Development and
Climate Change

BACKGROUND NOTE

REVIEW AND QUANTITATIVE ANALYSIS OF INDICES OF CLIMATE CHANGE EXPOSURE, ADAPTIVE CAPACITY, SENSITIVITY, AND IMPACTS

by

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Review and quantitative analysis of indices of climate change exposure, adaptive capacity, sensitivity, and impacts

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1   Introduction

Adaptation to climate change is necessary, in addition to mitigation of climate change, to avoid unacceptable impacts of anthropogenic climate change [IPCC 2007]. UNFCCC Article 4 requires developed countries to assist developing countries that are "particularly vulnerable" to climate change in meeting costs of adaptation to its adverse effects. As a result, three funds have been established under the UNFCCC and Kyoto Protocol to provide financial resources for assessing, planning, and implementing adaptation measures in developing countries. Further adaptation funding is provided bilaterally and by multilateral institutions (including the World Bank) outside the UNFCCC framework. The ambiguous and imprecise language used in the UNFCCC does not provide operational definitions for key concepts, including the identification of "particularly vulnerable" countries [Verheyen 2002]. This document discusses how science-based indicators of vulnerability to climate change and of adaptability can inform the prioritisation of adaptation assistance from a global adaptation fund.

The text is structured as follows. Section 2 reviews different conceptualizations of 'vulnerability', focussing on the two main interpretations of this term in climate change research: outcome vulnerability and contextual/social vulnerability. This section also discusses the normative challenges involved in the construction of vulnerability indices. Section 8 reviews the main aggregated national-level vulnerability indices for climate change, including indices of outcome vulnerability as well as indices of contextual/social vulnerability. This section also includes a more general discussion of the potential and limitations of aggregated indices of vulnerability to climate change. Section 4 discusses the relationship between countries' aggregated vulnerability to climate change and their prioritization for international adaptation assistance, considering the implications of different principles of distributive justice. Section 5 develops a conceptual framework of vulnerability to climate change that structures disaggregated information on the vulnerability of countries in a way that is particularly well suited to inform the prioritization of international adaptation assistance. This conceptual framework distinguishes 5 groups of vulnerability factors and 2 groups of adaptability factors. It is based on the IPCC definition of vulnerability but also considers more recent findings on the components of vulnerability to climate change. The relationship between the various components of vulnerability and adaptability and 'fair' allocations for adaptation are discussed, and controversial normative issues are highlighted. The conceptual framework is illustrated by vulnerability indicators for four main climate-sensitive sectors. Section 6 presents results from a quantitative assessment of selected vulnerability factors for different climate-sensitive sectors, including on the justice implications of climate change for different sectors. A comprehensive quantitative assessment is beyond the scope of this study. Section 7 summarizes the main findings of this report, drawing primarily on the enumerated key messages highlighted in bold face.

2   Conceptualization of vulnerability to climate change

1. **The term vulnerability has been defined in many different ways by various scholarly communities. Definitions of vulnerability differ so widely that the term becomes almost useless in an interdisciplinary context without further specification.**

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 research contexts such as natural hazards and disaster management, 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. 2004, Gow 2005].

Almost 30 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"*. Exposure, sensitivity, coping capacity, criticality, and robustness could easily be added to this list. For a recent overview of definitions of 'vulnerability', see [Kasperson et al. 2005][Box 14.1]. 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, 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, O'Brien et al. 2004, Eakin and Luers 2006, Füssel 2007, O'Brien et al. 2007].

2. Several conceptual frameworks have been developed to categorize vulnerability factors and to describe different vulnerability concepts. The minimal classification scheme of vulnerability factors distinguishes internal from external factors and socio-economic from biophysical factors.

Various authors distinguish an 'external' and an 'internal' side of vulnerability to environmental hazards [Chambers 1989, Ellis 2000, Bohle 2001, Sanchez-Rodriguez 2002, Pielke Sr. and Bravo de Guenni 2003, Turner II et al. 2003]. Several researchers distinguish biophysical (or natural) vulnerability from social (or socioeconomic) vulnerability, even though there is no agreement on the meaning of these terms [Cutter 1996, Klein and Nicholls 1999, Brooks 2003, Füssel 2007]. Other classifications have been suggested by [United Nations 2004] (physical, economic, social, and environmental factors) and by [Moss et al. 2001] (physical-environmental dimension, socioeconomic dimension, and external assistance). The minimal classification scheme of vulnerability factors is spanned by the two largely independent dimensions sphere (distinguishing internal from external factors) and knowledge domain (distinguishing socio-economic from biophysical factors). This classification scheme is presented in Table 1. Table 2 applies this framework to illustrate the conceptualization of vulnerability in different schools of vulnerability research.

Sphere	Domain	
	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: Examples for each of the four categories of vulnerability factors classified according to the dimensions sphere and knowledge domain. Source: [**Füssel 2007**]

Approach	Vulnerability factors			
	IS	IB	ES	EB
Risk-hazard	–	X	–	–
Political economy	X	–	?	–
Pressure-and-release	X	X	–	–
Integrated (e.g., hazard-of-place)	X	X	X	X
Resilience	X	X	?	?

Table 2: Correspondence between the conceptualization of vulnerability according to several major approaches to vulnerability research and the vulnerability factors included. A question mark indicates that a vulnerability factor may or may not be included in the respective conceptualization of vulnerability. Abbreviations: IS, internal socioeconomic; IB, internal biophysical; ES, external socioeconomic; EB, external biophysical. Source: [**Füssel 2007**]

3. **The hybridization of concepts from different traditions of vulnerability research in studies on climate change and global environmental change contributes to considerable confusion regarding appropriate conceptualizations of vulnerability to climate change.**

Many climate change vulnerability assessments link vulnerability to the outcome of hazard exposure, which is a central element of the risk-hazards approach. At the same time, they emphasize the importance of socio-economic factors (often denoted as adaptive or coping capacity) for the differential vulnerability of regions and population groups, which is a central feature of the political-economy approach. Global climate change has several features that are uncommon to other vulnerability assessments, such as defining vulnerability with reference to a slowly evolving and partly uncertain future hazard. Integrated approaches to vulnerability assessment are increasingly producing new insights into the causes and consequences of vulnerability but they also contribute to some of the present conceptual and terminological confusion [Eakin and Luers 2006, Füssel 2007].

4. **The most prominent interpretations of vulnerability in the climate change context are contextual vulnerability and outcome vulnerability. These interpretations of vulnerability are based on different conceptual frameworks, they produce different rankings, and they suggest different strategies for reducing vulnerability.**

Contextual vulnerability (also known as starting-point interpretation or internal social vulnerability) is rooted in political economy. It is determined exclusively by internal characteristics of the vulnerable system or community that determine its propensity to harm for a wide range of hazards. Outcome vulnerability (also known as end-point interpretation or integrated cross-scale vulnerability) represents an integrated vulnerability concept (in the terminology of Table 2) that combines information on potential climate impacts and on the socio-economic capacity to cope and adapt [O'Brien et al. 2004, O'Brien et al. 2007, Füssel 2007]. The two interpretations are further explained in Figure 1 and Table 3.
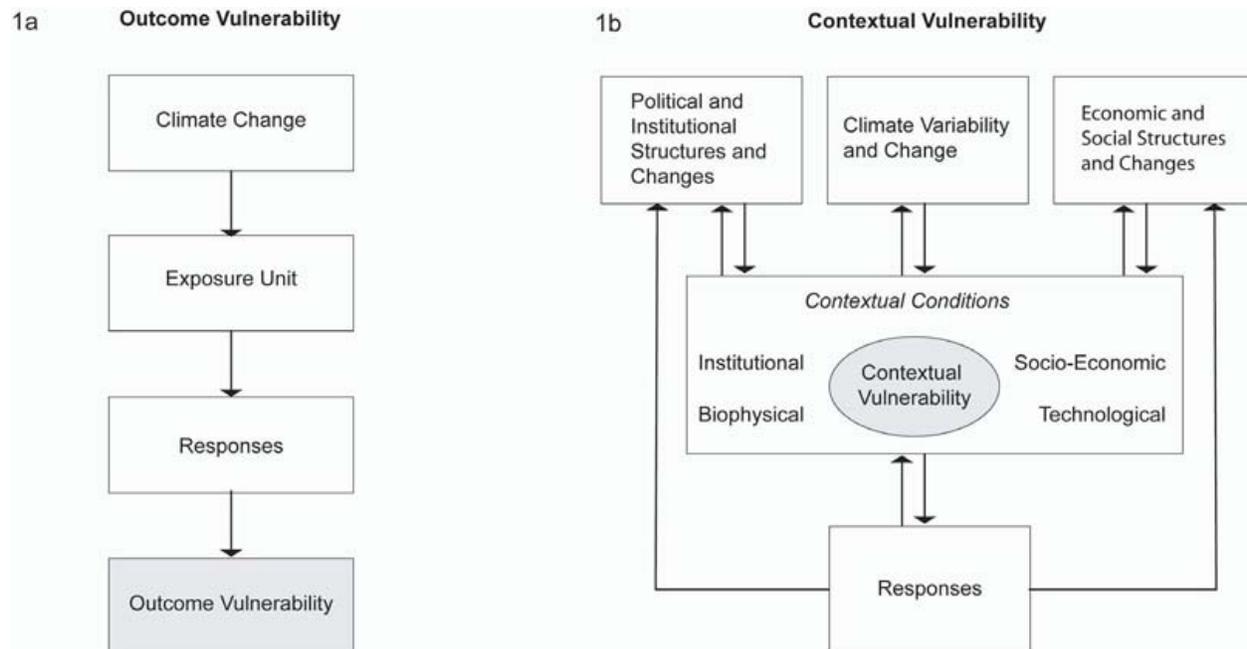

Figure 1: Frameworks depicting two interpretations of vulnerability to climate change: (a) outcome vulnerability; (b) contextual vulnerability. Source: [**O'Brien et al. 2007**]

	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)

Table 3: Two interpretations of vulnerability in climate change research. Source: [**Füssel 2007**]

Different interpretations of vulnerability do not only produce different rankings of vulnerable regions or systems; they also suggest different strategies for reducing vulnerability. 'Outcome studies' tend to focus on technological adaptation to minimize particular impacts of climate change whereas 'contextual studies' tend to focus on sustainable development strategies that increase the response capacity of human populations for dealing with a large variety of hazards [O'Brien et al. 2007, Eriksen and Kelly 2007].

