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To What Extent Are African Countries Vulnerable to Climate Change? Lessons from a New Indicator of Physical Vulnerability to Climate Change

by
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Abstract

This paper examines the vulnerability of African countries to climate change, for which they are not responsible. It is based on an index of structural or physical vulnerability to climate change at the country level, denominated below by the acronym PVCCI. This index has been created recently by the authors, and has been made available on the FERDI website.

The design of this index draws both on the environmental literature, and some principles used by the United Nations to measure structural economic vulnerability via the Economic Vulnerability Index (EVI) for the identification of the Least Developed Countries (LDCs). As an environmental index, the PVCCI uses components which reflect only the physical consequences of climate change which can directly affect population welfare and activity, rather than on an assessment of their economic consequences. At the same time this index of vulnerability to climate change refers only to a vulnerability which does not depend on the present will of African countries. In other words, this index refers to a "structural" or "physical" vulnerability, putting to one side resilience which is usually integrated into vulnerability assessments, but is largely dependent on policy factors. The components of this new index respectively capture two kinds of risks related to climate change: the increasing risk of recurrent shocks (such as droughts), and the risks of progressive irreversible shocks (such as flooding due to higher sea level). Moreover the components refer both to the likely size of the shocks and to the country exposure to these shocks.

The study shows a high heterogeneity among countries in their level of physical vulnerability to climate change, even within the same regional area or continent. On average African countries, which have already been found to show a relatively high economic vulnerability (c.f. the UN Economic Vulnerability Index), also appear to have a relatively high physical vulnerability to climate change, but with significant differences between countries, mainly due to the risk of drought. The index permits the characterization of climate change vulnerability for developing countries, particularly African countries, laying some foundations for the improvement of adaptation policies. With regard to the growing concern of the international community as to how to mobilize resources to deal with adaptation, the PVCCI index sheds light on the challenge of climate change for African countries. We suggest that such an index should be considered as one of the relevant criteria for the geographical allocation of resources devoted to adaptation.

Résumé

L'article examine la vulnérabilité des pays africains au changement climatique, changement dont pour l'essentiel ils ne sont pas responsables. Il repose sur un nouvel indice établi par pays, qui est un indice de vulnérabilité structurelle ou physique, désigné ci-après par son acronyme anglais PVCCI (Physical Vulnerability to Climate Change Index), récemment construit par les auteurs et disponible sur le site web de la Ferdi.

La définition de cet indice s'appuie à la fois sur les travaux relatifs à l'environnement et sur les principes appliqués pour mesurer la vulnérabilité économique structurelle à travers l'Indice de vulnérabilité économique (EVI) établi aux Nations unies en vue d'identifier les pays les moins avancés. Indice environnemental, PVCCI repose sur des composants reflétant les conséquences physiques du changement climatique qui peuvent directement affecter le bien-être et l'activité des populations, plutôt que sur une évaluation de ses conséquences économiques. Simultanément cet indice de vulnérabilité au changement climatique vise à refléter seulement la vulnérabilité qui ne dépend pas de la volonté présente des pays, autrement dit la vulnérabilité physique ou structurelle, laissant de côté la résilience, souvent intégrée aux évaluations de la vulnérabilité, mais qui largement dépend de la politique présente des pays. Les composants de l'indice saisissent deux types de risques liés au changement climatique: ceux qui correspondent à une intensification des chocs récurrents (tels que les sécheresses) et ceux qui correspondent à des chocs progressifs et irréversibles (tels que l'élévation du niveau de la mer). De plus ils se rapportent soit à l'amplitude probable des chocs, soit au degré d'exposition à ces chocs.

L'étude fait apparaître une forte hétérogénéité entre les pays quant au niveau de vulnérabilité physique au changement climatique, même à l'intérieur d'une région ou d'un continent. Les pays africains, qui en moyenne ont déjà une forte vulnérabilité économique structurelle au regard de l'indice EVI, manifestent aussi une forte vulnérabilité physique au changement climatique au regard du nouvel indice PVCCI ; au demeurant l'indice fait apparaître des différences sensibles entre eux, notamment en raison des risques de sécheresse. L'indice permet de caractériser la vulnérabilité au changement climatique des pays en développement, en particulier africains, donnant ainsi des bases aux politiques d'adaptation. Face à la préoccupation croissante de la communauté internationale pour mobiliser des ressources afin de faire face aux problèmes d'adaptation, l'indice PVCCI peut permettre de mieux comprendre ce que sont les défis du changement climatique pour les pays africains. Nous suggérons qu'un indice tel que l'indice de vulnérabilité physique au changement climatique peut être un des critères pertinents d'allocation géographique des ressources pour l'adaptation.

Keys words: environment, vulnerability, climate change, shock, adaptation policies

JEL code : E01, E61, C43, O10, O13, O19, Q54, Q56

Introduction

It has been shown that African countries face a higher structural economic vulnerability than other developing countries (Guillaumont, 2007).The purpose of this paper is to present some new evidence which shows that African countries also face a relatively high vulnerability to climate change. It should be remembered that climate change associated to global warming is due in large part to the destruction of the ozone layer, which is mainly due to industrial activity in developed countries, and to lesser extent in large emerging countries, but not to the expansion of African industrial activity.

Most African countries frequently deal with risks resulting from climate, such as droughts, a frequent event in semi-arid countries of Sub-Saharan Africa. The effects of drought are exacerbated in these regions by deep rural poverty, limited government capacity, and exposure to additional shocks (Kazianga and Udry, 2006). Such climatic risks particularly affect poor countries, and it is a growing concern that climate change will worsen these events through increased rainfall variability (IPCC, 2007). Indeed climate change tends to magnify the frequency, size and distribution of these hazards. These changes represent a severe problem in many geographical areas, especially in developing countries. Developing countries are generally considered more vulnerable to the effects of climate change because they have a lower capacity of adaptation (Wisner et al., 2004, Thomas and Twyman, 2005). Among developing countries, many in Africa are seen as being the most vulnerable to climate change (Slingo et al., 2005). High levels of vulnerability as well as limited financial and institutional ability to adapt, low per capita GDP and high poverty tend to exacerbate the consequences of climate change. The impact of climate change is likely to be considerable in tropical regions. Overall, crop yields may fall by 10 to 20% in the period to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003). As a consequence there is a considerable and increasing activity by development agencies and governments to support the development of appropriate adaptation strategies. A good knowledge of the vulnerability in climate change faced by each country is necessary to guide the aid for adaptation.

The recognition of climate change as a dominant issue for world economy and policy, has led to a search for resources for financing mitigation and adaptation. Raising funds for mitigation and for adaptation meets the same problems, but their allocation should be ruled by different criteria. The creation of the Adaptation Fund by the Parties to the Kyoto Protocol of the UN Framework Convention on Climate Change illustrates the awareness of the international community of the need to mobilize human and monetary resources in order to deal with adaptation problems, and the specificity of the adaptation issues. Adaptation is defined by the Intergovernmental Panel on Climate Change (IPCC) in their 4th Assessment report as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities” (IPCC 2007). The resources already mobilized to meet the adaptation aim seem to be well below what would be required. This makes it all the more necessary to allocate these resources according to criteria which reflect the countries’ adaptation needs, as well as their capacity to effectively use the resources to this end. From that perspective, the country vulnerability to climate change could be considered as one of the most relevant criteria for the allocation of adaptation resources between developing countries. So an appropriate indicator of vulnerability to climate change available for all the countries concerned is required for this purpose.

According to the Adaptation Fund website, resources for the needs of development and adaptation cannot be the same: “Helping the most vulnerable countries and elements of societies is thus an increasing challenge and duty for the international community, especially because adaptation to climate change requires significant resources *in addition* to what is already needed to achieve internationally agreed-on development objectives such as the Millennium Development Goals” (Adaptation Fund website). Even if this separation is sometimes debated, it seems presently to correspond to an actual trend.

The aim of this paper is to draw out particular dimensions of vulnerability to climate change in African countries, based on an index likely to provide a quantitative and comparative assessment. An assessment of the vulnerability to climate change is proposed, focusing on the vulnerability which depends only on structural factors. Factors considered as structural are those which do not depend on the present will or policies of the countries. As for the vulnerability to climate change; these factors are essentially geo-physical. This “Physical Vulnerability to Climate Change Index” (PVCCI) presents various results for the African continent, and confirms the importance of vulnerability to drought and desertification in this region. Moreover the study lays out a first step for the design of criteria for the allocation of adaptation resources.

In the recent political debate about the implications of climate change, the need for an index of vulnerability to climate change has been recognized, noticeably in United Nations circles, and at the Adaptation Fund (UNFCC, 2008a, 2008b, 2008c). However, no clear recommendation has made as to what kind of index is required. Tentative indices have been proposed by a large number of international or research institutions, (two major examples were given by the World Bank in *World Development Report* 2010, p.278 and, by Adger et al., 2004) . However all previous indices raise issues of definition, database, purpose, and use.

The new index presented in this paper reflects only the physical components of vulnerability to climate change. Moreover, it relies on few components, both relevant and reliable, which are available for the whole set of developing countries, and which are easily understandable, so that the index can be used in a transparent manner. In the search for such an indicator, it seems useful to refer to two streams of literature. First, the environmental literature offers various definitions and concepts of vulnerability, on which we draw as far as needed, although we do not include the adaptive capacity and resilience to vulnerability, as done in this research stream. Second, the endeavour to measure structural economic vulnerability to external and natural shocks for the identification of the Least Developed Countries (LDCs) by the United

Nations has led to build a related indicator, called the Economic Vulnerability Index, (EVI) (United Nations CDP 2008, Guillaumont 2009a and 2009b). The EVI, which does not ignore environmental vulnerability, includes components related to natural shocks (through the "average of homeless due to natural disaster index" and the "instability of agricultural production index"), as well as components reflecting the exposure to these shocks (such as low population size). But it is not focused on long term vulnerability to climate change, and it only captures the likelihood that they re-occur in the near future through recurrent shocks.

This study shows a high heterogeneity among countries in their level of physical vulnerability to climate change, even within the same regional area or continent. It shows both the high relative vulnerability of African countries and the differences among those countries, mainly due to the risk of drought. The PVCCI index permits the characterization of climate change vulnerability for developing countries, particularly African countries, laying some foundations for the improvement of the design of adaptation policies. With regard to the growing concern of the international community about the ways of mobilizing resources to deal with adaptation, such an index sheds light on the challenges of climate change for African countries. In particular the PVCCI should be considered as one of the relevant criteria for the geographical allocation of resources devoted to adaptation.

The first part of the paper presents the various concepts of vulnerability to climate change. It tries to connect development economics and environmental research by building a physical vulnerability to climate change concept and index. The second part discusses the composition of the index and its calculation. The third part presents the results for this index on developing countries, more specifically for African countries.

What is Vulnerability About?

Beginning with the main definitions of vulnerability to climate change, this section tries to define physical vulnerability to climate change. The "vulnerability of systems to climate change" is examined in what is a rapidly growing literature, relying on various fields of research, such as climate science, disaster management and development economics. This part is also a step towards a "necessary greater synergy between ecologists and economics", as recommended by Wam (2009),

General economic vulnerability versus structural economic vulnerability

The word 'vulnerability' has been used with various meanings and by various researchers into food security, natural hazards, disaster risk, public health, global environment, climate change or development economics (see as a sample of applications of the concept of vulnerability in these various fields: Timmerman 1981; Cutter 1996; UNEP 2002; Turner et al. 2003; Prowse 2003; Blaikie 1994; McCarthy

2001; Guillaumont and Chauvet 2001).In development economics, the notion of vulnerability has been used mainly at the micro level (see for instance Yamano et al. (2005) or Dercon et al. (2005)). It has also been used at macro level, with the search for measurable and comparable indices (this literature is reviewed in Guillaumont, 2009a and 2009b).

