereas anthropogenic climate change is not.

Let us now attempt to define ‘future vulnerability to global climate change’ following the general approach in the risk-hazard framework, which assumes that the risk to a system is fully described by two risk factors: hazard and vulnerability. DRA traditionally sees climatic hazards as stationary and assumes vulnerability to be constant. The long time scales of climate change, in contrast, shift the focus to *future* risks, which require a dynamic assessment framework that accounts for changes in all vulnerability factors over time. The *future risks* to a system from climate change are determined by its *future exposure* to climatic hazards and by its *future sensitivity* to these hazards. (The term ‘sensitivity’ is used here equivalent to ‘internal integrated vulnerability’.) Future sensitivity depends on the *current sensitivity* of the system as well as its current and future *adaptive capacity*. Hence, any conceptualization of ‘vulnerability to climate change’ needs to consider the adaptive capacity of the vulnerable system, which largely determines how its sensitivity evolves over time.

Table 5
Characteristics of vulnerability assessments addressing natural hazards and climate change

	Natural hazards	Climate change
Hazard characteristics:		
Temporal	Discrete events	Discrete and continuous
Dynamics	Stationary	Non-stationary
Spatial scope	Regional	Global but heterogeneous
Uncertainty	Low to medium	Medium to very high
Attribution	Natural variability	Natural and anthropogenic
Systems of concern	Social systems and built infrastructure	All systems
System view	Static	Dynamic and adaptive
Targets for risk reduction	Exposure to hazards and internal vulnerability	Magnitude of hazards and internal vulnerability
Analytical function	Normative	Positivist and normative

For the same magnitude of the hazard ‘global climate change’ (e.g., expressed in terms of global temperature change), the exposure to regional climate change will be different (e.g., reduced precipitation in one location and increased precipitation in another). Furthermore, the impacts of a given change in regional climate depend on the baseline climate (e.g., whether the region is currently dry or humid). Hence, the *future exposure* of a system to climatic hazards is not only determined by the *future hazard* level on a global scale (e.g., the amount of GMT change) but also by a *regional exposure factor* that describes the manifestation of global climate change at the regional level. This information can in principle be derived from downscaled climate change scenarios but it is generally associated with significant uncertainty. If we hold on to the conceptual model underlying the risk-hazard approach in which the risk to a system is fully described by the two risk factors ‘hazard’ and ‘vulnerability’, the definition of ‘future vulnerability to *global* climate change’ needs to include the regional exposure factor in the conceptualization of ‘vulnerability’.

The IPCC Third Assessment Report (McCarthy et al., 2001, Glossary) defines vulnerability as follows: ‘‘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.’’ This definition has been criticized by some scholars as confusing, inconsistent, or impractical (e.g., Downing et al., 2001) but it has recently been operationalized in the ATEAM project (Metzger et al., 2005). Summarizing the discussion above, the future risk from global climate change is determined by the future hazard level and three other factors: (current) sensitivity, (dynamic) adaptive capacity, and a regional exposure factor. Since these three factors are the same as in the contended IPCC vulnerability definition, we conclude that this definition consistently characterizes the ‘future (or dynamic) vulnerability of any natural or social system to global climate change’. We note that the classical risk-hazard definition of vulnerability focussing on the (current) ‘sensitivity’ of a system had to be extended to account for the long-term nature of the climate problem (by including ‘adaptive capacity’) and for the heterogeneity and complexity of the hazard (by including a ‘regional exposure factor’). As a result, the IPCC definition resembles the conceptualization of vulnerability in integrated frameworks (cf. Table 2). Since the definition of vulnerability in the IPCC Third Assessment Report does not contain any qualifiers some scholars have wrongly concluded that the IPCC intended to redefine vulnerability in *all* contexts (which would indeed be inappropriate). This misconception reemphasizes the need for defining vulnerability in relation to specific hazards, outcomes, and time horizons, as called for by the conceptual framework of vulnerability proposed in this paper.

4. Concluding remarks

Vulnerability describes a central concept in climate change research as well as in the research communities dealing with natural hazards and disaster management, ecology, public health, poverty and development, secure livelihoods and famine, sustainability science, and land change. Each of these communities has developed their own conceptual models, which often address similar problems and processes using different language. Vulnerability, in particular, is conceptualized in many different ways. The existence of different conceptualizations and terminologies of vulnerability has become particularly problematic in research on global climate change, which brings together scholars from all these communities. Despite several attempts to resolve the conceptual confusion around 'vulnerability', none of the earlier frameworks has achieved this goal.

This paper presents a conceptual framework of vulnerability that combines a nomenclature for describing any vulnerable *situation* in terms of the vulnerable system, the hazard(s) of concern, the attribute(s) of concern, and a temporal reference; a classification scheme for vulnerability *factors* according to their sphere and knowledge domain; and a terminology for vulnerability *concepts* that is based on the vulnerability factors included. This conceptual framework allows to concisely describe any vulnerability concept in the literature as well as the differences between alternative concepts.

The conceptual framework of vulnerability presented here is intended to be a useful tool for scholars engaged in interdisciplinary vulnerability assessments, in particular those concerned with climate change, and for those developing formal models of vulnerability. Its application requires to accept the diversity of conceptual models and definitions of vulnerability as a reflection of the wide range of valid perspectives on the integrated human–environment system. Applications of the conceptual framework in this paper include a characterization of the conceptualization of vulnerability in the major approaches to vulnerability research, a critical review of earlier attempts at developing conceptual frameworks of vulnerability, and a discussion of the conceptualization of vulnerability in climate change research, where many of the simplifying assumptions underlying classical conceptualizations of vulnerability cannot be taken as a given.

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