5. The IPCC definition of vulnerability to climate change corresponds to outcome vulnerability.

The IPCC definition characterizes vulnerability (to climate change) as a function of a system's exposure and sensitivity to climatic stimuli and its capacity to adapt to their (adverse) effects [IPCC 2007], which corresponds to outcome (or end-point) vulnerability, but it does not provide a clear definition of these attributes or the relationship between them. Figure 2 illustrates the relationship between key terms employed in climate change impact, vulnerability, and adaptation assessment. Note that the term 'vulnerability' refers to outcome vulnerability and the term 'impacts' refers to potential biophysical impacts.
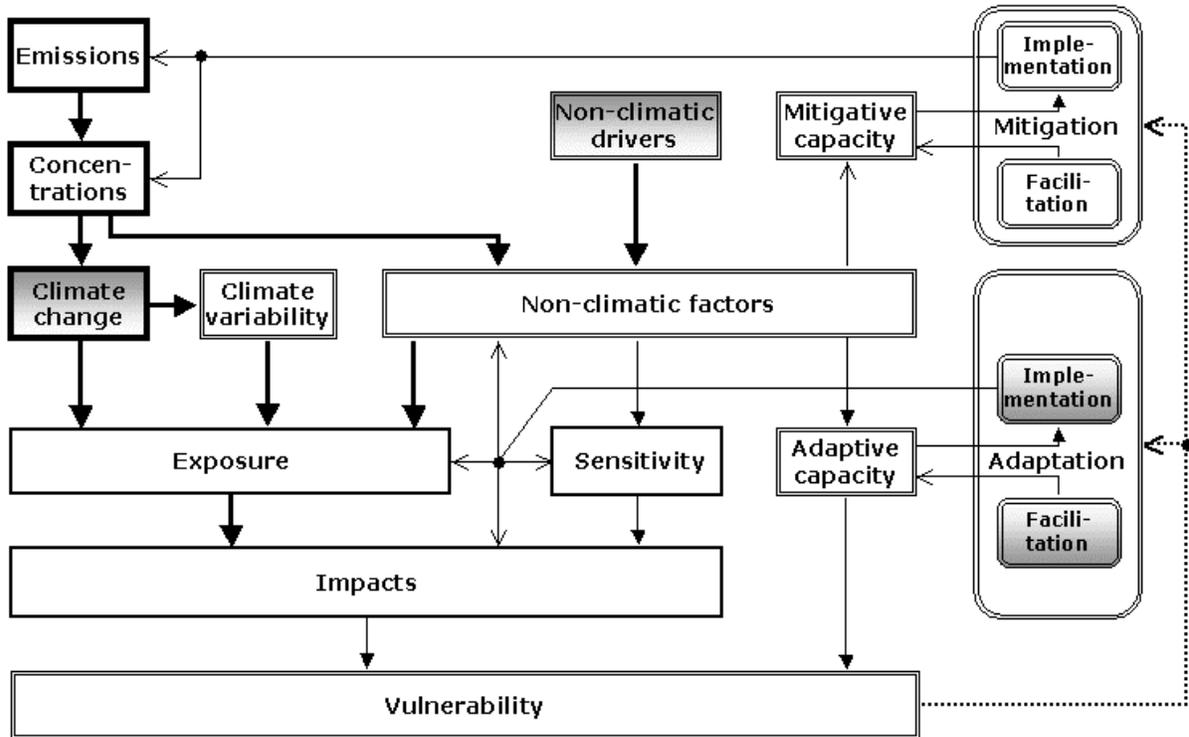
Figure 2: Relationship between key terms employed in climate change impact, vulnerability, and adaptation assessment. The different types of arrows, borders, and shadings are not of central importance in this context. Source: [**Füssel and Klein 2006**]

6. **All quantitative vulnerability concepts need to specify the vulnerable system, the hazards it is exposed to, the attributes at risk from this exposure, and the time period considered.**

Several authors have emphasized that the term 'vulnerability' can only be used meaningfully with reference to a particular vulnerable situation [Brooks 2003, Luers et al. 2003, Downing and Patwardhan 2004, Metzger et al. 2005, Füssel 2007]. The following four dimensions are fundamental to describe a vulnerable situation: the *system* of analysis, the valued *attributes* of concern, the external *hazard*, and a *temporal reference* [Füssel 2007].

7. **Clarity over its primary purpose is crucial to guide the development of any vulnerability index, or set of indicators. Given the diversity of decision contexts that can be informed by climate change vulnerability assessments and of normative preferences, the design of vulnerability indices is as much a political as a scientific task.**

Vulnerability indices are applied for many scientific purposes (e.g., for identifying causal processes and explaining attributes of vulnerable systems, for linking system attributes to vulnerability outcomes, and for mapping, ranking and comparing vulnerability across regions), at many scales (from local to global), and with different policy objectives (e.g., more realistic assessment of climate change risks, aiding the allocation of resources across regions, monitoring the progress in reducing vulnerability over time, and identifying suitable entry points for interventions) [Füssel and Klein 2006, Eakin and Luers 2006]. Different decision contexts and scales generally require different kinds of information. For instance, an indicator developed to

describe household vulnerability to natural hazards in Mozambique may be largely irrelevant in the German context, and outright inapplicable at the national scale [Vincent 2007].

8. **The development of aggregated national-level vulnerability indices requires substantial normative choices in the selection and aggregation of diverse information across time, affected systems and regions, and impact metrics, which largely determine the resulting vulnerability ranking.**

The vulnerability of a country to climate change cannot be measured directly. Even if the decision context is clear, legitimate normative differences may strongly influence the combination of diverse information sources into an aggregated vulnerability index. Normative challenges include the aggregation of future and current climate risks; of monetary, human health and other non-market impacts of climate change; of high-certainty and low-certainty impacts; and of beneficial and adverse impacts occurring in different sectors and/or regions.

3   Review of aggregated vulnerability indices

9. **Theory-driven as well as data-driven approaches have been used in developing indices of vulnerability to climate change.**

Theory-driven (also known as deductive) approaches are based on a conceptual framework for identifying relevant indicators and determining their relationships whereas data-driven (also known as inductive) approaches select vulnerability indicators based on their statistical relationship with observed vulnerability outcomes (e.g., mortality due to natural hazards) [Eriksen and Kelly 2007]. Data-driven approaches have only been applied in the development of vulnerability indices for specific climate-sensitive systems because there is no well-defined vulnerability outcome that could be used for the development of aggregated vulnerability indices. An important limitation of all data-driven indices is that they are being developed and tested in the context of coping with short-term climate variability and extremes rather than adaptation to long-term climate change. This limitation is particularly relevant if future climate change exceeds the range of current climate variability.

10. **Indices of vulnerability to climate change may include observed data on socio-economic, environmental and other factors as well as model-based estimates of future conditions. Each of these data sources is associated with specific advantages and disadvantages.**

Observed data is more transparent and thus more amenable to be included in contested political decisions (e.g., on the allocation of adaptation resources). Observed data is, however, unable to identify some important risks of climate change, in particular in the medium and long term. Sophisticated model simulations can provide a much more detailed picture of future climatic risks but their results are less transparent and thus likely to be more contested in political decision processes. Some aggregated vulnerability indices have included projections of regional climate change [Yohe et al. 2006b, Diffenbaugh et al. 2007] but none of them has considered projections from climate impact models.

11. **All existing indices of (social and outcome) vulnerability to climate change show substantial conceptual, methodological and empirical weaknesses including lack of focus, lack of a sound conceptual framework, methodological flaws, large sensitivity to alternative methods for data aggregation, limited data availability, and hiding of**

legitimate normative controversies. As a result, there is little agreement regarding the most vulnerable countries.

[Eriksen and Kelly 2007] have assessed whether national-level vulnerability indices can provide an *"objective comparison of levels of vulnerability between countries […] as a way of allocating priorities for funding and intervention, for example, in the context of the Adaptation Fund set up under the United Nations Framework Convention on Climate Change"* (p. 496). Their review includes five quantitative national-level indices of social vulnerability to climate change: vulnerability-resilience indicators (VRI) [Moss et al. 2001], the Environmental Sustainability Index (ESI) [Esty et al. 2005], dimensions of vulnerability [Downing et al. 1995], Index of Human Insecurity [Lonergan et al. 1999], and a preliminary version of the Predictive Indicators of Vulnerability, denoted as country-level risk measures [Brooks et al. 2005]. The study finds that *"a lack of a clear theoretical and conceptual framework for the selection of indicators has hampered the robustness, transparency and policy relevance"* of these indicator studies, and they note *"a serious deficiency in existing studies, the limited testing and verification of indicators and of the validity of underlying conceptual frameworks"* (p. 504). As a result, the three indices that provide a ranking of countries show *"relatively little agreement regarding which particular countries are the most vulnerable, with only five countries ranked among the 20 most vulnerable in two or more of the studies and only one country ranked among the 20 most vulnerable in all three. This finding […] firmly underlines the challenge in making objective judgments about which countries are more vulnerable than others as a basis for allocating of funding"* (p. 502).

[Eakin and Luers 2006] express serious concerns regarding the validity of national-scale vulnerability assessments noting that *"Ranking and comparing vulnerability across countries […] is challenged by everything from the quality of the available data, to the selection and creation of indicators, to the assumptions used in weighting of variables and the mathematics of aggregation. There are also problems in the interpretation of indices"* (p. 377).

Other studies found that several aggregated vulnerability indices express strong sensitivity to the selection of specific proxy variables as well as to variations in the mathematics of index construction [Moss et al. 2001, Gall 2007, Schmidtlein et al. 2008].

12. A multi-criteria evaluation concludes that the human development index outperforms several more recent indices as a generic national-level index of social vulnerability to climate change.

Key evaluation criteria for vulnerability indices include the level of theoretical understanding, comparability across regions and time, soundness of methods for indicator selection and aggregation, parsimony and transparency, data availability and quality, robustness with respect to uncertain input data and alternative aggregation methods, and level of validation [Gall 2007, Eriksen and Kelly 2007].