In this macroeconomic context, the vulnerability of a country is taken as "the risk of being harmed by exogenous, generally unforeseen, events or shocks" (Guillaumont, 2009a). Based on several decades of literature (in particular on export instability), this macro vulnerability is considered to be an impediment to growth. Economic vulnerability can be seen to consist of three main components: *shock, exposure and resilience***.** Shocks are exogenous and generally unforeseen events (external e.g. the instability of exports, or natural e.g. typhoons, hurricanes, earthquakes, droughts). Exposure corresponds to factors on which the direct impact of shocks depends. Resilience is the capacity to react to shocks, which can be considered, when weak, as a part of general vulnerability (Miller et al. 2010)

Assessments of vulnerability retain some or all of these three components. When the three elements are considered, a general or overall vulnerability is assessed. When the size of the exogenous shocks and the extent of exposure to these shocks are the only components considered, the vulnerability considered is essentially a "*structural*" vulnerability. Resilience, even if it may include some structural elements, is mainly related to policy factors. Structural economic vulnerability is the kind of vulnerability captured by the Economic Vulnerability Index (EVI), used by the United Nations to identify the Least Developing Countries (LDCs). This index is intended to reflect the likely size of recurrent external and natural shocks, as well as the main structural factors of the exposure to these shocks, in a parsimonious transparent manner (seven indicators). It mainly refers to vulnerability in low-income countries (see UN CDP web site and Guillaumont 2009a, 2009b, 2011). In the same way, this paper tries to define an index of structural vulnerability to climate change, using only a small number of indicators related to the size of climate shocks and to the exposure to these shocks.

Structural or physical vulnerability to climate change: can it be identified?

Vulnerability to climate change is defined here as a vulnerability to environmental shocks resulting from climate change. These shocks are considered to be the physical consequences of climate change. They appear as more droughts, floods, and storms, as well as through the rise in sea level; and they are reflected by the change in the mean values of climatic variables (such as temperature or rainfall), and by related changes in the instability of these variables.

Climate change and vulnerability have always been associated. For instance Timmerman (1981) considers the thinking on the vulnerability concept to be at the core of climate change research. He defines vulnerability as "the degree to which a system may react adversely to the occurrence of a hazardous event". For the World Meteorological Organization's Climate Program the announced goal is "determining the characteristics of human societies at different levels of development which make them either especially vulnerable, or especially resilient, to climatic variability or change (p.3)”. Liverman in 1990 notes that the concept of vulnerability “has been related or equated to concepts such as resilience, marginality, susceptibility, adaptability, fragility and risk” and proposes a distinction between vulnerability as a biophysical condition, and as political economy.

There has been a profuse recent literature on vulnerability to environmental change and more specifically on climate change, and also on vulnerability to natural hazards, which partly overlaps with the former. Not surprisingly, there is no universally accepted definition of vulnerability to climate change (and there is even a different definition in each IPCC report - Downing and Patwardhan 2005). Beyond the semantic issue, a definition of vulnerability is obviously needed to make the theoretical concept clear. The choice of the definition influences the orientation of the vulnerability analysis (O’Brien et al. 2007). The main references to environmental vulnerability include Adger (1999), Downing and Patwardhan (2005), H. M Füssel (2007), P. M. Kelly and Adger (2000), O’Brien et al. (2004), Olmos (2001), Ionescu et al. (2009), and to vulnerability to natural hazards, Birkmann (2006a and 2006b), Cardona et al. (2003) or Thywissen (2006).

In fact the definition and then the assessment of vulnerability have encountered two difficulties. First, the notions have been used with different meanings depending on the scientific field (Hinkel 2008, Bruckner 2010). Second, within each field various conceptual frameworks have been defined. As a result, this literature has been qualified as a “Tower of Babel” (Janssen and Ostrom 2006). Facing this “tower” authors have suggested building a formalized common framework (Ionescu et al. 2009, Hinkel 2008). All these authors agree that the multiplication of frameworks and definitions leads to the blurring of the message drawn from the analyses.

To identify the structural or physical vulnerability to climate change, it is useful to refer to the three usual components of economic vulnerability (size of the shocks, exposure to the shocks, resilience), and to consider that structural vulnerability is mainly captured through the shock and exposure components, while resilience is more related to policy. We now briefly review the literature on vulnerability to climate change with the aim of seeing whether it isolates these structural or physical components of vulnerability to climate change. For the sake of this review, we identify three main approaches in the literature on vulnerability.

Main current approaches to climate change vulnerability

Let us call the *chronological approach (ex post/ex ante analysis)* the sequential analysis of a shock that compares the situation before and after the shock. Elements defining the environment before the shock occurs constitute the context. The consequences and impacts of the shock are defined and assessed after the shock occurs. Kelly and Adger (2000) adopt this approach by defining the end point vulnerability and starting point vulnerability. They define the “starting point vulnerability” as the body of elements in the environment that makes (ex-ante) the consequences of shocks worse (e.g. by an increase in the sensitivity of the environment). This vulnerability is affected by social and economic dynamics, and by political and institutional characteristics. The starting point vulnerability is linked to the human security framework and is related to the context. The "end point vulnerability" results from the consequences of climate change. It is captured by an assessment of the losses from the shock, related to its characteristics and size. The assessment of end point vulnerability has been the subject of studies; for instance O'Brien et al. (2007) use a similar distinction. The authors deal with an outcome vulnerability and contextual vulnerability whose definitions are close to the end point and starting point vulnerability of Kelly and Adger (2000). To a large extent the starting point vulnerability corresponds to what is considered in the economic literature as the "exposure" to shocks, but the end point depends both on the size of the shocks and on the resilience, including structural factors, and present policy factors as well.

What can be called the *matriochkas approach* consists of elaborating a progressively encompassing concept of vulnerability. The aim of this framework is to make the definition of vulnerability gradually more complex following different scales (often geographic scales). This type of analysis is proposed by Birkmann (2007). The author considers the core of the vulnerability definition as intrinsic vulnerability (vulnerability defined as an internal risk factor). Then he introduces a continuum of definitions of vulnerability from the tightest to the widest definition: "multi dimensional vulnerability encompassing physical, social, economic, environmental and institutional features" (Birkmann 2006a). A similar analysis is found in the "onion framework" proposed Bogardi and Birkmann (2004). It is an enlightening approach, but not adapted to our purpose in so much as policy factors may interfere at each step of the concept's enlargement.

The *social and ecological dichotomic approach* is a framework which finds its roots in the ecological literature. Adger et al. (2004) distinguish a biophysical vulnerability and a social vulnerability. This separation is close to that presented by Brooks (2003) who identifies two kinds of vulnerability to climate change in the literature. Biophysical vulnerability is defined by environmental scientists in terms of physical (potential) damage caused to a system by a particular climate-related event or hazard (Jones and Boer, 2005; Nicholls et al., 1999).Vulnerability being analyzed in terms of the likelihood of occurrence and impact of weather and climate related events (Nicholls et al., 1999). The second type of vulnerability is defined as the "state that exists within a system before it encounters a hazard event" (Allen, 2003). It is close to the "starting point vulnerability" of Kelly and Adger (2000). This is also, according to Brooks, the definition of social vulnerability. Social vulnerability depends on biophysical factors, but also includes the set of socio-economic factors that determine peoples' ability to cope with stress or change (Allen, 2003). It can be seen as including what has been called exposure and resilience factors, and following both structural and policy factors. The distinction made by Brooks (2003) led him to aggregate in a unique system social and biophysical vulnerability (see also Füssel and Klein 2006). This concept must be distinguished from climate hazard assessments. Moreover, in the conceptual framework of "eco-sociological system", the distinction between social and biophysical vulnerability could be included (see part 1). Adger (2006) proceeds in the same way: after distinguishing two main streams, entitlements and natural hazards; he gathers these two streams in a global framework named: “socioecological system”.

Let us finish with the *IPCC’s approach.* The IPPC has a precise definition of vulnerability which is often used in climate change vulnerability analysis. The IPCC’s definition is “Vulnerability is the degree, to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity” (IPCC 2007b). This definition is close to the definition of economic vulnerability, previously presented with the three components of shock, exposure and resilience. The diagram given by Füssel (2010), see figure 1, helps to better understand, what in the IPCC definition concerns structural vulnerability and what does not: the sign (+/-) next to a factor indicates the direction of this factor’s influence on vulnerability. Here, “social impacts” must be understood as “vulnerability to climate change”. This framework with three components is also recognized by the Committee for Development Policy (CDP) of the United Nations (Brückner 2010).

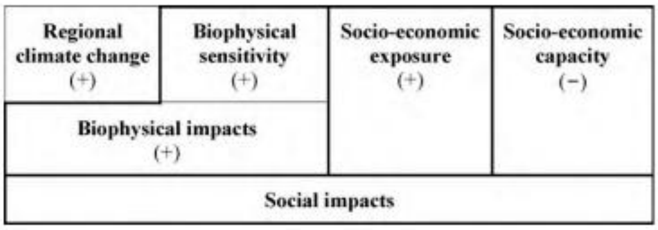

Figure 1: Vulnerability to climate change framework, the reading of IPPC definition by Füssel (2010)

	Chronological analyses		*“Onion” or “Matriochkas” analysis*	*Dichotomic analyses*				*The ‘IPCC’ analysis*		
	Kelly and Adger (2000)	*O'Brien et al. (2007)*	*Birkmann (2007)*	*Brooks (2003)*		*Adger (2006)*		*Füssel (2010)*		
SHOCKS	End point vulnerability	Outcomes vulnerability	Intrinsic vulnerability	Biophysical Vulnerability	Social and biophysical vulnerability	Natural disasters	Socioecological vulnerability	Regional climate change	Biophysical Impacts	Social Impacts (vulnerability to CC)
EXPOSURE/ SENSITIVITY			Human centred vulnerability					Biophysical sensitivity Socio-economic exposure		
RESILIENCE	Starting point vulnerability	Contextual vulnerability	Multidimensional vulnerability	Social Vulnerability		Entitlements		Socio economic capacity		

–·– : Continuum of vulnerability concepts

········ : Approximate delimitation

In grey the structural components of vulnerability

Figure 2: Vulnerability frameworks in the light of the Shocks,Eexposure and Resilience definitions

In any case, when referring to environmental vulnerability to climate change, the distinction established with reference to macroeconomic vulnerability between shock, exposure and resilience should be kept in mind. This can help to take account of those components of climate change vulnerability that are not structural, in other words those which depend to a large extent on the present policy of countries, which make them more or less resilient to shocks. Many useful frameworks of vulnerability to climate change, including the various vulnerability dimensions, have been presented. However, the building of an indicator useful for guiding allocation of resources involves taking account of the present policy components, mainly captured through the resilience concept. Indeed this choice is necessary to produce a "Simple, Measurable, Accurate, Reliable, and Timely" (SMART) indicator.

From analysis to measurement of the vulnerability to climate change

Existing indices: not focused only on structural vulnerability

The authors of the existing indices point out the growing need for such an index (a need also expressed by the international community and organizations), while often underlining the confusion resulting from the multiplicity of conceptual frameworks for the analysis of the impact of climate change. As for the indices related to climate change we choose first to note that some indices only try to reflect the evolution of climate change, without assessing an impact of vulnerability. These include the Climate Change Index of Baettig et al. (2007) and the National Climate Change Indices of Diffenbaugh (2007) and of Giorgi (2006). These indicators can be seen as essentially reflecting the size of the shocks without consideration of exposure and resilience. Moreover, these indices do not agree on the areas where the phenomenon is the most severe.

As for the indices more precisely focused on the vulnerability to climate change, their numbers have exploded in recent years. The aim of these authors is to put forward a measure of vulnerability to climate change, and to highlight the differential impact of climate change between socio-economic units (nation states, local governments or collectivities). Among these indices we note, among others, the Environmental Sustainability Index (Esty et al. 2005), the Vulnerability-Resilience Indicators (Moss et al. 2001), the Index of Human Insecurity (Lonergan et al. 1999), the Predictive Indicators of Vulnerability (first calculated in Brooks et al. 2005), the Environmental Vulnerability Index to Climate Change (EVI-CC Kaly 2004), the Indicator of Vulnerability to Climate Change (IVCC Barr et al. 2010), The Global Distribution of Vulnerability (Yohe et al. 2006a and 2006b), Social Vulnerability Index (SVI Cutter et al. 1996), Downing et al. (1995), and Buys et al. (2007). However these indices often present the same strengths and weaknesses as the theoretical frameworks that they refer to and previously presented. Thus, they capture a global (or "generic", Füssel 2010) vulnerability to climate change and not just structural vulnerability, which is what we propose[1].