[Gall 2007] has undertaken a detailed comparison of 7 national-level indices of social vulnerability to climate change with a particular focus on natural hazards (see Table 4): Human Development Index (HDI) [UNDP 2007], Human Wellbeing Index (HWI) [Prescott-Allen 2001], Prevalent Vulnerability Index (PVI) [Cardona 2007], Index of Social Vulnerability to Climate Change for Africa (SVA), later renamed to National Adaptive Capacity Index [Vincent 2007], Predictive Indicators of Vulnerability (PIV) [Adger et al. 2004], and the socioeconomic components of the Disaster Risk Index (DRI) [UNDP 2004] and of the Environmental

Sustainability Index (ESI) [Forum 2005]. The study finds *"significant shortcomings in the construction of most of the evaluated indices with particular gaps in empirical validity and methodological robustness"* (p. vi). The key issues that *"contribute to variability and uncertainty embodied by current vulnerability indices [are]: subjective interpretation of vulnerability concepts, ignorance of sound statistical practices, limited data availability, and absence of reliable approaches to calibrate social vulnerability indices"* (p. vii). The multi-criteria assessment concludes that the human development index outperforms the more recent indices as a generic national-level index of social vulnerability to climate change (see Table 5) but that *"all indices hover around low to medium scores"* (p. 120).

Index	Author & Data Source	Concept	Sub-indices #	Variables #	Vulnerability Ranking	Input Data Sources
HDI	UNDP (1990; 2005)	Quality of life	1	4	Low to high vulnerability	UN data
HWI	Prescott-Allen (2001)	Quality of life	5	33	Low to high vulnerability	Mostly UN data
ESI*	Esty et al. (2005)	Sustainable Development	21 (7*)	76 (31*)	Low to high vulnerability	Mostly World Bank, UN data, etc.
PVI	IADB (2005)	Social Vulnerability	3	24	High to low vulnerability	UN data, national census data
SVA	Vincent (2004)	Social Vulnerability	4	8	High to low vulnerability	World Bank, UN data
DRI*	UNDP (2004)	Social Vulnerability	3 (4)	10 (6*)	High to low vulnerability	UN data, EM-DAT
PIV	Adger et al. (2004)	Social Vulnerability	none	46	High to low vulnerability	EM-DAT, HDI, UNEP/GRID, Freedom House Index, and more

*For comparative purposes, biophysical elements have been eliminated from the original index design to ensure analysis of socioeconomic characteristics only. The reduced number of indicators and/or sub-indices is provided in parenthesis.

HDI   = Human Development Index
HWI   = Human Wellbeing Index
ESI*   = Human Vulnerability Component of the 2005 Environmental Sustainability Index
PVI   = Prevalent Vulnerability Index
SVA   = Index of Social Vulnerability to Climate Change for Africa
DRI   = Disaster Risk Index
PIV   = Predictive Indicator of Vulnerability

Table 4: Evaluated global indices that related to issues of social vulnerability. Source: [**Gall 2007**]

Index	Theoretical understanding	Data	Empirical	Method	Validation	Feasibility	Total Score
HDI	2	3	2	2	0	4	2.2
HWI	2	3	2	1	0	2	1.7
ESI	3	3	2	2	0	2	2.0
PVI	2	3	2	1	0	3	1.8
SVA	2	3	2	1	0	4	2.0
DRI	1	2	2	1	1	2	1.5
PIV	1	3	2	1	1	2	1.7

Table 5: Pedigree matrix applied to selected social vulnerability indices. Source: [**Gall 2007**]

The reviewed indices are classified into four development-driven indices (HDI, HWI, ESI, and PIV) and three vulnerability-driven indices (DRI, SVA, and PVI). The country rankings produced by all development-driven indices agree well and correspond largely to clusters of high and low socioeconomic development. The PVI is difficult to compare with other indices because of its small sample size (12 countries in Latin America). Regarding the other two vulnerability-driven indices, the study finds that *"the DRI and SVA create spatial patterns that are inconsistent with development-driven indices. […] their patterns often contradict expert knowledge, which leads one to conclude that their results are confounded by technical shortcomings of index design"* (p. 178). In a nutshell, [Gall 2007] acknowledges the limitations of the HDI but regards the other indices of social vulnerability as even more problematic.

13. **The common mathematical method for constructing indices of social vulnerability to climate change or of adaptive capacity assumes perfect substitutability of the constituent factors even though this assumption is at best partly confirmed by analysis of pertinent data.**

The construction of theory-driven indices of social vulnerability and adaptive capacity generally involves the (possibly weighted) summation of several (possibly normalized) indicators or sub-indices (see, e.g., [Gall 2007], Table 3-4). This summation assumes that all components are perfect substitutes for each other, an assumption that is not generally supported by empirical studies. In particular, examination of the empirical relationship between components of adaptive capacity and several observed vulnerability outcomes suggests that these components are close to perfect substitutes for some climatic risks and closer to perfect complements for others [Tol and Yohe 2007].

14. **Three recently developed aggregated indices of outcome vulnerability to climate change (21st century socioclimatic exposure, global distribution of vulnerability, and the climate change subindex of the SOPAC Environmental Vulnerability Index) are inappropriate for prioritizing international adaptation funding due to severe conceptual, methodological and empirical weaknesses.**

Recently two research groups have independently developed aggregated indices of outcome vulnerability to climate change by combining measures of severity of climate change with

measures of socioeconomic capacity. [Diffenbaugh et al. 2007] have developed an 'indicator of 21st century socioclimatic exposure' that combines data on the severity of regional climate change, economic capacity, and assets at risk (see Figure 3).
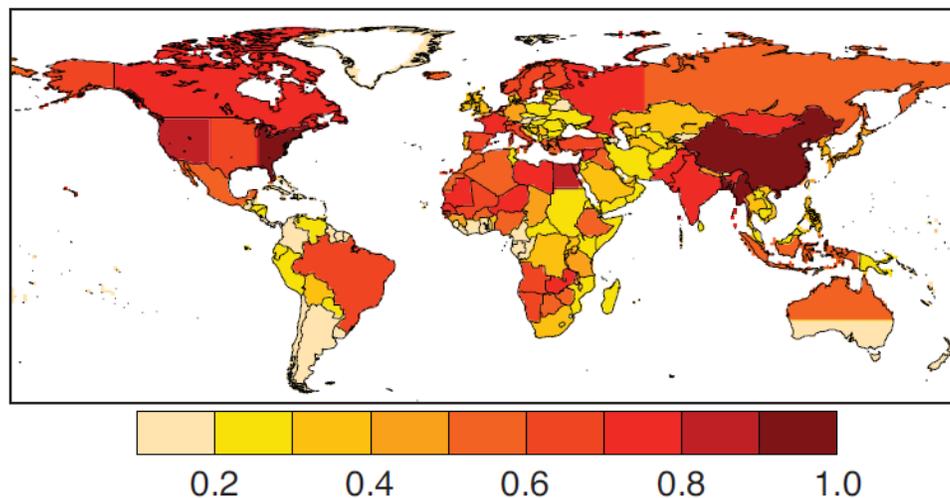

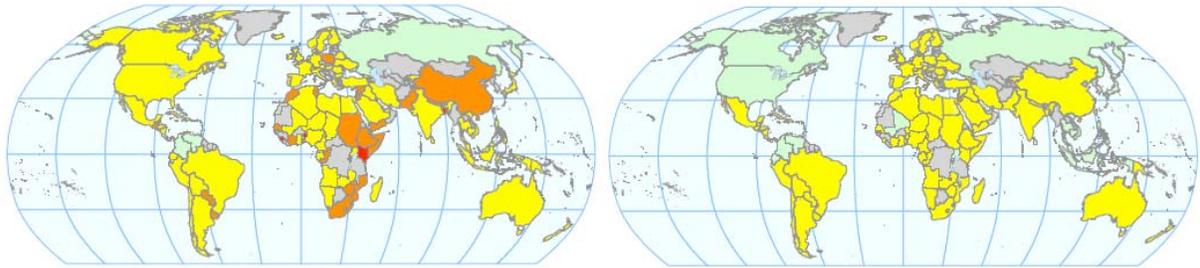**Figure 3:** 21st century socioclimatic exposure. Source: **[Diffenbaugh et al. 2007]**

The aggregated index is calculated as follows:

Socioclimatic exposure = climate change index * (population index + wealth index + poverty index).

This calculation method is associated with fundamental methodological problems. First, the summation of an index that scales with population and two indices that are normalized by population (e.g., GDP per capita) mixes two different concepts (denoted as 'intensity' and 'density' by [Diffenbaugh et al. 2007]) in a way that prohibits meaningful interpretation of the results. Further inconsistencies are introduced by determining an index that scales with population at the national level for most countries but at the level of subnational regions for others (e.g., USA and Russia). Second, the summation of a wealth index and a poverty index essentially adds proxies for economic risks and for risks to human lives due to a lack of coping capacity in an arbitrary and intransparent way, revealing a lack of focus. As a result of the flawed mathematics of indicator construction, China (read: very populous) and the East Coast of the USA (read: very wealthy) are identified as the most vulnerable regions whereas many least developed countries are assessed to have very low vulnerability.
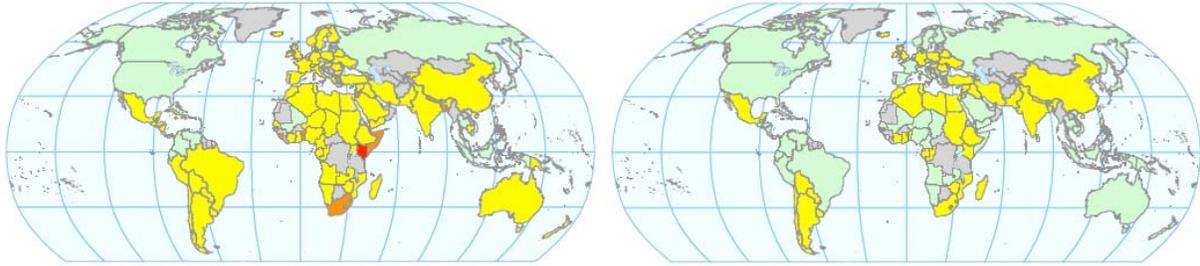
[Yohe et al. 2006b] have developed a set of indices of (aggregated outcome) vulnerability to climate change that vary according to different assumptions regarding climate sensitivity, the development of adaptive capacity, and other calibration parameters.. The project website [1] displays 144 global vulnerability maps, 8 of which are reproduced in the journal article (see Figure 4).

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[1] *http://www.ciesin.columbia.edu/data/climate/maps.html*

Figure 4: Global distribution of vulnerability to climate change for different parameter choices (top four: year 2050; bottom four: year 2100). Source: **[Yohe et al. 2006b]**

This set of indices suffers from fundamental methodological and conceptual limitations. First; the aggregated vulnerability of country i at time t is calculated as

$$V_i(t)=\Delta T_i(t)/AC_i(t),$$

whereby $\Delta T_i(t)$ is the projected change in national average temperature (i.e., a rational-scaled variable) and $AC_i(t)$ is a normalized index of national adaptive capacity (i.e., an ordinal-scaled variable) [Brenkert and Malone 2005]. Division (or multiplication) of a rational-scaled and an ordinal-scaled variable is a fundamental methodological flaw, and the result cannot be meaningfully interpreted.[2] In the present case, the variation of the resulting "vulnerability" quotient *within* maps largely reflects the distribution of adaptive capacity for specific parameter choices whereas the variation *across* maps largely reflects differences in projected changes in global mean temperature.

Second, the description of the index construction is inconsistent. The short journal article [Yohe et al. 2006b] simply states that $AC_i(t)$ is *"an index of national adaptive capacity from Brenkert & Malone (2005)"*. That article [Brenkert and Malone 2005] only develops subnational vulnerability-resilience indicators for Indian states which combine (subnational) indicators for sensitivity and adaptive capacity according to two different methods (VRIP and VRIP2). The description in the technical report on which the short journal article is based [Yohe et al. 2006a] adds to the confusion by suggesting alternatively that $AC_i(t)$ reflects sensitivity, adaptive capacity, and the VRIM index which combines sensitivity and adaptive capacity: *"The Vulnerability-Resilience Indicator Model (VRIM) takes a hierarchical approach in constructing a vulnerability index as the geometric mean of various measures of sensitivity [...] and adaptive capacity. ... A series of maps was created to portray the geographical distribution of combined national indices of exposure and **sensitivity**. These indices were, for each year and each combination of underlying parameters, defined as the quotient of modified national VRIM **adaptive capacity indices** (anchored to unity for the global average) and projected temperature change. To be more specific, we converted each national **VRIM index** to a number anchored at unity by dividing each by the world average;"* (p. 2). The most likely interpretation of the available texts is that $AC_i(t)$ in [Yohe et al. 2006b] is an unpublished national vulnerability-resilience index constructed according to the VRIP2 method described in [Brenkert and Malone 2005] for the subnational level. The alternative interpretation that $AC_i(t)$ reflects only the adaptive capacity component of that vulnerability-resilience index appears less likely (despite the wording in in [Yohe et al. 2006b]). The third interpretation that $AC_i(t)$ reflects only the sensitivity component of that vulnerability-resilience index appears least likely.

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[2] The variation of the resulting quotient is determined by the accidental ratio of the standard-deviation of the log-transformed numerator and denominator, respectively. The table below illustrates how the equation used to calculate this vulnerability index can identify any of three countries (or all three of them) as most vulnerable for four common transformations of an adaptive capacity indicator that depends only on income per capita.

Temp. change	Income per cap.		Log of income		Standard score of income		Standard score of income +1		Standard score of income +4	
ΔT_i	AC^1_i	V^1_i	AC^2_i	V^2_i	AC^3_i	V^3_i	AC^4_i	V^4_i	AC^5_i	V^5_i
	c_i	$\Delta T_i/AC^1_i$	$\log_{10}(c_i)$	$\Delta T_i/AC^2_i$	$z(c_i)$	$\Delta T_i/AC^3_i$	$z(c_i)+1$	$\Delta T_i/AC^4_i$	$z(c_i)+4$	$\Delta T_i/AC^5_i$
1	10	0.1	1	1	-0.6576	-1.5206	0.3424	2.9205	3.3424	0.2991
2	100	0.02	2	1	-0.4932	-4.055	0.5068	3.9463	3.5068	0.5703
3	1000	0.003	3	1	1.1507	2.606	2.1507	1.3948	5.1507	0.5824

In addition to the methodological flaws and the lack of transparency, the presentation of 144 different global vulnerability maps without any consistent geographical pattern prohibits their use in any conceivable policy context.

The Environmental Vulnerability Index (EVI) assesses environmental vulnerability (i.e., the risk of damage to the health of ecosystems) at the national level [Kaly et al. 2004]. The EVI considers 50 normalized indicators that represent (i) the risk of hazards occurring, (ii) the inherent resistance to damage and (iii) the acquired vulnerability resulting from past damage. A climate change subindex (EVI-CC) is defined based on 13 of these 50 indicators: five of them represent the magnitude of recent climate change; four of them represent the exposure and sensitivity of ecosystems; two of them essentially represent land area; and two others essentially represent population density.

Environmental Vulnerability Index (EVI 2004 - Climate Change)
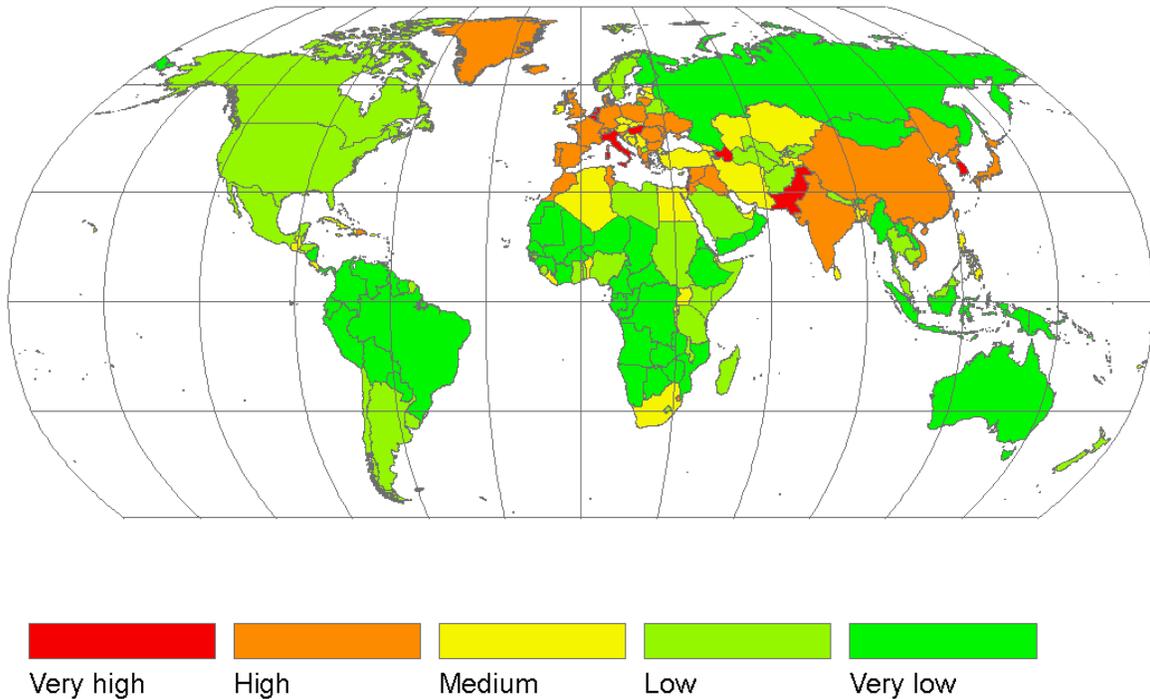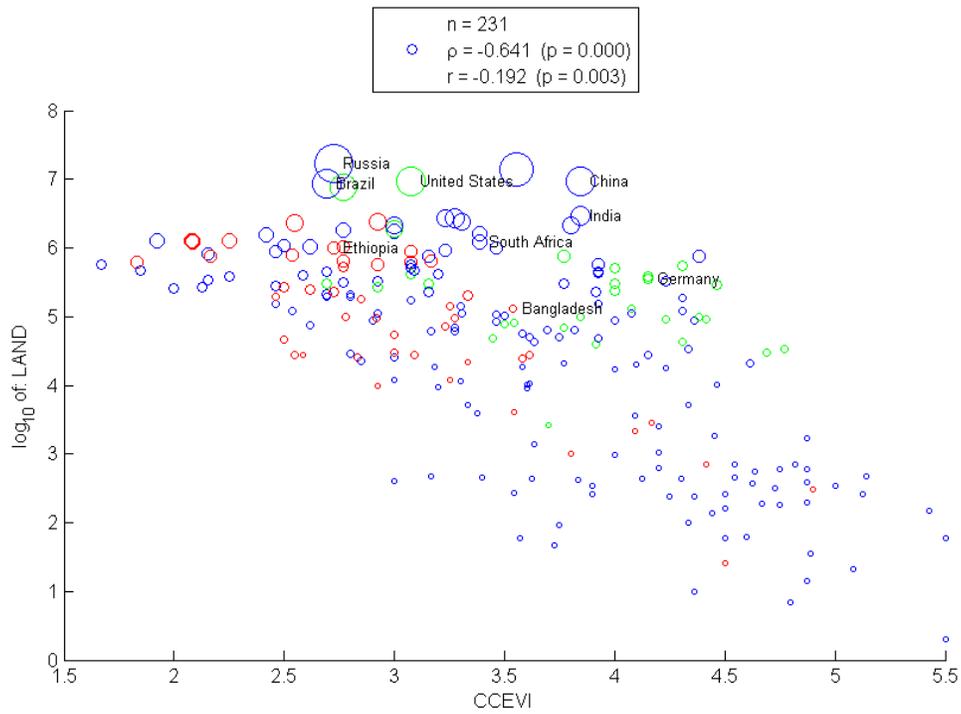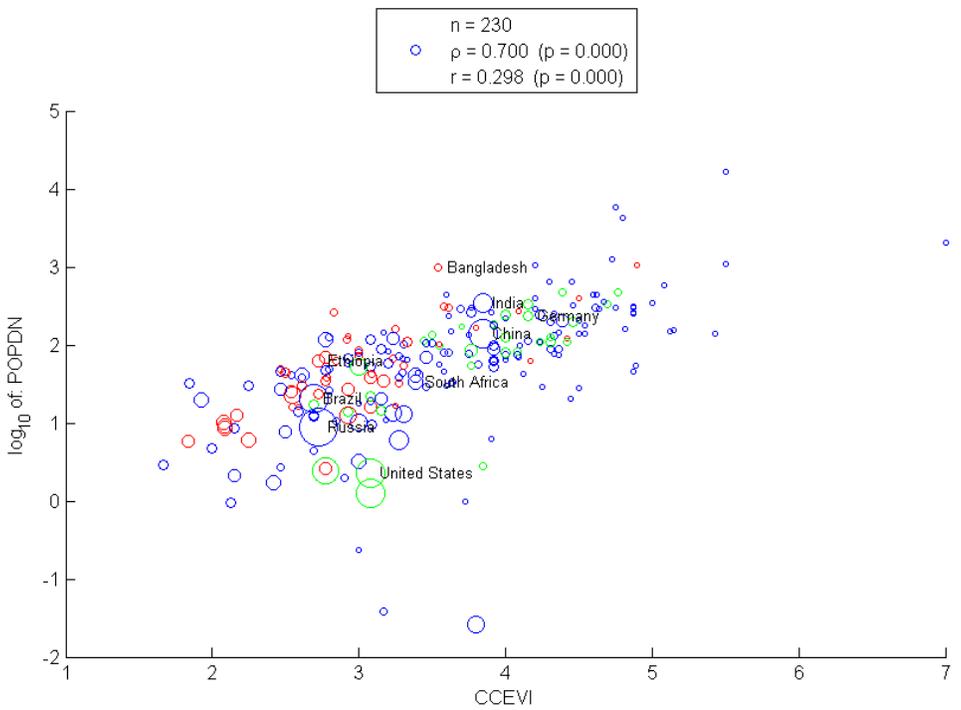