These indices of "generic" vulnerability to climate change are the topic of a wide literature about their method of calculation and the country ranking. For instance, Füssel (2009) compares works of Yohe (2006), Kaly (2004) and Diffenbaugh (2007). In these papers, after analyzing the existing vulnerability to climate change indices, Gall (2007) and Füssel (2009) note that most of the indices are unstable and very sensitive to their proxy and to the aggregation method. Also, the indices are not comparable even though they refer to the same framework, as noted by Moss et al. (2001), Gall (2007), Füssel (2009), Eriksen and Kelly (2007). Some authors also criticize the choice of a national scale considering it to be irrelevant to assess the effects of a phenomenon which does not follow borders (Eakin and Luers 2006). Also the substitutability of components in building the index has been noted (Tol and Yohe 2007). The generic indices of vulnerability to climate change are widely criticized because they present "methodological flaws or severe doubts regarding their validity" (see Füssel 2010 for a good review of the major defficiencies of these indices).

Concerning the relevance of an index measured at the country level

The impact of climate change does not follow country borders. Some effects will affect only a zone in a country, some others will be the same for several neighboring countries in a particular region. Although the choice of a national scale for the index does not follow climate change characteristics, it corresponds to feasibility constrains important for use of the index.

As noted at the beginning of this paper, the index we propose should be used as a criterion for the allocation of the resources for adaptation between countries, leading to allocation of more resources to countries which are more vulnerable to climate change. Of course it does not capture others factors which must be taken into account in the allocation of resources (e.g. population size and poverty level). For this reason the choice of scale for the analysis is the country[2]. Thus, even if some authors express reservations about such an analysis (Eakin and Luers 2006); others choose the national level for the reasons developed by Barr et al. (2010), and Brooks et al. (2005).

More than the geographic scale, the time frame of the index raises an important issue. To what extent can the indicators rely on past trends and characteristics to forecast a vulnerability to future shocks? Components can be calculated as ex-ante or ex-post. It seems possible to rely on forecasting when data are available and reliable (e.g. likelihood of sea level rises). Other components can be calculated ex-post from past trends.

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[1] When this paper was written we did not have the opportunity to take in consideration the stimulating paper written by D.Wheeler different from that mentioned in our index.

[2] D.Wheeler's paper pursues a similar goal

The demand for an index of climate change vulnerability has become bigger and bigger. This growing demand has lead international institutions and researchers to provide related frameworks and indices. But in the large literature on vulnerability to climate change, there seems to be neither a common framework nor a universally accepted definition. This can be seen to be the result of a lack of connection between the design of frameworks and indices, and the goal they are expected to attain. This is why we have tried to define a vulnerability to climate change index with the aim of guiding the allocation of adaptation funds; derived from literature, this design allows us to combine various existing frameworks based on the split of the vulnerability of climate change into three elements: Shocks, Exposure and Resilience. This framework permits the assessment of the part of the vulnerability to climate change which can be considered as physical or structural, and essentially relies on shocks and exposure components[3].

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[3] These elements are often linked to the notions of vulnerability in the literature but they are very difficult to quantify. They partly overlap the notions of resilience, and their role in guiding aid allocation is controversial.

The analysis of vulnerability to climate change undoubtedly faces the usual distinction between adaptation to and mitigation of climate change. Adaptation primarily seeks to moderate the adverse effects of climate change through actions targeted at the vulnerable system by reducing system sensitivity, or by reducing the consequent level of damage. Mitigation consists in limiting the number, and the magnitude, of potential climate hazards due to climate change (e.g. by reducing the emissions of greenhouse gases). Both are likely to lower the vulnerability to climate change, but not in the same way. Mitigation has a direct effect on the size of climatic shocks while adaptation may either consist in lowering the exposure to shocks or in enhancing the resilience. In the search for an index to be used for the allocation of resources devoted to adaptation, it seems useful to focus on the structural need for adaptation, namely the structural components of the exposure to climatic shocks. For more information on the relation between mitigation and adaptation see Smit and Wandel (2006), Jones et al. (2007) and Buob and Stephan (2010).

Components of the Physical Vulnerability to Climate Change Index.

An examination of the expanding literature on the economic consequences of climate change leads to the formation of a distinction between two kinds of consequences and related risks: *risks of permanent shocks* and *risks of recurrent shocks*. These two categories roughly correspond to the second and the first of the three broad categories of hazard identified by Adger et al. (2004), namely:
“Category 1: Discrete recurrent hazards, as transient phenomena such as storms, droughts and extreme rainfall events.
Category 2: Continuous hazards, for example increases in mean temperatures or decreases in mean rainfall occurring over many years or decades, desiccation such as that experienced in the Sahel over the final decades of the 20th century (Hulme 1996; Adger and Brooks 2003).”
Although there is a third and important category identified by these authors, its assessment faces big obstacles so that it has to be ignored: it covers “discrete singular hazards” (e.g. shifts in climatic regimes associated with changes in ocean circulation), **-** the paleoclimatic record provides many examples of abrupt climate change events associated with the onset of new climatic conditions which then prevailed for centuries or millennia (Cullen et al. 2000; Adger and Brooks 2003).

Starting from the distinction between the risk of permanent shocks and the risk of recurrent shocks, our aim is to identify some reliable indicators that can be used as relevant components of an index of physical vulnerability to climate change. Since it is very difficult to assess the final impact of climate change, indicators should rely on intermediary and measurable consequences, estimated either directly or by the means of proxies. Differing from other attempts to assess climate change vulnerability to, the expected consequences of climate change on physical variables are the only elements considered. They are likely to have an impact on socio-economic variables, but they are not socio-economic variables. Relying on these physical indicators (e.g. sea level, rainfall, temperature) means using only objective or neutral data. It avoids reference to indicators partly influenced by policy or resilience factors. It does not rely on the assessment of the expected impact of climate change on socio-economic variables such as health and agriculture, and as a consequence, it can be used to assess the link between climate change and these economic variables.

In any case, the set of indicators presented below should be considered more illustrative than as an exhaustive set of components. They try to capture the main channel through which climate change is a factor of vulnerability. It should be remembered that a good index should use a minimum number of indicators, which are transparent, and focused on the most relevant issues.

Risk of progressive and durable shocks

The risk of permanent shocks (or continuous hazard) refers to possible persistent consequences of climate change at the country level. The two main kinds of such risks, as identified in the literature, are rise of sea level, and increasing aridity, which may lead to desertification.

Risk of flooding from the rise of sea level: shock and exposure

The vulnerability of a country to the rise in sea level corresponds to the risk of this country being flooded. Its assessment involves making a distinction between the size of this shock (magnitude of rise of the sea level) and the exposure to this shock (altitude). An assessment of the vulnerability of zones likely to be flooded then depends on the two following factors:

- the exposure to sea-level rise depends on the relief, since it influences the likelihood of flooding, so that the indicator should take into account the distribution of the heights of arable lands *or* the distribution of the population according the height of occupied lands
- the shock could be estimated by the distribution of the likelihood of a sea-level rise in *t* future years.

The combination of the exposure and potential shocks allows assessment of the likelihood of flooding resulting from the sea level rise (in t years).

The measurement of the exposure component does not raise a difficulty. Its assessment depends on a good knowledge of the geographical configuration of the country. Indeed a discussion could be opened on the type of area which is considered (e.g. all areas of the country, or only arable areas or areas with a minimum population density?), and if the population distribution is considered, it may be expected to change over time (but the *structural* vulnerability does not really depend on this change).

It is more difficult to assess the risk of sea level rise, for two reasons. Firstly there is still some degree of uncertainty about the rise of the sea level in a given time horizon, the probability distribution being debated among climate specialists. Secondly this probability distribution is changing over time with rising average sea levels and increasing dispersion. Let us suppose that we know the probability distribution of the sea level rise for each of the next *x* years, the impact on the percentage of flooded areas could normally be expressed in a present value, using a discount rate. We do this for two reasons. Firstly, the increasing uncertainty of estimations as the time horizon increases, if this growing uncertainty was not already captured by the increasing dispersion of the probability of sea level rise: if the sea level rise in each year is expressed only by an average level, then it is legitimate to discount for this reason alone. A second reason is the “pure time preference”: the disadvantage generated by a given sea level can be considered as higher the earlier it occurs; the later it occurs, the higher the capacity of a country to face it. So a logical indicator would be the present value of the likelihood of flooded areas over the next *t* years.

$$SLR_i = \int^{t}\int^{j} \frac{h_{ijt}}{(1+r)^t} \times s_{ij}$$

With:

SLR: sea level rise indicator
i, country indicator and *j*, the meters of sea level rise;
h_{ij}, probability that the sea level rises by *j* meters for the *i* country;
and s_{ij} the part of arable lands below *j* meters in country *i*.
t: number of years from now
r: discount rate

If it seems arbitrary to apply a discount rate (r=0), a simplified indicator could be the likely share of flooded areas in *x* years (the time horizon of x years being also arbitrary): :

$$SLR_{ix} = \int^{j} h_{ijx} \times s_{ij}$$

Risk of increasing aridity: assessment from, and past trends in, temperature and rainfall,l and initial conditions

The literature on the consequences of climate change underlines the risk of some arid countries (in particular Sahelian countries) being affected by the rise of temperatures, and therefore being threatened by over-aridity, see for instance (IPCC 2007a). To set up a proxy indicator of this risk we rely on the distinction previously done between the exposure to shocks and the size of shocks.

Proxies for the exposure to the risk of an increasing aridity can be either the actual average level of rainfall in the country, or preferably the actual percentage of dry lands, which better fit the risk of desertification. The lower the rainfall level or the higher the dry lands percentage in a country, the more exposed it is to a long term decrease of rainfall or increase of temperature.

As for the size of the (future) shocks, it seems relevant to use the past trend in annual average temperature in each country over two or three decades. The hypothesis is that the rise of average world temperatures will be distributed over countries in the same way as during recent decades. In other words, taking into account possible non linearities at each country level, it is supposed that the past trends can be extrapolated. The information on this future distribution, thus made available, could be used to assess the risk at the country level. A similar and complementary proxy of the shock measurement for the risk of increasing aridity can also be found in the decreasing trend of average rainfall level. It supposes that the past trend in average rainfall is determined by climate change and will continue following the same trend in each country. At the country level, the permanent shock resulting from climate change, and evidenced in a rising trend in temperature or a decreasing trend in rainfall, is thus assessed by an extrapolation of recent past trends. If and when more relevant and reliable projections of the temperature and rainfall became available at the country level, it would be possible to use them instead of the (non linear) extrapolation used here (see for instance the Climate Research Unit data base).

Risk of increasing recurrent shocks

Climate change can also generate more frequent or more acute natural shocks, such as droughts, typhoons, and floods (World Bank, 2008). Here again the only variables to be considered should be unambiguously linked to climate and its change: such as rainfall and temperature, and their variability.

The vulnerability to rainfall and temperature shocks has two main kinds of components, corresponding to the previous distinction between exposure and shocks. The exposure components are here given by the average frequency of past (rainfall or temperature) shocks, which reflect climate, but not climate change as such: this average frequency during previous years can be taken as a proxy to the exposure. The shock components, more forward-looking, are drawn from the trend in this frequency, assuming it is determined by climate change, and likely to go on in the future. These two kinds of components are considered in the same way for rainfall and temperature.

Average present frequency as an indicator of exposure

When the Economic Vulnerability Index (EVI) was developed at the United Nations by the Committee for Development policy (CDP) for the identification of the Least Developed Countries, indirect and synthetic indicators were used which were likely to capture highly heterogeneous natural shocks (floods, typhoons, droughts, hurricanes, and earthquakes) with highly unequal intensity and consequences. Among the components of the Economic Vulnerability Index (EVI) the risks of natural shocks were assessed “ex post” by a measure of shock incidence over past years. The two related indicators of the EVI are an index of the instability of agricultural production (IA), and an index of the percentage of homeless population due to natural disasters[4] (HL). The instability of agriculture production is a square deviation of the agricultural production with regard to its trend. These two indicators are averaged in a natural shocks index:
NSI= (IA+HL)/2. Within the EVI this natural shock index, although calculated ex post, is considered as reflecting a risk for the future, due to the recurrent nature of the related shocks: the average past level is taken as a proxy for the risk of future shocks, an index indeed likely to change over time. A high past level can simultaneously be considered as generating a handicap to future economic growth.

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[4] The latter index comes from the Center of Research on Epidemiogical Diseases which also produces other indicators, such as the percentage of population affected by natural disaster.

As for vulnerability to climate change, the present approach is different. First, the average level of past shocks (considered as an exposure indicator) is related to rainfall and temperature, two variables clearly linked to climate, while the instability of agriculture production or homelessness also depends on natural shocks not all related to climate. Thus, the index of exposure to climate change, relying on past average levels of rainfall or temperature instabilities, is unambiguously physical, and by no way influenced by policy or resilience factors. Our preferred measurement is the year to year instability of rainfall or temperature, for instance calling R_t the index of rainfall in year t,

$$IR = \sum \frac{|R_t - \hat{R}_t|}{\hat{R}_t}$$

with $\hat{R}_t$ the trend level of R_t.

Second, the past average level of shocks is considered as an indicator of the *exposure to an increase in the frequency and size of these shocks*, which is captured by a specific index of the size of the shocks as explained below.

Trends in the intensity of past shocks as a proxy of future shocks

The risk of recurrent shocks associated with climate *change* is here assessed in a forward-looking manner. It is assumed that the more significantly their intensity has been increasing in the past, the more likely is their increase in the future. In other words, if the rainfall and temperature shocks have increased due to climate change, they are assumed to continue increasing. The proxy used will then be the trend in the size of instability.

For instance the proxy for the risk of increasing rainfall shocks will be the (positive) trend in the absolute (or squared) deviation of the yearly average of rainfall from its own trend, calculated as (supposing a linear trend):

$$\frac{|R_t - \hat{R}_t|}{\hat{R}_t} = \propto . t + \beta$$

with α being the trend in the intensity of rainfall instability.

It might also be more appropriate to estimate a non-linear trend, so that

$$\frac{|R_t - \hat{R}_t|}{\hat{R}_t} = \propto_1 . t + \propto_2 . t^2 + \beta$$

The index of the size of future (rainfall) shocks then depends on the time horizon retained, as is the case for the rise of the sea level, since this rise may also correspond to a non linear trend.

In the same way, it is possible to estimate an index of the size of future (temperature) shocks from the trend in the intensity temperature instability (α').

Aggregation of components in a synthetic index

Each of the previous component indicators gives information which can be used independently from the others. Making available the measure for each component and sub-component will allow the researcher to use them separately or to combine them in an aggregated index. A synthetic index may indeed be needed, in particular, as we have seen, for aid allocation. The aggregation of the above components, once they have been expressed as indices on a common scale, raises several issues.

Let us begin by noting that the structure of the index can be presented in two ways. The first one, illustrated by the graph below, distinguishes between risks related to progressive shocks, and to more intense recurrent shocks, both considered as resulting from climate change. The progressive shocks cover those due to (i) the sea level rise and (ii) to the trend in average rainfall and temperature. The intensification of recurrent shocks corresponds to (iii) rainfall shocks and (iv) temperature shocks. For each of these four main components an exposure index (in italics) and a shocks index have been identified. The second way of presenting the structure of the index, still starting from the distinction between progressive and recurrent shocks, is to split up the recurrent ones into two mains components: (a) the past average level of rainfall and temperature instability, a proxy for exposure, and (b) the trend in the size of these instabilities, a proxy for the shock itself. This presentation has been used in tables at the end of the paper.

A traditional aggregation issue is related to the weight given to each component. Since the components are forward-looking (in particular sea level rise), it is not possible to decide on weights from an econometric estimation of the expected respective impact on a socio-economic variable such as economic growth or poverty reduction; a method which is difficult to apply for the EVI (Guillaumont, 2009a). A simple and normal, although arbitrary, solution is to use equal weights: here equal weights would be given to the two main categories of shocks, then to the four main components, then to the eight sub-components.

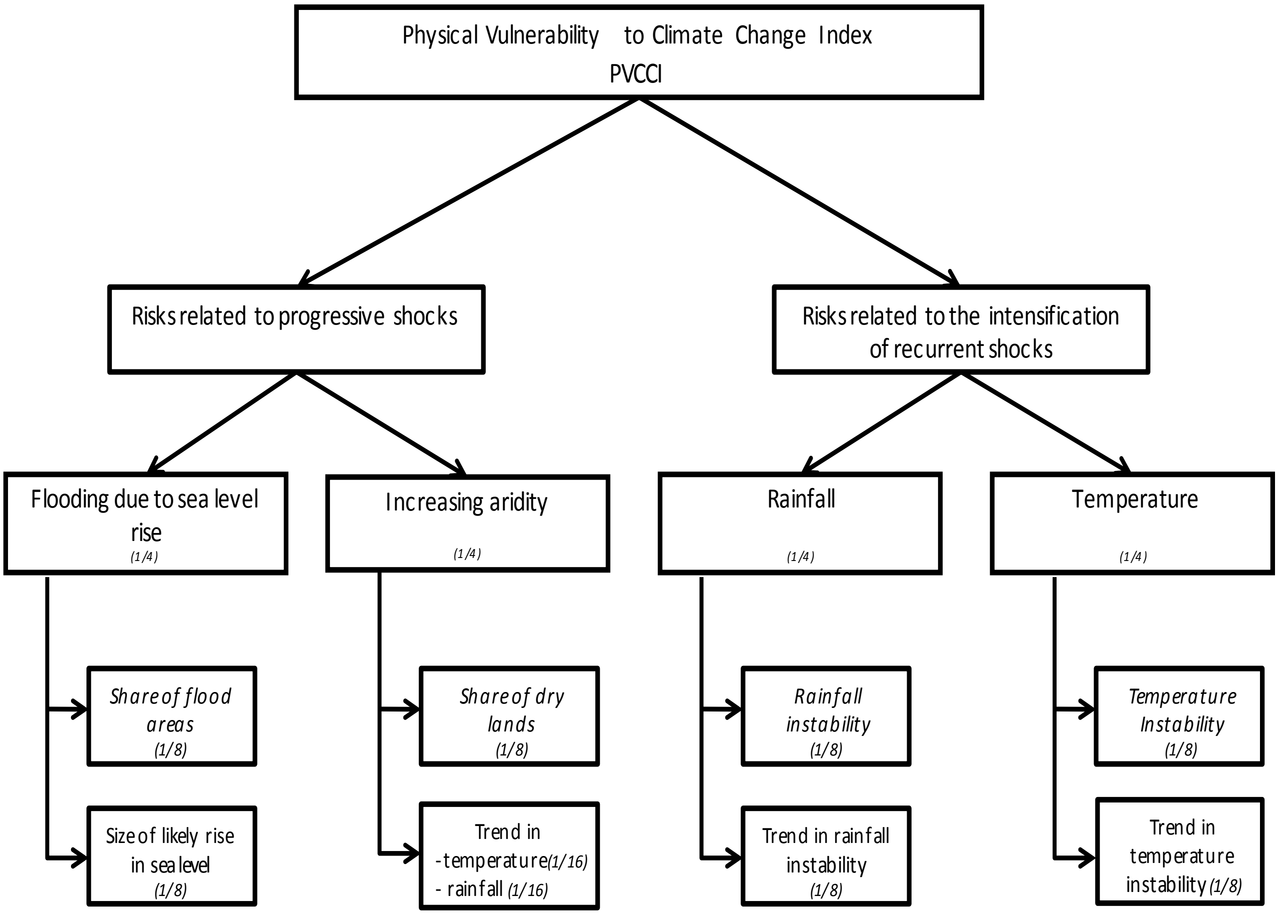
Finally, the way by which the values of the components are averaged is an important issue. The usual averaging practice for the calculation of synthetic indices is by arithmetic average (as for the Human Development Index or for the EVI). However, one should be aware that any of the main components of a vulnerability index may be of crucial importance for a country, more or less independently from the level of the other components. In that case it can be relevant to use an averaging method reflecting a limited substitutability between components (as already examined for the EVI in Guillaumont, 2009a). It can be obtained either by a quadratic average of the components, or by a reversed geometric average (G'), defined in the following way

$$G' = 1 - \sqrt[n]{\prod_{k=1}^{n}(1 - A_k)}$$

with A_k the index value of the k component.

For instance, let us take an island with a very large share of area likely to be flooded, or an arid country suffering from a high increasing trend in the level of temperature. Each of these two countries, where a component is close to one, will evidence a high vulnerability to climate change by using this modified geometric average.

Figure 3: Composition of the Physical Vulnerability to Climate Change Index



NB. The boxes corresponding to the two last rows of the diagram respectively refer to exposure components *(in italics)* and to size of the shocks components

In the above presentation, the physical vulnerability to climate change index gathers eight sub-components into four components reflecting two kinds of shocks (progressive ones and increasing recurrent ones), according to a unified framework.

Calculation of the Index

The physical vulnerability to climate change index has been calculated from data beginning in 1950, thus covering the last sixty years. The index could be updated and calculated every three or five years.

Data

The calculation of the risk of flooding due to sea level rise has not been possible due to a lack of agreed data on the evolution of the average level rise, and even more on the probability distribution of this rise. However Dasgupta and al. (2009) give data for the calculation of the exposure to sea level rise, supposing a rise upto 1 meter: so, a convenient proxy for the risk of flooding due to sea level rise is the index of the "part of country affected by a rise of 1 meter of the sea level[5]" (as calculated by Dasgupta et al.2009).

Rainfall and temperature data come from *Global Air Temperature and Precipitation: Gridded Monthly and Annual Time Series (Version2.01)* interpolated and documented by Cort J. Willmott and Kenji Matsuura, with support from IGES and NASA, University of Delaware (for more information see Legates et al.,1990a 1990b, and Willmott et al.,1995). This is the monthly total precipitation for the years 1900-2008 interpolated to a 0.5 by 0.5 degree grid resolution. We associate each kriging point to a country, and then aggregate our data to obtain a mean rainfall for each country. Trends are calculated from average rainfall country data since 1950 (considered as the beginning of climate change)[6]. For this work we could use the Climate Research Unit (CRU) as used by Burke et al. (2009) to assess the role of warming in futures conflicts in Africa. The results would be similar but could open a discussion about this database.

Trends are calculated on monthly data, before a seasonal adjustment according to:

$$Rj = \alpha + \beta t + \theta j + \varepsilon j \qquad \text{for each i country}$$

With

Rj: monthly rainfall data

t : trend

θj : dummy monthly variable

εjt: term or error

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[5] We use (???) the database for 72 countries, mainly landlocked (we assign the null value for these elements). For the other countries we propose an approximation of the index according to the geographic features of the country (altitude, distribution of population). We test the validity of data by some tests of sensitivity (rank correlation).

[6] For countries where kriging points are not exactly in the country (13 countries), we use buffering technique and couple the point closest to the country in the country where data are missing.

For instance, the results of estimation of trend in Benin on rainfall data since 1950 are presented below.

Table 1: Trend in rainfall in Benin

VARIABLES	Rainfall
Trend	-0.0338***
	(0.009)
d2	2.4355
	(1.907)
d3	21.0101***
	(2.525)
d4	68.9388***
	(4.850)
d5	108.6456***
	(5.504)
d6	143.0438***
	(6.051)
d7	198.5777***
	(8.972)
d8	254.7878***
	(9.007)
d9	246.6013***
	(8.841)
d10	100.0894***
	(6.154)
d11	12.1215***
	(3.079)
d12	1.9435
	(1.728)
Constant	34.0590***
	(8.177)
Observations	708
R-squared	0.824

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

If the trend is not significant at the level of 0.1, we assign the null value for this sub-component.

In this first version of the index, we have retained a definition of shocks slightly different from that presented in the conceptual framework of the PVCCI, but likely to better reflect the increasing risk of rainfall or temperature shocks. Shocks are identified as the (monthly) events over two standard deviations of the trend in the temperature or rainfall. Then a trend in the number of shocks is calculated, taking into account only the negative shocks for rainfall and only positive shocks for temperature. In all instances, data are seasonally adjusted. All estimations are done with the method of Ordinary Least Squared (OLS), with robust standard error (control for heteroskedasticity).

Data on the exposure of dry lands come from the World Resources Institute (1999), and the United Nations Environment Program/Global Resource Information Database (UNEP/GRID 1991). This is the part of dry land, considered to be three of the world's six aridity zones -the arid, semi-arid, and dry sub-humid zones, as a percent of the country's total terrestrial area.

Each of components is normalized following the method[7]:

$$\mathrm{CN} = \frac{(C - min_C)}{\mathrm{max_C} - \mathrm{min_C}} * 100$$

With
CN : normalized component
C: value of component

Components averaging

Different methods of aggregation of the components have been tested: arithmetic, geometric modified (G'), quadratic means. As for weighting the components a principal component analysis (PCA) was implemented, to test the impact of an alternative weighting, compared to the equal weights retained. Finally to test the sensitivity of results, some rank correlation tests (Spearman and Kendall tau) were done.