Figure 5: Map of the climate change subindex of the Environmental Vulnerability Index.

Figure 6: Correlation between the climate change subindex of the Environmental Vulnerability Index and (a) land area; (b) population density.

Figure 5 shows a global map of the EVI-CC, and Figure 6 shows the large correlation of the EVI-CC with land area and population density. The most vulnerable countries according to the EVI-CC largely fall into two groups: small island countries due to their small area and large population density (not detectable in Figure 5) and European countries due to their high scores on indicators of recent climate change. A few other countries (notably China, India, and Japan) are highly vulnerable due to a combination of reasons. The very high scores for recent climate change in European countries may be related to particularities of the short time period (1999-2003) used to identify a trend in climate compared to the (overlapping) baseline period (1973-2003). The EVI-CC does not appear to be useful for prioritizing adaptation assistance for several reasons. First, the EVI-CC deliberately does not consider the social vulnerability or adaptive capacity of different peoples; second, the EVI-CC scales strongly with land area and population density for reasons not related to the vulnerability of peoples; and finally, most least developed countries with the exception of small island states are identified as having very low vulnerability according to the EVI-CC, which is in strong contrast to all indices of social vulnerability.

15. Global vulnerability indices cannot adequately consider special conditions that make certain countries, or groups of countries, particularly vulnerable to climate change.

The development of vulnerability indices needs to balance the partly competing goals of simplicity, robustness, and comprehensiveness. In the words of [Gall 2007]: *"Ultimately, (global) social vulnerability indices reflect the smallest common denominator of vulnerability concepts and data availability"* (p. 61). For that reason, aggregated vulnerability indices generally cannot adequately consider special circumstances that make certain countries, or groups of countries, particularly vulnerable (or resilient) to climate change. For example, [Brooks et al. 2005] note that *"The vulnerability of small island states is likely to be under-represented as they constitute a minority 'special case'; the particular factors that lead to large negative outcomes in islands (small size, low elevation, isolation, etc.) are not characteristics of the majority of the countries assessed here, and their effects will therefore not lead to a significant statistical signal in the analysis"* (p. 161). This problem appears particularly relevant for two types of countries. First, countries whose economy is strongly dependent on climate-sensitive activities that are not considered by the aggregated vulnerability indicator, such as tropical countries that specialize in perennial crops grown near their upper temperature limit (e.g., coffee in Uganda). Second, countries that may be exposed to unprecedented climatic hazards due to climate change in the future. For instance, if tropical cyclones were regularly building in the South Atlantic, this would pose a significant new threat to Brazil.

4 Aggregated vulnerability indices and international adaptation funding

16. National-level vulnerability indices can, in principle, inform two types of decisions regarding international adaptation funding: classifying countries into discrete vulnerability categories and determining fair allocations for adaptation assistance.

The establishment and operationalisation of a global adaptation fund requires finding answers to the following fundamental questions:

a. What is the overall amount of funds needed to assist adaptation in particularly vulnerable countries?

b. Which countries (or non-governmental actors) contribute how much to meet the total amount of resources needed?

c. Which countries are eligible and/or prioritized for international adaptation assistance?

d. What are 'fair' national allocations for eligible countries?

e. What are adequate mechanisms and conditions for the disbursement of funds to recipient countries?

Questions a and b are not addressed here. For recent summaries of the discussion on these topics, see [Behrens 2008] and [Fujiwara et al. 2008], respectively. Questions c and d are related but finding an answer to Question c may be easier (politically and in terms of information needs) than to Question d. Ordinal information on the vulnerability of countries and/or of systems and sectors within countries is sufficient to assign countries to different groups that define their eligibility and conditions for funding (e.g., the fraction of necessary adaptation costs covered from domestic resources). Determining fair national allocations for adaptation, in contrast, requires quantitative information on the differential vulnerability of countries as well as on their adaptability. Given the challenges of constructing quantitative aggregated vulnerability indices, sector-specific information on potential climate impacts and adaptive capacity is required for this purpose. Question e is not addressed here. Disaggregated vulnerability information can, however, inform the specification of conditions for international adaptation funding, including on the most appropriate mechanisms for the disbursement of funds (e.g., budget support, project funding, and technology transfer).

17. Prioritization of international adaptation assistance involves several normative challenges in addition to those of assessing countries' vulnerability to climate change.

Key normative challenges in determining priority for, or levels and disbursement conditions, of international adaptation assistance include balancing of climatic and non-climatic risks, of assistance for specific adaptation to climate change and more general development assistance, of equity and efficiency goals, and of adaptation costs and residual climate damages.

18. The common postulation that those countries most vulnerable to climate change should receive priority assistance for adaptation is ambiguous; its naïve implementation can produce highly controversial outcomes.

The discussion in Section 2 has emphasized the substantial variety across vulnerability concepts and indicators, and Section 3 has shown that this variety can lead to substantial differences in the identification of the most vulnerable countries. Independent of the particular vulnerability concept applied, however, prioritization of adaptation assistance to the most vulnerable countries can lead to highly controversial results as it may implicitly "reward" poor governance. As an illustration, imagine two countries at the same level of economic development that are exposed to identical climatic hazards (e.g., tropical cyclones) and have identical biophysical sensitivity to these hazards. Under these conditions, the population in the country with poorer governance (e.g., in terms of effective disaster preparedness and response) will be more vulnerable than the population in the country with better governance. It is likely to be controversial whether the country with poor governance (and thus higher vulnerability) should receive higher, equal, or lower adaptation assistance than the other. The underlying conflict is whether the population in the country with poor governance should be regarded primarily as vulnerable or also as (partly)

responsible for its vulnerability. This conflict suggests that it may be impossible to address the level and conditions of adaptation funding separately.

19. The consideration of factors determining the "adaptability" of countries in decisions on international adaptation assistance will be particularly controversial because they can have contrary effects on the magnitude of national allocations for adaptation, depending on the applied principle of distributive justice.

Under most interpretations of the UNFCCC, fair national allocations from a global adaptation fund are positively related to outcome vulnerability (as a measure of the risks from climate change in the absence of international assistance) and to aid effectiveness. Governance factors generally have opposite effects on vulnerability and aid effectiveness, which makes their consideration in the prioritization of adaptation assistance particularly controversial. Everything else being equal, poor performance of national governments generally increases vulnerability to climate change, suggesting that a country should receive priority assistance for adaptation. At the same time, poor governance generally decreases aid effectiveness, suggesting that a country should *not* receive priority assistance for adaptation. The net effect of governance effectiveness on international adaptation funding thus depends on the relative weights given to the *vulnerability* of poor populations and the (partial) *responsibility* of their national governments for this situation [Miller 2007].

Everything else being equal, countries with unfavourable environmental-economic conditions for adaptation (e.g., in the case of coastal protection: a jagged coastline, low population density, or high price levels for construction services) require more resources per person to reduce adverse social impacts of climate change than others. Therefore, environmental-economic adaptability should also be considered in determining fair national allocations for adaptation. Different principles of distributive justice, however, suggest positive as well as negative effects on fair national allocations under resource constraints (see Table 6). Therefore, consideration of this factor is likely to be controversial in negotiations about adaptation funding (see Section 4 for further discussion).

	Allocation principle	**Countries favoured**
Parity	Same amount to all	Small countries
Proportionality	Proportional to damages	Countries with large (potential) damages
Equitable results	Preserve the current distribution of climate-sensitive resources or risks	Countries where adaptation is relatively 'expensive'
Classical utilitarianism	Maximize adaptation benefits regardless of location	Countries where adaptation is relatively 'cheap'
Priority view	Maximize welfare of those worst off	Least developed countries

Table 6: Alternative principles of distributive justice under resource scarcity.

5 Disaggregated vulnerability factors and adaptation assistance

20. The prioritization of countries for international adaptation assistance requires disaggregated information on the vulnerability of countries because aggregated indices tend to hide legitimate political or ethical controversies.

The chapters above have revealed severe limitations of all published indices of national-level vulnerability to climate change. While some of the empirical and methodological problems can in principle be addressed by improved index construction, the fundamental conceptual and normative challenges in the development of aggregated vulnerability indices cannot be overcome by better science alone. Therefore, the prioritization of countries for international adaptation assistance requires either clear political prioritization that can be implemented by a tailor-made aggregated vulnerability index or disaggregated vulnerability information that can inform the political debate.

21. Priorities for adaptation assistance should be determined separately for key climate-sensitive systems and sectors to account for large differences in the geographical distribution and predictability of climate impacts and in the types and time scales of adaptation measures.