The quadratic and the modified geometric average enhance the value of the index if one of the vulnerability components has an extremely high value (Guillaumont et al., 2010). Nevertheless between these two methods of aggregation the rank differences are not significant. Moreover the two methods correlate well with the arithmetic methods.

As for weights, comparing the arithmetic average results obtained with equal weights, and using weights given by the PCA, we observe that there is no significant difference in rank between the two indices, and their correlation is high (0.70 with level of signification of 0.01%)[8]. It may be seen as validating the choice of equal weights

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[7] For the component "trend in rainfall", C values are negative. So $\mathrm{CN} = 100 * [1 - \frac{(C - min_C)}{\mathrm{max_C} - \mathrm{min_C}}]$

[8] The same types of comparison of rank are made to test the sensitivity to the proxy.

Finally the geometric modified average with equal weights has been retained, instead of the arithmetic average, although the latter is the simplest method. Differences with other methods are very small (see results presented in Annex).

The Vulnerability to Climate Change of African countries

Why are African countries considered as vulnerable to climate change?

Various reasons lead us to consider Africa as particularly vulnerable to climate change, and climate variability. Referring in this paper to an index of physical vulnerability to climate change, we should examine these reasons through the lens of the components of this index. In doing that we do not forget that Africa is also likely to have a low adaptive capacity, mainly due to a low level of income per capita, which may exacerbate the impact of the physical vulnerability? Let us underline again that the components of our PVCCI are supposed to reflect the impact of a global warming due to CO2 emissions, essentially generated by non African countries. Three main reasons for African countries vulnerability to climate change should be taken into consideration.

First, African economies are very dependent on climate sensitive sectors such as agriculture, forestry and fishery. Agricultural production in many African countries and regions is likely to be severely undermined by climate change. Numerous African countries are classified as arid or semi-arid, and climate change is likely to reduce the length of the growing season in these areas (IPCC, 2007, chapter 9). Projected reductions of yields in some countries could be as much as 50% by 2020. The small-scale poor farmers will be probably the most affected. This effect on agriculture would result both in lower economic growth, and in lower food security.

Second, extreme events, such as droughts, have major effects on many African countries. The impact of droughts has been thoroughly reported in numerous studies, which show various economic and social consequences, including migration (WDR 2010). One-third of the population of Africa lives in drought-prone areas and is vulnerable to their effects (World Water Forum, 2000). During the mid-1980s the economic losses due to droughts were assessed at several hundred million U.S. dollars (Tarhule and Lamb, 2003). Droughts are prevalent in the Sahel, the Horn of Africa and Southern Africa. Some African countries also experienced floods events, which can result in significant economic deprivation (Mirza, 2003).

Finally, climate change exacerbates the water stress currently faced by some countries, also generates water stress in countries where this problem did not previously exist.

All these consequences affect African economies, which are already weak. Of 54 African countries, 33 are classified as Least Developed Countries. An IPCC report considers that Africa is facing an annual loss of 1 to 2 % annual GDP because of climate variability (IPCC 2007). The climate change impact is likely to enhance existing development challenges, and its consequences are generally expected to be bigger in lower income countries, as is still the case for many African countries.

What the PVCCI shows

The Physical Vulnerability to Climate Change Index is particularly useful to assess the degree and channels of this vulnerability in African countries. It should cast light on the characteristics of vulnerability to climate change within this particular area. Some of these characteristics have already been stressed in the literature, briefly recalled below.

Some previous findings… to be confirmed by the index

Some measurements of the supposed consequences of global warming in Africa : the warming of Africa since the 1960s is recognized by scientists. While this trend seems to affect the whole continent, the change is not uniform. For instance in South Africa and Ethiopia, minimum temperatures have increased (Conway et al., 2004), but Eastern Africa has experienced a trend of decreasing temperature. As for precipitation, the situation is more complicated: rainfall exhibits spatial and temporal variability (e.g., Hulme et al., 2005). In West Africa a decline in annual rainfall has been observed: 20 to 40% noted between the periods 1931-1960 and 1968-1990 (Dai et al., 2004). In the tropical rain-forest zone, the decline is smaller, and some other regions, such as Southern Africa, show no long-term change in rainfall. Increased interannual variability has been observed in the post-1970 period, with higher rainfall anomalies (Richard et al., 2001). South Africa has registered a significant increase in rainfall events (Usman and Reason, 2004). This heterogeneous picture is confirmed by the results of our index (summarized in the map below).

A high average level of vulnerability to climate change in Africa

Sub-Sahara African countries have a higher average PVCCI than other developing countries (Table 2 and Figure 4).
This level is on average higher because of the impact of the increasing recurrent shocks (mean for Developing Countries: 46.72 and for African Developing countries 51.07), not of progressive shocks (identical mean around 24 for the two groups).

As for the level of the index of the risk associated with progressive shocks, this is a result of a rather low impact of the sea level rise in Africa: a difference of 3 points in the mean between DCs and African DCs. Compared to other developing countries Africa does not include many small islands (which are more threatened by this trend). This difference in the composition of the group explains the high level of standard deviation for sea level rise in the group of developing countries (DCs), and the low level of standard deviation for the African group, which include more landlocked countries. This effect of less vulnerability concerning sea level rise is limited by a greater vulnerability to increasing aridity. The component “increasing aridity” is in fact more important for African DCs (2 points of difference in the mean) and the trend in temperature increase is more acute in Africa. Finally, the index of the risk of progressive shocks is not significantly different in Africa and in other developing countries, because of these two opposed effects. It should be noted that we are here comparing Africa and other developing countries through simple averages or median levels, consistent with the aim of our index. If the country indices of the risk of progressive shocks were weighted by the population, the (weighted) average would probably be higher for Africa because the simple average of other developing countries is affected by the level of numerous small islands threatened by sea level rise (as shown by the simple average for SIDS).

As for the index of increasing recurrent shocks, which is higher in Africa, this is due both to the trends of rainfall and of temperature instabilities, from departure levels which are themselves rather high. For these components the difference between DCs and African DCs is large and non ambiguous.

Country group results presented in the table below also show the high physical vulnerability to climate change of the Least Developed Countries, already found to have a high structural economic vulnerability, as evidenced by EVI, a feature used for their identification (Figure 4).

Heterogeneous levels, heterogeneous kinds of vulnerability among African countries

Since the index is estimated country by country, it exhibits a large heterogeneity in the levels and the kinds of vulnerability among countries (Annex 2). Its results, while showing a high average vulnerability to climate change in Africa (Figure 5), also show levels very different among African countries, and this is so for various reasons.

On a scale including 147 countries in the world, the PVCCI ranking (in increasing order, i.e. from the least to the most vulnerable) varies for African countries between 23 (Lesotho) and 144 (Namibia). The ten seemingly most vulnerable African countries with regard to the PCCVI are Namibia, Senegal, Botswana, Gambia, Burkina Faso, Mali, Zambia, Sudan, Benin and Burundi. These countries present a high level of overall physical vulnerability, generally due to a high level of several components of the index. Five main regions can be distinguished: the three most vulnerable sub-regions seem to be West Africa, a group of Eastern Africa countries and Southern Africa (not including South Africa). North Africa and a group of Central Africa countries present lower vulnerability than the rest of continent.

As for vulnerability to progressive shocks, the level of this component (due to two sub-components, sea level rise and intensification of aridity) is for some African countries (Botswana, Chad, Comoros and Mali) at the highest level in the world. This high level of vulnerability to progressive shocks is in Africa generally not mainly due, to sea level rise, except in the case of Seychelles. African countries are mainly landlocked and so not exposed to sea level rise, but many of them are highly exposed to increasing aridity. Indeed most of the African countries with a high level of vulnerability to progressive shocks are those exposed to increase of aridity. This vulnerability seems to be high for countries in desert areas Mali, Burkina Faso, Sudan, Namibia and Botswana. The ranking of African countries vulnerable to aridification is the highest in the world, along with some Central Asia countries (e.g. Afghanistan, Turkmenistan). Some African countries also face both kinds of progressive shocks: Senegal is highly vulnerable to progressive shocks because of a high level of vulnerability to an increase of aridity in the North of the country, but also because of the sea level rise in the Senegal river delta (a similar vulnerability is found in Gambia). It should be noted that the standard deviation of the “increasing aridity” component is bigger in the African group than in the group of other developing countries.

As for the “risk of intensification of recurrent shock”, this component, on average high for African countries, also shows significant differences between African countries (ranked from 27 for Chad, the lowest, to 201 for Zambia among 201 countries). After Zambia, the African countries seemingly most vulnerable to an intensification of rainfall and/or temperature recurrent shocks are Namibia, Burundi, Sierra Leone, Madagascar, Senegal, Angola, Guinea, Rwanda and Guinea-Bissau (these ten African countries are among the thirteen countries in the world with the highest level of vulnerability to the increase of recurrent risks).These high levels are either due to a very high level of the indices of intensification of both rainfall and of temperature shocks (Zambia, Namibia, Madagascar[9], Guinea), or mainly due to the intensification of temperature shocks (Burundi, Rwanda, Sierra Leone, Senegal), or mainly due to the intensification of rainfall shocks (Guinea-Bissau, Angola). Of course these countries, among the most vulnerable to the intensification of recurrent shocks are to a large extent vulnerable to both kinds of shocks. Some other African countries appear to be essentially vulnerable to one kind of shocks (Comoros and Sao Tome to temperature, Zimbabwe, Malawi, Eritrea, Mali, and Gambia to rainfall).

Thus, although many African countries seem to be highly vulnerable to climate change for physical reasons, the precise reason or channel of this (physical) vulnerability may significantly differ from one country to another one. These various profiles of vulnerability to climate change may help in the design of appropriate adaptation policies.

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[9] The vulnerability of Madagascar is not a surprise due to the large number of typhoons which affect the country

Table 2: PVCCI by group of countries

group of countries	**PVCCI**				**PROGRESSIVE SHOCKS**				**RECURRENT SHOCKS**			
	number of countries	Mean	Median	Standard Deviation	number of countries	Mean	Median	Standard Deviation	number of countries	Mean	Median	Standard Deviation
All Developing Countries (DCs)	116	35,96	35,81	6,74	116	24,33	21,53	11,60	142	46.72	45.75	7.48
African[10] Developing Countries	43	37,97	37,63	5,87	43	24,64	23, 37	9,32	47	51,07	50,92	7,18
Least Developed Countries (LDCs)	46	37,93	37,38	7,83	46	24,92	18,80	14,22	49	51.03	51.02	7.58
African LDCs	30	38,11	38,14	5,72	30	23,63	20,09	9,29	32	52,44	52,01	7,14
Low and LMI Countries non LDCs	84	37,25	36,84	7,16	84	25,53	22,37	13,00	95	48.54	48.92	7.50
African Low and LMI Countries	37	37,61	37,65	5,49	37	23,84	21,77	8,86	40	51,25	50,97	7,27

group of countries	**PROGRESSIVE SHOCKS**				**Sea level rise**				**Increasing aridity**			
	number of countries	Mean	Median	Standard Deviation	number of countries	Mean	Median	Standard Deviation	number of countries	Mean	Median	Standard Deviation
All Developing countries (DCs)	116	24,33	21,53	11,60	122	5,35	0,99	16,79	135	43.31	37.97	18.54
African Developing countries	43	24,64	23,37	9,32	45	1,90	0,26	6,56	45	47,09	41,86	19,04
Least Developed Countries (LDCs)	46	24,92	18,80	14,22	48	7,51	0,67	24,19	47	42.50	36.41	18.48
African LDCs	30	23,63	20,09	9,29	31	1,01	0,36	1,42	31	46,75	40,70	17,91
Low and LMI countries non LDCs	84	25,53	22,37	13,00	88	6,70	0,84	21,22	91	45.64	40.70	19.00
African Low and LMI countries	37	23,84	21,77	8,86	39	0,94	0,16	1,34	38	47,13	44,02	17,23

group of countries	number of countries	**RECURENT SHOCKS**			**Rainfall shocks**			**Temperature shocks**		
		Mean	Median	Standard Deviation	Mean	Median	Standard Deviation	Mean	Median	Standard Deviation
All Developing countries (DCs)	142	46.72	45.75	7.48	43.31	43.39	10.77	50.13	46.60	10.07
African Developing countries	47	51,07	50,92	7,18	47,92	49,06	11,49	54,22	51,76	10,59
Least Developed Countries (LDCs)	49	51.03	51.02	7.58	47.74	49.06	11.91	54.32	50.18	10.90
African LDCs	32	52,44	52,01	7,14	49,36	50,43	10,87	55,52	53,37	11,04
Low and LMI countries non LDCs	95	48.54	48.92	7.50	43.45	43.25	8.86	48.26	45.63	9.55
African Low and LMI countries	40	51,25	50,97	7,27	48,26	49,57	11,56	54,25	51,79	10,40

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[10] We consider here only Sub-Saharan African countries following the World Bank classification

Figure 4: Map of PVCCI for Developing Countries

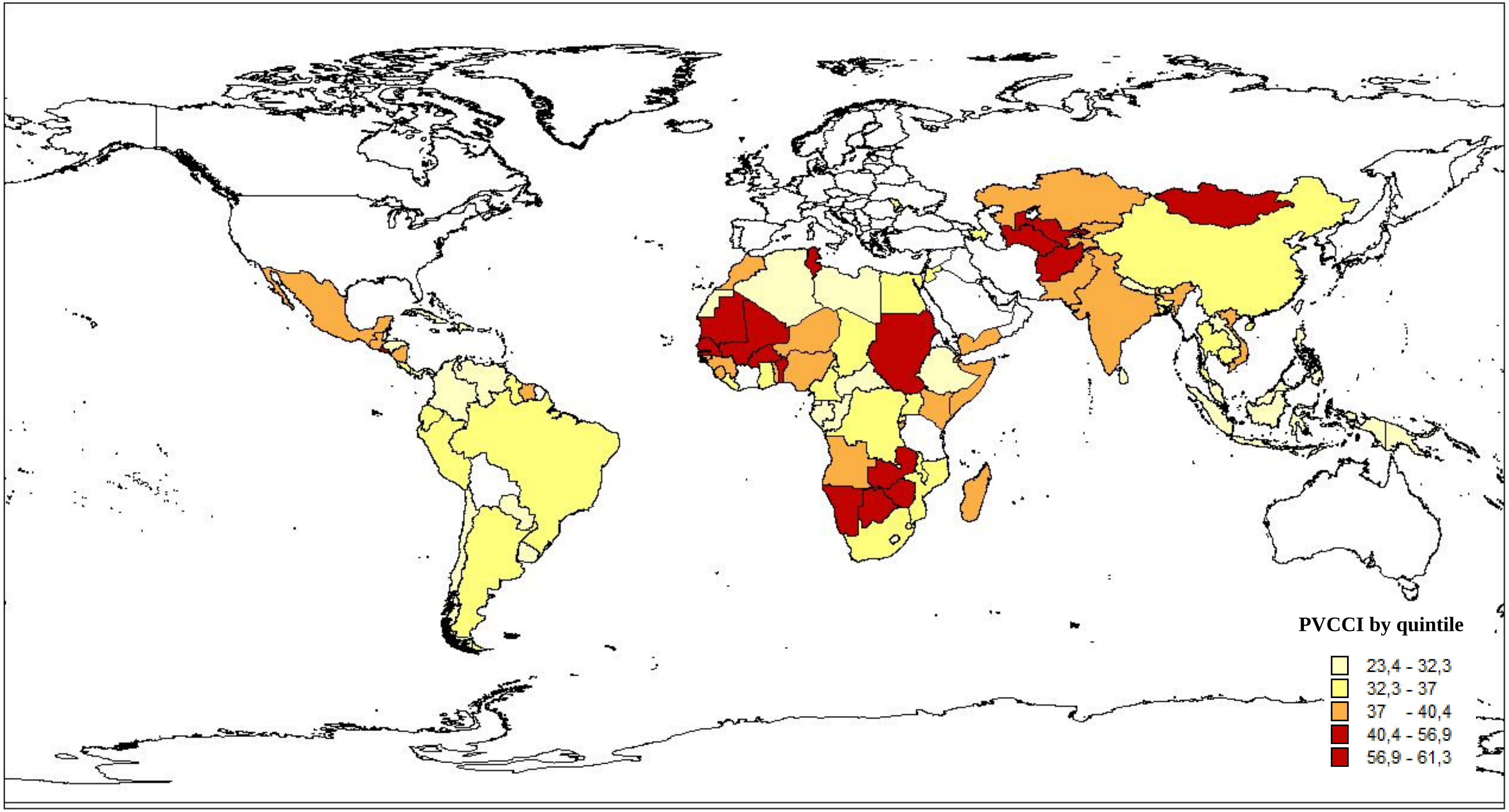
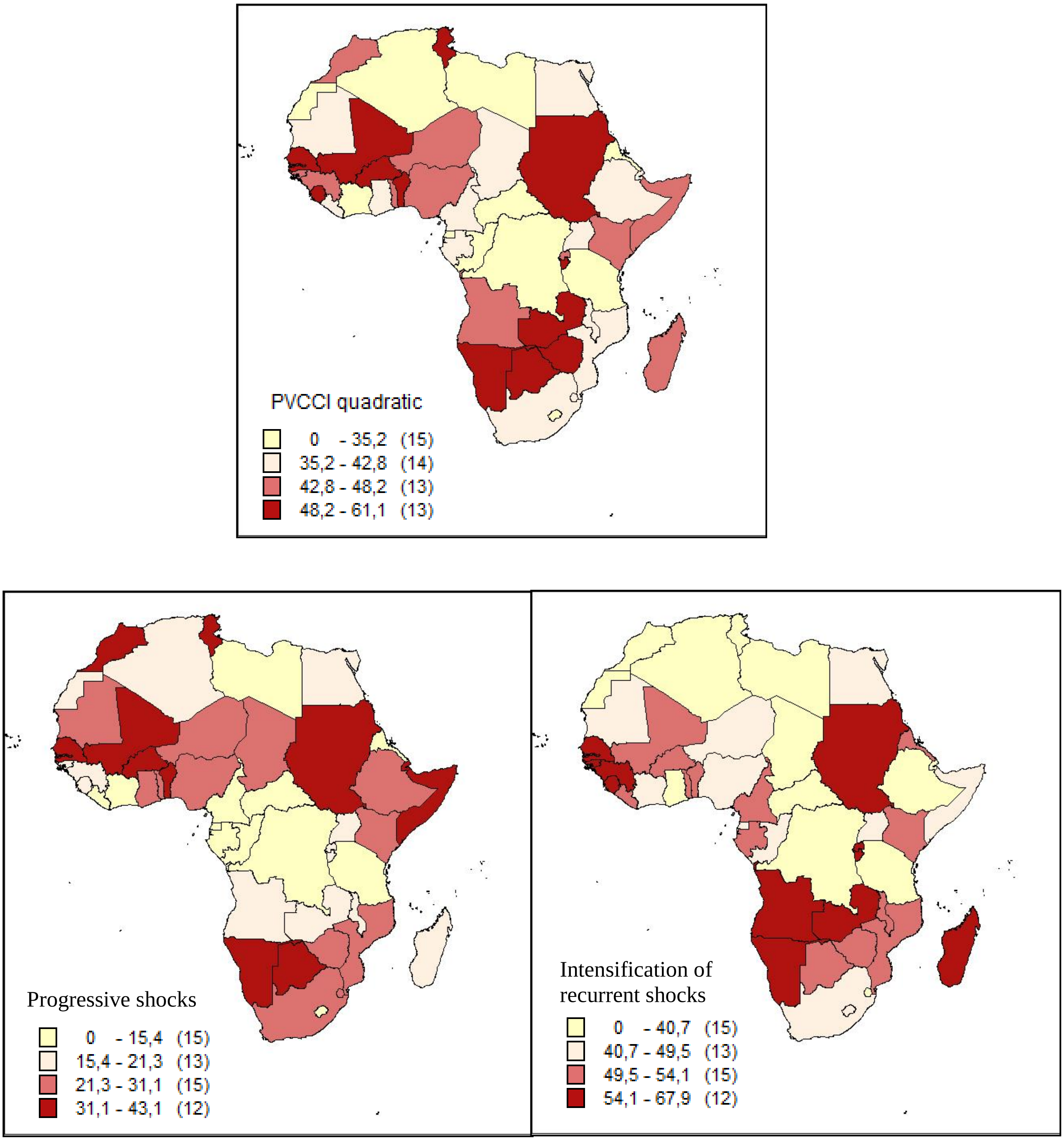


Figure5 : PVCCI in African Countries and by components



Conclusions

This paper presents a first attempt to build a Physical Vulnerability to Climate Change Index (PVCCI) and the preliminary results of this Index for African countries. The index deviates from the already rich literature on vulnerability to climate change by only considering the part of the vulnerability which does not depend on present and or future policy. To this aim, it relies only on physical components reflecting the likely impact of climate change, without any use of socioeconomic data. It is an index of physical or geo-physical vulnerability to climate change, changing only progressively and slowly. It differs from other vulnerability indices, both from the more general environmental vulnerability indices, which include resilience and policy components, and from the Economic Vulnerability Index (EVI) used by the Committee for Development Policy (CDP) for the identification of the Least Developed Countries (LDCs). The latter is related only to structural vulnerability (independent from the present will of countries), but it covers all kinds of exogenous shocks likely to affect economic growth, and not just those resulting from climate change.

The components of the PVCCI index capture two kinds of risks related to climate change: the risks of an increase of recurrent shocks (such as droughts), and the risks of progressive and irreversible shocks (such as flooding due to higher sea level). Moreover the assessment of these risks relies on components referring both to the likely size of the shocks and to the country exposure to these shocks.

The calculation of the index of physical vulnerability to climate change shows both a higher average level for African countries than for other developing countries, and a significant heterogeneity among African countries, as well as among the others. Five main regions have been distinguished: the three most vulnerable sub-regions appear to be West Africa, a group of East African countries, and Southern Africa (excluding South Africa), on the other hand North Africa and a group of Central African countries present lower vulnerability than the rest of continent. The ten seemingly most vulnerable African countries with regard to the PCCVI are Namibia, Senegal, Botswana, Gambia, Burkina Faso, Mali, Zambia, Sudan, Benin and Burundi. These countries present a high level of overall physical vulnerability, generally due to a high level of several components of the index.

The high physical vulnerability to climate change of many African countries is itself the result of various combinations of the components of the index. The higher average level of the African PVCCI is due to a greater intensification of recurrent shocks (rainfall or/and temperature), more than to progressive shocks. In fact the impact of progressive shocks in Africa is mitigated by the fact that many African countries are landlocked, and so not threatened by sea level rise, although many of them are concerned by a trend of increasing aridity. The higher level of the risk of increasing recurrent shocks appears to result either from rainfall or temperature shocks

The UN Economic Vulnerability Index (EVI) has been proposed as a possible criterion for the allocation of development assistance between countries (Guillaumont, 2008; Guillaumont et al., 2010). In the same way the PVCCI could be used as a criterion for the allocation of the international resources available for the adaptation to climate change. It would be a relevant criterion precisely because it does not depend on present policy, and only gives an indication of the need for adaptation. The two indices EVI and PVCCI can have a complementary role in the allocation of international resources, as far as these resources are provided from separate sources. Should that not be the case, it would be interesting to investigate how the ranking of the PVCCI follows that of the EVI, or deviates from it.

REFERENCES

Adger, W. N., 1999, “Social Vulnerability to Climate Change and Extremes in Coastal Vietnam”, *World Development,* 27:249-269.

Adger, W. N., 2006, “Vulnerability”, *Global Environmental Change,* 16:268-281.

Adger, W. N., N. Brooks, 2003, “Does environmental change cause vulnerability to natural disasters?” in Pelling (ed.), *Natural Disasters and Development in a Globalising World,* Routledge, London,19-42.

Adger, W.N., N. Brooks, G. Bentham, M. Agnew and S. Eriksen, 2004, “New indicators of vulnerability and adaptive capacity”, *Centre for Climate Research* 5.

Allen, K., 2003, “Vulnerability reduction and the community-based approach” in Pelling (ed.), *Natural Disasters and Development in a Globalising World*. Routledge, London, 170-184.

Barr, R., S. Fankhauser, K. Hamilton., 2010, “Adaptation investments: a resource allocation framework”, *Mitigation and Adaptation Strategies for Global Change,* 15:843–858.