Adaptation measures need to be tailored to the circumstances of a particular climate-sensitive system, sector, or population group at a particular location. Different systems and sectors vary widely with respect to the most relevant climate variables (e.g., temperature and precipitation for agriculture, mean precipitation for water infrastructure, extreme precipitation for flood risks, sea level and storminess for coastal zones, extreme heat for health effects, sea surface temperature for coral reefs, etc.) and in their relationship between climate variables and impacts. For example, the relationship between sea-level rise and the risk to coastal populations and infrastructure is always positive whereas the relationship between temperature and agricultural productivity may be positive or negative, depending on the current climate in a region and the potential to switch crops. As a result, the geographical distribution of climate impacts and their predictability differs widely across sectors. Different climate-sensitive sectors are also distinguished by the typical policy horizons for adaptation measures. For example, cereal farmers can adjust crop varieties annually, which allows for reactive adaptation to perceived climate change. In contrast, urban planners and forest managers need to adapt proactively to future climate change because many of their decisions shape the vulnerability of a system for many decades [Reilly and Schimmelpfennig 2000]. Furthermore, for some systems climate change will manifest primarily as changes in the frequency of existing climate extremes whereas others will face unprecedented climate conditions. These qualitative differences in climate impacts and suitable adaptation strategies suggest that priorities for adaptation assistance should be determined separately for key climate-sensitive systems and sectors (e.g., water supply, agriculture and fisheries, health, natural hazards, coastal zones). Another advantage of a sector-specific approach is that adaptation funding can already be made available for systems and sectors in clear need of adaptation now due to current impacts or long policy horizons even if impact projections or adaptation needs in other sectors are more contested.

22. The prioritization of international adaptation assistance should distinguish five groups of vulnerability factors and two groups of adaptability factors.

The discussion in Section 2 has presented several conceptual frameworks of vulnerability factors. The IPCC definition of vulnerability distinguishes exposure, sensitivity, and adaptive capacity. A review of several other conceptual frameworks suggested, among others, to clearly distinguish biophysical and socioeconomic factors [Füssel 2007]. Finally, the discussion in Section 4 concluded that adaptability may be an important (though controversial) criterion for adaptation funding, and that governance factors should be separated from other vulnerability and adaptability factors due to their potentially controversial effects on fair allocations for adaptation. Taking these requirements together, the five groups of vulnerability factors and two groups of adaptability factors presented in Table 7 are suggested as the minimum framework for structuring information that may guide the prioritization of international adaptation assistance.

Factors determining (outcome) vulnerability

1.	Magnitude of regional climate change	+
2.	Biophysical sensitivity	+
3.	Socio-economic exposure/ importance	+
4.	Lack of adaptive/coping capacity (non-governance)	+
5.	Lack of adaptive/coping capacity (governance)	o/+ (−)
➢	Potential climate impacts (integrates 1-3)	+
➢	Social vulnerability (integrates 4-5)	+/o (−)
➢	**Outcome vulnerability (integrates 1-5)**	+/o (−)

Factors determining adaptability

6.	Environmental-economic adaptability	−/o/+
7.	Aid effectiveness (governance)	+/o (−)
➢	**Adaptability (integrates 6-7)**	+/o/−

Table 7: Key determinants of (outcome) vulnerability and adaptability. The right column depicts the sign of their assumed effect on fair allocations for adaptation (see text for details).

The sign of factors 4 and 5 has been inverted (by inserting "lack of …") so that increasing any of the factors 1 to 5 increases outcome vulnerability, and increasing any of the factors 6 to 7 increases adaptability. Note that variables available in international databases may combine factors from more than one category. For instance, indicators on the effectiveness of institutions generally reflect governance as well as non-governance aspects of adaptive capacity.

Table 7 not only identifies key groups of vulnerability and adaptability factors, it also illustrates how these factors are expected to influence fair national allocations from a global adaptation fund. The higher a country scores on any of the factors 1 to 4, the larger is its fair allocation. The same applies to potential climate impacts, which combines factors 1 to 3. The *direct* effect of a high score on factor 5 (i.e., low adaptive/coping capacity due to poor governance) on the adaptation allocation is either positive or neutral, depending on the applied principle of justice. If factor 5 is largely the inverse of factor 7, however, the *total* effect of a high score on factor 5 can be negative. A sign noted in brackets indicates that the sign of the combined effect of this factor may differ from the sign of the direct effect. The signs for potential climate impacts, social vulnerability, and outcome vulnerability result from the combination of the signs for its components.

If the resources in a global adaptation fund are sufficient for meeting all legitimate claims, factor 6 is negatively related to fair allocations for adaptation. In other words, the easier the environmental conditions for adaptation, the fewer resources are needed and allocated. As discussed in Section 4, however, this negative relationship does not necessarily hold under resource constraints. In particular, a utilitarian perspective suggests allocating scarce financial resources first to those countries where adaptation is easiest. Therefore, the direct relationship between factor 6 and adaptation allocations can be positive, negative or neutral. The direct effect of factor 7 is positive or neutral. If we assume that factor 7 is largely the inverse of factor 5, the *total* effect of a high score on factor 7 can also be negative. The sign for adaptability results from the combination of the signs for its components.

23. Some vulnerability indicators are applicable across climate-sensitive sectors whereas others are only relevant for a particular sector or system.

Table 8 illustrates the conceptual framework of vulnerability factors presented in Table 7 by applying it to key climate-sensitive sectors and systems. Most vulnerability indicators are relevant for particular sectors only but some indicators of socio-economic adaptive/coping capacity are relevant across sectors.

	Coasts	Water	Food	Human health
GHG emissions	Cumulative CO_2 emissions per cap. since 1990 from fossil sources Cumulative CO_2 emissions per cap. since 1990 from all sources			
Climate change	Climate Change Index (Baettig et al.) National Climate Change Index (Diffenbaugh et al. / Giorgi)			
Biophysical sensitivity	Share of coastal area	Current temperature		
		Water resources per capita	Change in crop yields	
Socio-econ. exposure	Coastal population	Water use ratio	Agricultural GDP and labour force	Population in disaster hotspots
Potential impacts	Increase in population flooded	Change in runoff	Ricardian impacts	Mortality from climate change
Social vulnerability (lack of adaptive capacity)	Human development index Physical capital stock per capita Government effectiveness			
	GDP per capita	Households with improved water supply	Prevalence of undernourishment	Vulnerability index for mortality from natural disasters

Table 8: Conceptual framework of generic and sector-specific vulnerability factors with illustrative indicators.

6 Analysis of disaggregated vulnerability factors

24. The geographic pattern of vulnerability factors and the causal relationship with responsibility for climate change varies widely across sectors.

Table 9 shows the statistical relationship between the vulnerability factors identified in Table 8 and historic responsibility for climate change. Red colours depict vulnerability factors that are negatively correlated with responsibility for climate change (i.e., countries less responsible for

climate change are significantly more vulnerable) whereas green colours depict vulnerability factors that are positively correlated with responsibility for climate change. Shaded colours indicate vulnerability factors that are significantly correlated with responsibility for climate change if carbon emissions from fossil sources are considered but not if carbon emissions from land use are included as well [Bondeau et al. 2007]. Obviously, those countries least responsible for climate change (on a per capita basis) generally have the highest social vulnerability to it. In the case of food security and human health, this injustice also extends to other vulnerability factors. For example, agriculture in low-emitting countries is generally more negatively impacted by climate change, and the population in these countries is more sensitive to and less able to cope with these impacts than in high-emission countries. The situation is more complex for water and for coastal zones.

	Coasts	Water	Food	Human health
GHG emissions	Cumulative CO_2 emissions per cap. since 1990 from fossil sources Cumulative CO_2 emissions per cap. since 1990 from all sources			
Climate change	Climate Change Index (Baettig et al.) National Climate Change Index (Diffenbaugh et al. / Giorgi)			
Biophysical sensitivity	Share of coastal area	Current temperature		
		Water resources per capita	Change in crop yields	
Socio-econ. exposure	Coastal population	Water use ratio	Agricultural GDP and labour force	Population in disaster hotspots
Potential impacts	Increase in population flooded	Change in runoff	Ricardian impacts	Mortality from climate change
Social vulnerability (lack of adaptive capacity)	Human development index Physical capital stock per capita Government effectiveness			
	GDP per capita	Households with improved water supply	Prevalence of undernourishment	Vulnerability index for mortality from natural disasters

🟩	High-emitting countries score higher on vulnerability factor
🟥	Low-emitting countries score higher on vulnerability factor

Table 9: Justice implications of climate change across sectors (see text for details).

25. The two aggregated national-level indices of climate change in the literature do no agree about those regions where climate change is strongest.

Two aggregated national-level climate change indices have been suggested in the literature. [Baettig et al. 2007] present a national climate change index (NCCI) that relates future changes in seasonal and annual temperature and precipitation extremes simulated by 3 GCMs to current climate variability. Hence, it highlights those regions where the magnitude of projected climate change is particularly large compared to current interannual climate variability. **[**Diffenbaugh et al. 2007**]** present a climate change index (CCI) that was adapted from the regional climate change index (RCCI) by [Giorgi 2006]. The CCI combines projected changes in temperature and

precipitation from 22 global climate models (GCMs) as well as the population share in coastal regions. Hence, the CCI comprises indicators of climate change and of socio-economic exposure. Current climate variability is not considered in the construction of the CCI.
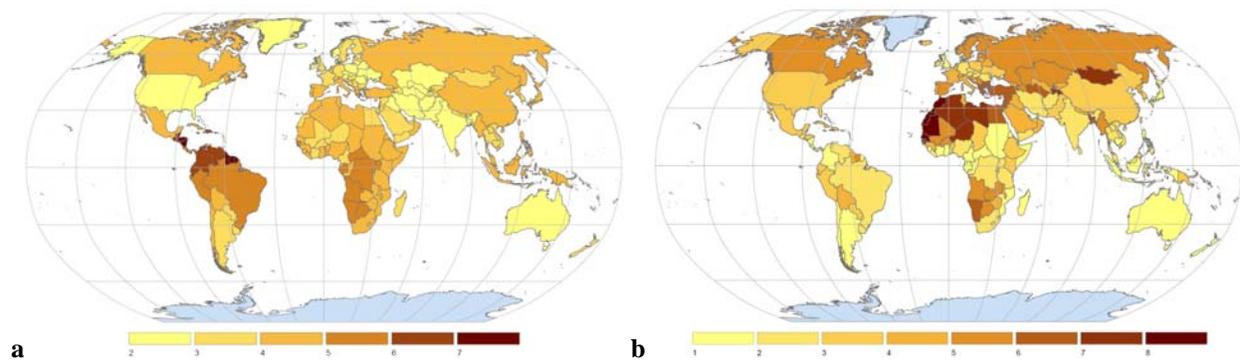

Figure 7: Two national-level climate change indices. Source: (a) [**Baettig et al. 2007**]; (b): [**Diffenbaugh et al. 2007**]

Figure 7 shows that the CCI and NCCI show little agreement regarding climate change hotspots. The rank correlation between the two indices is actually slightly negative (but not statistically significant). The NCCI is regarded as the more suitable aggregated climate change index because of its more consistent conceptual framework and its less subjective construction but its relevance for policy decisions (e.g., on international adaptation funding) appears to be limited.

26. Global studies on the combined effect of climate change and CO_2 increase on crop production show limited agreement regarding the most affected regions.

Two global studies of the potential effects of climate change and CO2 increase on agricultural production and food security stand out because they made available national-level estimates of rain-fed yield of major food crops based on multiple climate model simulations. [Parry et al. 2005] apply the IBSNAT/DSSAT crop models to calculate yield changes for 4 staple crops (wheat, rice, coarse grains, and soybeans) in 13 individual countries and 19 multi-country regions assuming 'full' carbon fertilization (data available from [Cline 2007]). The climate projections for the 2080s are based on 4 GCMs forced by the IPCC IS92a emissions scenario. [Fischer et al. 2002] apply the GAEZ model to calculate yield changes for 83 cereal types with carbon fertilization for individual countries (data available at http://www.iiasa.ac.at/Research/LUC/SAEZ/app/dwnxls.htm?f=xls/data14.xls). The climate projections for the 2080s are based on 3 GCMs forced by the IPCC SRES A2 emissions scenario.
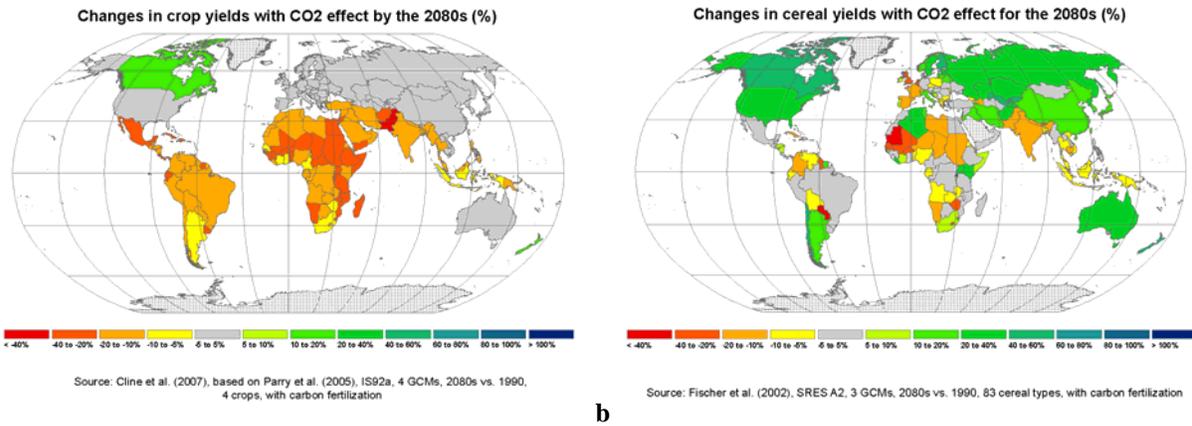
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Figure 8: Combined influence of climate change and increased CO_2 concentration on the yield of major food crops. Source: (a) **[Parry et al. 2005]**; (b) **[Fischer et al. 2002]**
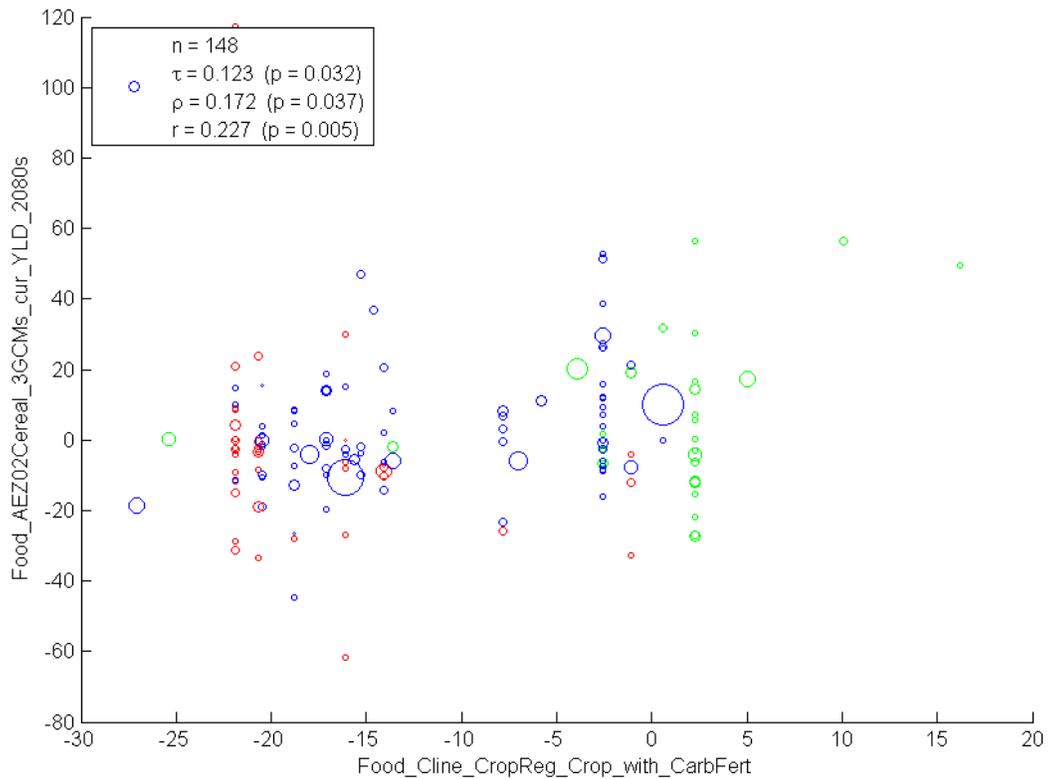

Figure 9: Scatter plot of projected changes (in %) in rain-fed crop yields by the 2080s according to **[Parry et al. 2005]** (horizontal axis) and **[Fischer et al. 2002]** (vertical axis). Each circle represents one country, whereby circles are scaled according to population size. *Red*, *green,* and *blue* markers represent least developed countries, OECD countries, and other countries, respectively.

Figure 8 shows global maps of projected changes in rain-fed crop yield due to climate change by the 2080s from both studies; Figure 9 depicts the associated scatter plot. The two studies agree on projected yield changes in some regions and disagree in others. According to [Parry et al.

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2005], least developed countries (LDCs; depicted by red markers in Figure 9) will be strongly negatively affected whereas small effects are projected for most OECD countries (depicted by green markers). Note that this pattern is influenced by the coarse spatial resolution of the original study (revealed by the vertical lines of points). For instance, the same climate impact response function was applied to the 15 countries of the European Union (status of 2003). [Fischer et al. 2002] shows only weak systematic differences in yield projections between LDCs and OECD countries. The rank correlation between the results from the two studies of ρ=0.17 is just significant at the 5% level. The grouping of heterogeneous countries in [Parry et al. 2005] is one factor for this low correlation. Nevertheless, both studies agree that climate change may be associated with substantial risks for agriculture in many regions that are currently food-insecure.

27. Global studies on the vulnerability of coastal zones to sea-level rise and storm surges are severely hampered by the unavailability of data on coastal protection at the global level. Studies based exclusively on biophysical data identify different regional hotspots than studies that include estimates of coastal protection levels.

Global studies on the vulnerability of coastal zones have applied two different methods. Some of them have combined digital elevation models with datasets on the distribution of population and other valued assets to estimate the risks of sea-level rise assuming no coastal protection. As an example, Figure 10.a shows results from [Buys et al. 2007, Dasgupta et al. 2007]. Other studies have included estimates of coastal protection levels based on regional economic and demographic data. As an example, Figure 10.b shows results from DIVA 1.5.5 [Hinkel 2008, Klein and Hinkel 2009]. The two maps show little agreement regarding the most vulnerable countries, and the rank correlation (excluding land-locked countries) is actually slightly negative but not significant. (The numerical values in the two maps are not directly comparable due to differences in forcing scenarios and depicted indicators.) The scatter plot in Figure 11 presents additional information for different groups of countries. (Note that small island states are not depicted because they are not included in the World Bank studies [Buys et al. 2007, Dasgupta et al. 2007]; the Netherlands are excluded for better readability.) The two indicators show no agreement at all in OECD countries (depicted in green) where flood risk is estimated to be very low regardless of the population share in low-elevation coastal zones. Even in poorer countries, however, there is little agreement on the most vulnerable countries. With the exception of Vietnam, those countries with the largest increase in population flooded according to DIVA have a surprisingly low population fraction living below 1 m according to the World Bank studies. Hence, there is a clear need to improve datasets on coastal population, in particular in Africa.
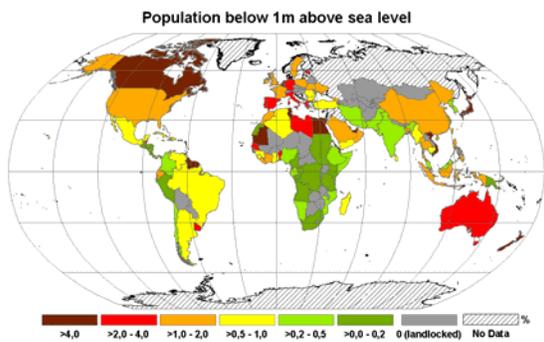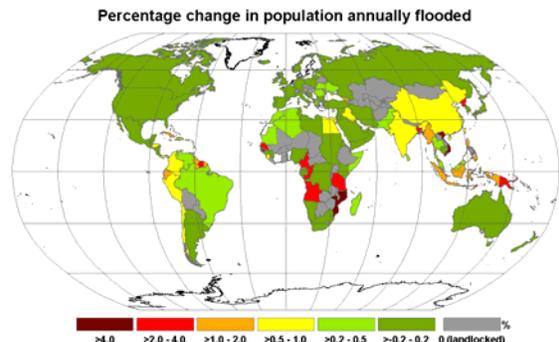
Source: DIVA Model (Hinkel, 2008)
Scenario: SRES A2, 2070 vs. 2000, with SLR & natural subsidence, no coastal protection, constant population