Baettig, M., M. Wild, D. Imboden, 2007, “A climate change index: where climate change may be most prominent in the 21st century”, *Geophysical Research Letters 34.*

Birkmann, J., 2006a, “Measuring Vulnerability to Promote Disaster resilient Societies: Conceptual Frameworks and definitions” in *Measuring Vulnerability to Natural Hazards – Towards Disaster Resilient Societies,* edited by Birkmann, J., United Nations University Press, Tokyo, 9–54.

Birkmann, J., B. Wisner, 2006b, “Measuring the Un-Measurable – The Challenge of Vulnerability”, Source 05/2006, United Nations University, Institute for Environment and Human Security, Bonn

Birkmann, J., 2007, “Risk and vulnerability indicators at different scales: Applicability, usefulness and policy implications”, *Environmental Hazards,* 7:20–31.

Blaikie, P. M., 1994, *At risk: natural hazards, people's vulnerability, and disasters,* Routledge.

Bogardi J., J. Birkmann, 2004, “Vulnerability Assessment: The first step towards a sustainable risk reduction” in Malzhan D., T. Plapp ed. Disaster and Society- *From Hazard Assessment to Risk Reduction.* Berlin: Logos Verlag Berlin 75-82

Brooks, N., 2003, “Vulnerability, risk and adaptation: A conceptual framework”, *Tyndall Centre, University of East Anglia*.

Brooks, N. W.N. Adger, P.M. Kelly, 2005, “The determinants of vulnerability and adaptive capacity at thenational level and the implications for adaptation.”, *Global Environmental Change,* 15(2005): 151-163

Bruckner, M., 2010, "Identifying least developed countries-the role of climate change vulnerability" background note, Committee for development Policy Secretariat, unpublished.

Buob, S., G. Stephan, 2010, “To mitigate or to adapt: how to combat with global climate change”, *European Journal of Political Economy*

Buys, P., U., Deichmann, C., Meisner, T.T., That, D, Wheeler, 2007, “Country Stakes in Climate Change Negotiations: Two Dimensions of Vulnerability”, *World Bank Policy Research Working Paper 4300,* World Bank, Washington, DC

Burke, M.B., E. Miguel, S. Satyanath, J.A. Dykema, D. B. Lobell, 2009 “Warming increases the risk of civil war in Africa”, *Proceedings of the National Academy of Sciences,* 106 (49): 20670-20674

Cardona, O.D., 2003,“The need for rethinking the concepts of vulnerability and risk from a holistic perspective: a necessary review and criticism for effective risk management” In: Bankoff, G., Frerks, G., Hilhorst, D. (Eds.), *Mapping Vulnerability: Disasters, Development and People. Inter-American Development Bank*, Washington, D.C. (Chapter 3).

Committee for Development Policy and Department of Social and Economic Affairs (2008), Handbook on the Least developed Country Category: Inclusion, Graduation, and Special Measures, United Nations.

Cullen, S.L, H. M., de Menocal, P. B., Hemming, S., Hemming, G., Brown, F. H., Guilderson, T. F., Sirocko, 2000, “Climate change and the collapse of the Akkadian empire: Evidence from the deep-sea”, *Geology,* 28 (4), 379-382.

Cutter, S. L., 1996, “Vulnerability to environmental hazards”, *Progress in human geography*, 20:529.

Cutter, S., B. J. Boruff, W.L. Shirley, 1996, “Vulnerability to environmental hazards”, *Progress in Human Geography,* 20 (4), 529–539.

Dasgupta,S. , B. Laplante, C. Meisner, D. Wheeler, J. Yan, 2009a, “The Impact of Sea Level Rise on Developing Countries: a Comparative Analysis”, *Climatic Change*, 93:379–388.

Dercon, S., J. Hoddinott, T. Woldehanna, 2005, “Shocks and consumption in 15 Ethiopian Villages, 1999-2004”, *Journal of African Economies,* 14:559.

Diffenbaugh N., F. Giorgi, L. Raymond, X. Bi, 2007, “Indicators of 21st century socioclimatic exposure”, *Proceedings of the National Academy of Sciences,* 104(51), 20195.

Downing, T. E, et A. Patwardhan., 2005, “Assessing vulnerability for climate adaptation”, in *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures*, *B.* Lim, E. Spanger-Siegfried, I. Burton, E. Malone, and S. Huq, Eds., Cambridge University Press, Cambridge and New York 67–90.

Downing, T., M. Watts, H. Bohle, 1995, “Climate change and food insecurity:towards a sociology and geography of vulnerability” In: Downing, T. (Ed.), *Climate Change and World Food Security*. Springer, Berlin, pp. 183–206.

Eakin, H., A.L., Luers, 2006, “Assessing the vulnerability of social-environmental systems”, *Annual Review of Environment and Resources* 31 (1), 365–394.

Esty, D.C., Levy, M., T. Srebotnjak, A. de Sherbinin, 2005, “Environmental Sustainability Index: Benchmarking National Environmental Stewardship”, *Yale Center for Environmental Law & Policy, New Haven.*

Eriksen, S., P. Kelly, 2007, “Developing credible vulnerability indicators for climate adaptation policy assessment”, *Mitigation and Adaptation Strategies for Global Change,* 12 (4), 495–524. http://dx.doi.org/10.1007/s11027-006-3460-6.

Füssel, H. M., 2007, “Vulnerability: a generally applicable conceptual framework for climate change research”, *Global Environmental Change* , 17:155–167.

Füssel, H. M., 2009 “Review and Quantitative Analysis of Indices of Climate Change Exposure, Adaptive Capacity, Sensitivity, and Impacts, Background note to the World Development Report 2010”, World Bank, Washington, DC.

Füssel, H M., 2010, "How inequitable is the global distribution of responsibility, capability, and vulnerability to climate change: A comprehensive indicator-based assessment", *Global Environmental Change*, 20(4): 597-611

Füssel, H M., R., Klein. 2006, "Climate Change Vulnerability Assessments: An Evolution of Conceptual Thinking", *Climatic Change*, 75:301-329.

Gall, M., 2007, *Indices of Social Vulnerability to Natural Hazards: A ComparativeEvaluation*. PhD Thesis. Department of Geography, University of South Carolina.

Giorgi, F., 2006, "Climate change hot-spots", *Geophysical Research Letters 33*, L08707.

Guillaumont,P., 2007, "La vulnérabilité économique, défi persistant à la croissance africaine", *African Development Review* 19 (1), p123-162

Guillaumont,P., 2008, "Adapting Aid Allocation Criteria to Development Goals" An Essayfor the UN Development Cooperation Forum, FERDI Working Paper, May (also availableon the web site of the UN).

Guillaumont, P., 2009a, *Caught in a trap. Identifying the least developed Countries,* Economica, 386p

Guillaumont P., 2009b, "An Economic Vulnerability Index: Its Design and Use for International Development Policy", *Oxford Development Studies*, Vol 37, No 3, Sept. 2009, 193-227

Guillaumont, P., L. Chauvet, 2001, "Aid and performance: a reassessment", *Journal of Development Studies,* 37:66–92.

Guillaumont P., S., Guillaumont Jeanneney, L., Wagner, 2010, "How to take into account vulnerability in aid allocation criteria and lack of human capital as well : improving the performance based allocation", Ferdi Working Paper http://www.ferdi.fr/uploads/sfCmsContent/html/112/P13-PG-SG-LW.pdf

Hinkel, J., 2008, *Transdisciplinary knowledge integration. Cases from integrated assessment and vulnerability assessment.* Ph.D. thesis, Wageningen University, Wageningen, The Netherlands.

Hinkel, J., 2011, "Indicators of vulnerability and adaptive capacity: Towards a clarification of the science–policy interface", *Global Environmental Change,* 21 (1).

Hulme, M., 1996, "Recent climatic change in the world's drylands", *Geophysical Research Letters*, 23(1): 61 -64

Ionescu, C., R.J.T., Klein, J., Hinkel, K.S.K., Kumar, 2009, "Towards a formal framework of vulnerability to climate change", *Environmental Modelling and Assessment*, 14, 1–16.

IPCC, 2007a, *Climate Change Impacts, Adaptation, and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report.* Cambridge University Press, Cambridge.

IPCC, 2007b, F*ourth Assessment Report of the Intergovernmental Panel on Climate Change Glossary Climate Change 2007: Climate Change Impacts, Adaptation, and Vulnerability* Cambridge University Press, Cambridge.

Janssen, M., E., Ostrom, 2006, "Resilience, vulnerability and adaptation: A cross-cutting theme of the international human dimensions program on global environmental change", *Global Environmental Change*, 16(3): 237–239. Editorial.

Jones. R. and R. Boer, 2005, "Assessing current climate risks", Technical Paper No. 4. Adaptation policy frameworks for climate change. Developing strategies policies and measures. United Nations

Development Program, Global Environment Facility. New York: Cambridge University Press, pp. 91–117. http://www.undp.org/GEF/documents/publications/apf-technical-paper04.pdf

Jones, R.N., P. Dettmann, G. Park, M. Rogers,T. White, 2007, “The relationship between adaptation and mitigation in managing climate change risks: a regional response from North Central Victoria, Australia”, *Mitigation and Adaptation Strategies for Global Change*, 12:685–712

Jones, P.G. and P.K. Thornton, 2003: The potential impacts of climate change on maize production in Africa and Latin America in 2055. *Global Environ. Change.*, 13, 51-59

Kaly, U.L., Pratt, C.R., Mitchell, J., 2004, “The Environmental Vulnerability Index (EVI) 2004”, SOPAC Technical Report 384. South Pacific Applied Geoscience Commission, Suva, Fiji. http://www.vulnerabilityindex.net/Files/EVI%202004%20Technical%20Report.pdf.

Kazianga, H., Udry, C., 2006. "Consumption smoothing? Livestock, insurance and drought in rural Burkina Faso," *Journal of Development Economics, Elsevier*, vol. 79(2), p 413-446, April.

Kelly, P. M., W. N. Adger, 2000, “Theory and practice in assessing vulnerability to climate change and Facilitating adaptation”, *Climatic Change,* 47:325–352.

Klein, R.J.T., 2009, “Identifying countries that are particularly vulnerable to the adverse effects of climate change: an academic or a political challenge?”, *Carbon & Climate Law Review* 3, 284–291.

Legates, D. R. and C. J. Willmott, 1990a, “Mean Seasonal and Spatial Variability Global Surface Air Temperature”, *Theoretical and Applied Climatology* , 41, 11-21.

Legates, D. R. and C. J. Willmott, 1990b, “Mean Seasonal and Spatial Variability in Gauge-Corrected, Global Precipitation”, *International Journal of Climatology*, 10, 111-127.

Liverman, D.M., 1990, “Vulnerability to global environmental change”, In *Understanding Global Environmental Change*, eds. R.E.Kasperson et al., pp.8-23, Worcester, MA: The Earth Transformed Program.

Lonergan, S., K. Gustavson, M. Harrower, 1999, “Mapping human insecurity” In:Lonergen, S. (Ed.), *Environmental Change, Adaptation, and Security*. NATO/Kluwer, Dordrecht, pp. 397–413.

McCarthy, J. J., 2001, *Climate change 2001: Impacts, adaptation, and vulnerability: contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change.* Cambridge Univ Pr.

Miller, F., H. Osbahr, E. Boyd, F. Thomalla, S. Bharwani, G. Ziervogel, B. Walker, J. Birkmann, S. Van der Leeuw, J. Rockström, J. Hinkel, T. Downing, C. Folke, and D. Nelson, 2010, “Resilience and vulnerability: complementary or conflicting concepts ? ”, *Ecology and Society,* 15(3): 11.

Moss, R.H.,A.L. Brenkert, E.L.Malone, 2001, *Vulnerability to Climate Change: A Quantitative Approach.* Technical Report PNNL-SA-33642. Pacific Northwest National Laboratory.

Nicholls, R. J., F. M. J. Hoozemans, M. Marchand, 1999, “Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses, *Global Environmental Change*, 9, S69-S87.

O’Brien, K., S. Eriksen, L. P Nygaard, A. Schjolden, 2007, “Why different interpretations of vulnerability matter in climate change discourses”, *Climate Policy* ,7:73–88.

O’Brien, K., S. Eriksen, A. Schjolden, L. Nygaard, 2004, “What’s in a word? Conflicting interpretations of vulnerability in climate change research” *Retrieved April* 15:2006.