a   b

Figure 10: Two coastal vulnerability indicators: (a) Percentage of population living in coastal zones below 1 m (Source: **[Buys et al. 2007, Dasgupta et al. 2007]**); (b) increase in the percentage of population annually flooded (Source: **[Hinkel 2008]**).
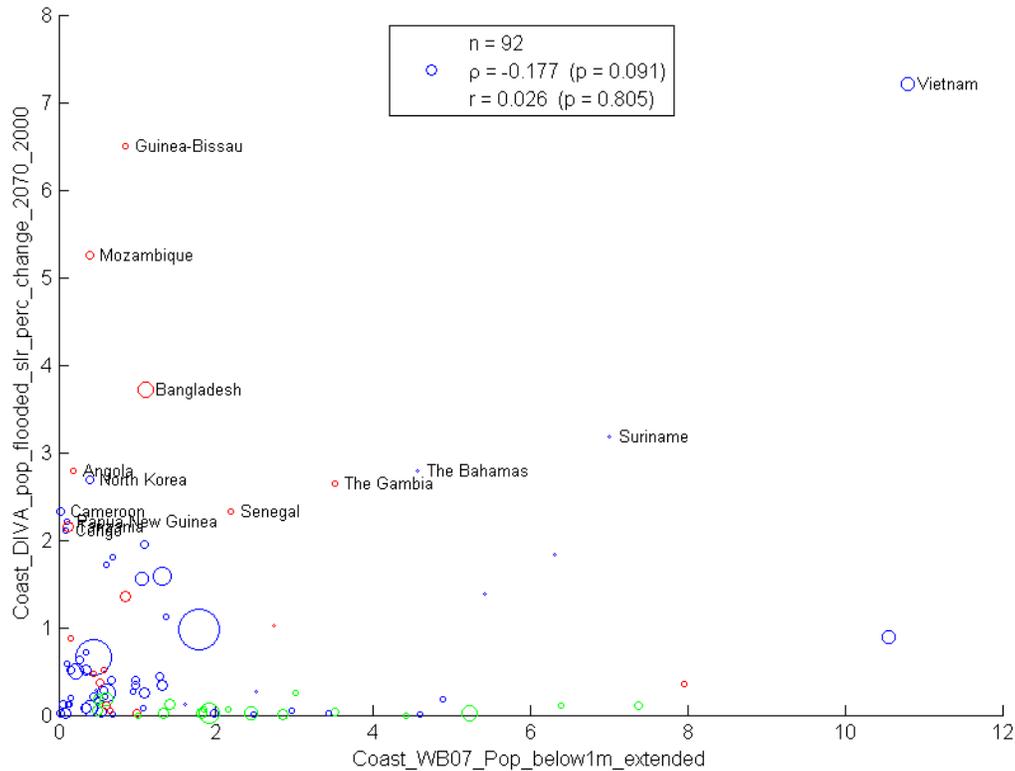

Figure 11: Scatter plot of the population share living in coastal zones below 1 m (horizontal axis, in %, according to **[Buys et al. 2007, Dasgupta et al. 2007]**) and the increase in population annually flooded (vertical axis, in %, according to **[Hinkel 2008]**). Each circle represents a coastal country, whereby circles are scaled according to population size. *Red*, *green*, and *blue* markers represent least developed countries, OECD countries, and other countries, respectively.

28. Cross-sectional analyses as well as modelling studies have found hill-shaped response functions between mean temperature and the productivity of major economic sectors. Current temperature may therefore serve as an indicator for the generic sensitivity of countries to climate change (other than sea-level rise) that has not been considered in any of the published indices of vulnerability to climate change. Almost all least developed countries are located in a climate zone where additional warming has negative effects on all main economic sectors.

Climate strongly influences opportunities for economic development, both directly (e.g., in terms of the potential for agriculture and tourism) and indirectly (e.g., in terms of its attractiveness for a skilled mobile workforce). A recent analysis identified current climate as the primary reason why poor countries are so vulnerable to climate change (in terms of percentage loss of their GDP) [Mendelsohn et al. 2006]. In that study, both cross-sectional analysis (based on data from the USA) and impact model simulations project negative effects of additional warming on

economic activity in all sectors for annual mean temperature above 15°C.[3] A cross-sectional analysis based on a global data-set also found decreasing economic activity per person as well as per area above 15°C [Nordhaus 2006]. These results are robust across variations of aggregation methods and apply for all precipitation regimes [Füssel 2009]. Current temperature may therefore serve as a generic indicator for the sensitivity of countries to climate change (other than sea-level rise) that has not been considered in any of the published vulnerability indices.
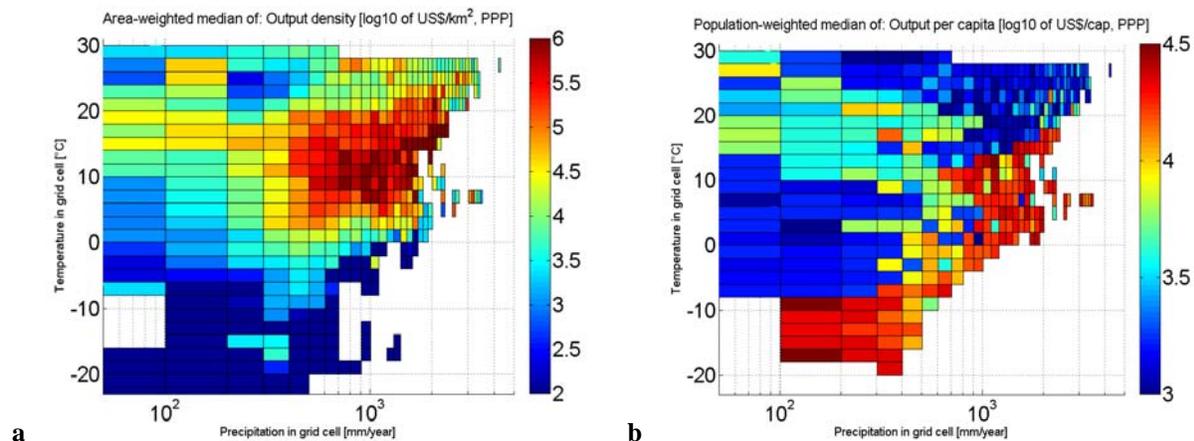

Figure 12: Combined influence of temperature and precipitation (log-scaled) on (a) economic output per area and (b) output per capita. Source: **[Füssel 2009]**

7 Conclusions

The term vulnerability has been defined in many different ways by various scholarly communities. The hybridization of concepts from different schools of vulnerability research in studies on climate change contributes to considerable confusion regarding appropriate conceptualizations of vulnerability to climate change. The most prominent interpretations of vulnerability in the climate change context are contextual vulnerability and outcome vulnerability, whereby the IPCC definition of vulnerability corresponds to outcome vulnerability. Clarity over its primary purpose is crucial to guide the development of any vulnerability index, or set of indicators. Given the diversity of decision contexts that can be informed by climate change vulnerability assessments and of normative preferences, the design of vulnerability indices is as much a political as a scientific task. The development of aggregated national-level vulnerability indices requires substantial normative choices in the selection and aggregation of diverse information across time, affected systems and regions, and impact metrics, which largely determine the resulting vulnerability ranking.

All existing indices of vulnerability to climate change show substantial conceptual, methodological and empirical weaknesses including lack of focus, lack of a sound conceptual framework, methodological flaws, large sensitivity to alternative methods for data aggregation, limited data availability, and hiding of legitimate normative controversies. As a result, there is little agreement regarding the most vulnerable countries. A multi-criteria evaluation concludes that the human development index outperforms several more recent indices as a generic national-level index of social vulnerability to climate change. Three recently developed aggregated indices of outcome vulnerability to climate change (21st century socioclimatic exposure, global

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[3] This climate zone comprises all least developed countries except parts of Afghanistan, Nepal and Bhutan.

distribution of vulnerability, and the climate change subindex of the SOPAC Environmental Vulnerability Index) are inappropriate for prioritizing international adaptation funding due to severe conceptual, methodological and empirical weaknesses.

National-level vulnerability indices can, in principle, inform two types of decisions regarding international adaptation funding: classifying countries into discrete vulnerability categories and determining fair allocations for adaptation assistance. These decisions involve several normative challenges in addition to those of assessing countries' vulnerability to climate change. The consideration of factors determining the "adaptability" of countries in decisions on international adaptation assistance will be particularly controversial because they can have contrary effects on the magnitude of national allocations for adaptation, depending on the applied principle of distributive justice. The common postulation that those countries most vulnerable to climate change should receive priority assistance for adaptation is ambiguous, and its naïve implementation can produce controversial outcomes.

The prioritization of countries for international adaptation assistance requires disaggregated information on the vulnerability of countries because aggregated indices tend to hide legitimate political or ethical controversies. Priorities should be determined separately for key climate-sensitive systems and sectors to account for large differences in the geographical distribution and predictability of climate impacts and in the types and time scales of adaptation measures. The prioritization should distinguish five groups of vulnerability factors and two groups of adaptability factors. Some vulnerability indicators are applicable across climate-sensitive sectors whereas others are only relevant for a particular sector or system.

Global studies on the combined effect of climate change and CO_2 increase on crop production show limited agreement regarding the most affected regions. Global studies on the vulnerability of coastal zones to sea-level rise and storm surges are severely hampered by the unavailability of data on coastal protection at the global level. Studies based exclusively on biophysical data identify different regional hotspots than studies that include estimates of coastal protection levels. Cross-sectional analyses as well as modelling studies have found hill-shaped response functions between mean temperature and the productivity of major economic sectors. Current temperature may therefore serve as an indicator for the generic sensitivity of countries to climate change (other than sea-level rise) that has not been considered in any of the published indices of vulnerability to climate change. Almost all least developed countries are located in a climate zone where additional warming has negative effects on all main economic sectors.

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