Olmos, S., 2001, *Vulnerability and Adaptation to Climate Change: Concepts, Issues, Assessment Methods. Climate Change Knowledge Network.*

Prowse, M. 2003, "Towards a clearer understanding of'vulnerability'in relation to chronic poverty", CPRC Working Paper No. 24, Chronic Poverty Research Centre, University of Manchester, Manchester, UK.

Slingo, J.M., A.J. Challinor, B.J. Hoskins and T.R. Wheeler, 2005: "Introduction: food crops in a changing climate." *Philos. T. Roy. Soc. B*, 360, 1983-1989.

Smit B. J. Wandel, 2006, "Adaptation, adaptive capacity and vulnerability", *Global Environmental Change*, 16 (2006) 282–292

Srinivasan U.T., 2010, "Economics of climate change: risk and responsibility by world region", *Climate Policy*, 10: 298-316.

Suppes, P., 1968, "The desirability of formalization in science", *The Journal of Philosophy*, 65:651–664.

Thomas, D.S.G. and C. Twyman, 2005: "Equity and justice in climate change adaptation amongst natural-resource-dependent societies." *Global Environ. Change*., 15, 115-124.

Thywissen, K., 2006, "Components of Risk: a Comparative Glossary" *Source 2*, Bonn: publication Series of UNU-EHS.

Timmerman, P., 1981, "Vulnerability, resilience and the collapse of society", *Environmental Monograph* 1.

Tol, R. S.J., 2009, "The economic effects of climate change", *Journal of Economic Perspectives*, 23:29–51.

Tol, R. S.J, T. E Downing, O. J Kuik, J. B Smith, 2004, "Distributional aspects of climate change impacts", *Global Environmental Change Part A*, 14:259–272.

Tol, R.S.J., Yohe, G.W., 2007, "The weakest link hypothesis for adaptive capacity: an empirical test", *Global Environmental Change*, 17 (2), 218–227.

Turner, B. L. Kasperson, R.E., Matson, P.A., McCarthy, J.J., Corell, R.W., Christensen, L., Eckley, N., Kasperson, J.X., Luers, A., Martello, M.L., Polsky, C., Pulsipher, A. and Schiller, A., 2003, "A framework for vulnerability analysis in sustainability science." *Proceedings of the National Academy of Sciences of the United States of America*, 100:8074.

United Nations Environment Program/Global Resource Information Database, 1991, "Global digital data sets for land degradation studies: a GIS approach" by U. Deichmann and L. Eklundh. *GRID Case Study Series No. 4*. UNEP/GEMS and GRID

UNFCCC, 2008a, A*d Hoc Working Group on Long-term Cooperative Action under the Convention. First session*. Bangkok, 31 March to 4 April 2008. FCCC/AWGLCA/2008/MISC.1. http://unfccc.int/resource/docs/2008/awglca1/eng/misc01.pdf.

UNFCCC, 2008b. *Ad Hoc Working Group on Long-term Cooperative Action Under the Convention. Third session.* Accra, 21–27 August 2008. FCCC/AWGLCA/2008/MISC.2/Add.1. http://unfccc.int/resource/docs/2008/awglca3/eng/misc02a01.pdf

UNFCC 2008c, *Rapport de la vingt-neuvième session de l'Organe subsidiaire de conseil scientifique et technologique*, tenue à Poznan du 1er au 10 décembre 2008

United Nations Committee for Development Planning (UNCDP), 1994. *Report on the 29th session E/1994/22, supplement 2.* Un Department of Economic and Social Affairs, United Nations, New York.

Wam, H. K., 2009, "Economists, time to team up with the ecologists!", *Ecological Economics,* 69:675-679.

Willmott, C. J. and K. Matsuura, 1995, "Smart Interpolation of Annually Averaged Air Temperature in the United States", *Journal of Applied Meteorology*, 34, 2577-2586.

Wisner, B., 2004, *At Risk: Natural Hazards, People's Vulnerability and Disasters*. London: Routledge.

World Bank, 2009, *World Development Report 2010. Development and Climate Change*. The World Bank, Washington.

World Bank, 2008, *World Development Report 2010. Agriculture for Development.* The World Bank, Washington

Yamano Y., L.Chritianensen, H.Alderman, 2005, "Child Growth, Shocks, and Food Aid in Rural Ethiopia**.**" *American Journal of Agricultural Economics.* 87(2) 273-288

Yohe, G., E., Malone, A., Brenkert, M., Schlesinger, H., Meij, X., Xing, 2006a, "Global distributions of vulnerability to climate change." *Integrated Assessment* 6 (3)

Yohe, G., E., Malone, A., Brenkert, M., Schlesinger, H., Meij, X., Xing, D. Leea, 2006b, *A Synthetic Assessment of the Global Distribution of Vulnerability to Climate Change from the IPCC Perspective that Reflects Exposure and Adaptive Capacity.* CIESIN (Center for International Earth Science Information Network), Columbia University, Palisades.

Appendix 1: Elementary components of the PVCCI for African Countries[11]

countries	1. Size of sea level	2. Share of flood areas	3. Share of drylands	4a. Trend in temperature	4b. Trend in rainfall	5. Rainfall instability	6. Temperature instability	7.Trend in rainfall instability	8.Trend in temperature instability
Algeria	1,00	0,37	20,90	45,73	67,18	23,44	39,67	31,97	54,08
Angola	1,00	0,02	19,30	35,41	71,62	87,50	40,50	39,22	69,32
Benin	1,00	0,53	87,50	27,16	72,03	73,44	45,45	32,37	58,06
Botswana	1,00	0,00	100,00	73,34	70,91	64,06	53,72	36,82	54,08
Burkina Faso	1,00	0,00	100,00	38,75	75,13	65,63	46,28	40,77	54,08
Burundi	1,00	0,00	0,00	61,98	70,04	62,50	72,73	35,62	83,57
Cameroon	1,00	0,02	13,00	14,73	77,81	67,19	28,93	39,28	68,30
Cape Verde	1,00	0,69	15,40	14,82	66,42	56,25	37,19	34,94	54,08
Central Af. Rep.	1,00	0,00	20,10	4,30	74,32	57,81	28,93	36,17	59,10
Chad	1,00	0,00	68,20	42,69	69,42	9,38	47,11	39,11	45,39
Comoros	1,00	0,71	0,00	74,86	87,93	50,00	100,00	0,00	54,08
Congo	1,00	0,01	0,10	15,30	74,58	56,25	33,88	35,78	61,16
Congo, Dem.Rep. of	1,00	0,00	0,40	31,05	71,98	54,69	58,68	35,76	57,39
Côte d'Ivoire	1,00	0,20		14,63	79,20	70,31	35,54	32,37	54,08
Djibouti	1,00	1,47	73,40	36,12	66,42	29,69	34,71	35,58	62,63
Egypt	1,00	0,67	7,80	42,16	65,79	50,00	43,80	32,81	54,08
Equatorial Guinea	1,00	0,10	0,00	17,35	84,68	37,50	28,10	41,43	70,92
Eritrea	1,00		83,00	17,15	66,42	79,69	23,14	35,99	62,04
Ethiopia	1,00	0,82	57,70	23,28	66,42	29,69	43,80	32,37	44,44
Gabon	1,00	0,19	0,00	19,94	79,01	60,94	32,23	40,17	65,32
Gambia	1,00	1,33	97,30	38,23	86,37	53,13	57,85	56,59	54,08
Ghana	1,00	0,40	66,20	31,30	73,02	0,00	60,33	32,37	54,08
Guinea	1,00	0,20	14,10	32,46	85,61	59,38	64,46	47,83	60,14
Guinea-Bissau	1,00	0,77	5,90	35,38	88,40	71,88	34,71	58,27	64,85
Kenya	1,00	0,04	68,00	26,10	66,42	62,50	51,24	32,37	54,08
Lesotho	1,00	0,00	0,00	0,00	71,77	54,69	26,45	32,37	61,61
Liberia	1,00	0,10	0,00	24,80	82,47	65,63	59,50	32,37	57,25
Libyan Arab Jam.	1,00	0,69	22,70	63,14	66,42	28,13	40,50	32,37	54,08
Madagascar	1,00	0,20	23,10	35,32	66,42	85,94	73,55	32,37	54,08
Malawi	1,00	0,00	0,00	63,77	74,79	75,00	31,40	41,35	54,08
Mali	1,00	0,00	80,20	47,04	71,09	75,00	49,59	37,70	54,08
Mauritania	1,00	0,69	45,60	46,90	69,56	54,69	42,15	34,12	54,08
Mauritius	1,00		0,00	22,03	66,42	59,38	39,67	32,37	50,51
Mayotte	1,00	0,95	0,00	74,86	87,93	50,00	100,00	0,00	54,08
Morocco	1,00	0,25	92,30	33,22	69,41	42,19	23,97	32,37	54,08
Mozambique	1,00	0,14	37,60	35,35	74,20	81,25	25,62	37,21	54,08
Namibia	1,00	0,07	90,80	75,02	70,04	90,63	69,42	36,57	60,25
Niger	1,00	0,00	62,10	52,60	69,08	64,06	52,07	36,12	43,57
Nigeria	1,00	0,07	58,20	34,42	71,49	46,88	48,76	32,37	61,49
Rwanda	1,00	0,00	0,00	58,01	66,42	40,63	73,55	36,30	80,42
Sao Tome and P.	1,00	0,69	54,90	7,98	81,31	65,63	32,23	60,83	62,77
Senegal	1,00	0,84	94,10	53,66	79,04	53,13	81,82	44,01	59,60
Seychelles	1,00	11,00	0,00	0,00	62,80	67,19	30,58	26,95	54,08
Sierra Leone	1,00	0,35	0,00	42,05	97,36	23,44	93,39	71,95	59,04
Somalia	1,00	0,09	79,90	35,26	66,42	35,94	42,15	34,99	70,31
South Africa	1,00	0,02	66,20	26,45	70,12	46,88	38,84	32,37	54,08
Sudan	1,00	0,02	66,80	63,83	66,42	68,75	61,98	35,71	54,08
Swaziland	1,00	0,00	49,00	49,38	72,61	32,81	34,71	28,71	54,08
Tanzania, Un. Rep.	1,00	0,02		24,37	66,42	73,44	42,15	32,37	54,08
Togo	1,00	0,19	33,60	27,77	72,46	75,00	55,37	26,53	58,91
Tunisia	1,00	1,08	93,70	65,12	68,16	34,38	31,40	32,37	54,08
Uganda	1,00	0,00	16,20	32,37	66,42	46,88	51,24	32,37	64,68
Zambia	1,00	0,00	16,30	46,42	70,74	95,31	66,94	42,63	66,34
Zimbabwe	1,00	0,00	67,30	34,36	71,68	81,25	31,40	38,52	62,07

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[11] In grey, countries not usually classified as Sub-Saharan Africa

Appendix 2: Aggregated components and overall level of CCVI for African countries[12] [13]

	Risks related to								Index of the risk of progressive shocks		Index of the risk intensification of recurrent shocks		**PVCCI** quadratic average	
	progressive shocks due to				intensification of recurrent shocks due to									
countries	Sea level rise		Intensification of aridity		Rainfall shocks		Temperature shocks							
	Value	**Rank/ 155**	**Value**	**Rank/ 188**	**Value**	**Rank/ 201**	**Value**	**Rank/ 201**	**Value**	**Rank/ 146**	**Value**	**Rank/ 201**	**Value**[14]	**Rank/ 147**
Algeria	1,46	82	38,68	112	27,70	16	46,87	116	20,07	77	37,29	32	33,40	30
Angola	0,08	44	36,41	104	63,36	196	54,91	158	18,24	64	59,13	192	45,70	110
Benin	2,11	92	68,55	168	52,90	170	51,76	149	35,33	126	52,33	168	50,45	127
Botswana	0,00	1	86,06	187	50,44	159	53,90	156	43,03	140	52,17	167	56,69	140
Burkina Faso	0,00	1	78,47	179	53,20	175	50,18	145	39,23	131	51,69	165	53,63	137
Burundi	0,00	1	33,00	81	49,06	155	78,15	199	16,50	52	63,60	197	49,00	126
Cameroon	0,09	46	29,63	67	53,23	176	48,61	133	14,86	37	50,92	159	38,97	71
Cape Verde	2,76	106	28,01	55	45,60	136	45,63	100	15,38	42	45,61	118	35,19	39
Central African Republic	0,00	1	29,70	68	46,99	143	44,01	76	14,85	36	45,50	117	35,45	42
Chad	0,00	1	62,13	157	24,24	5	46,25	110	31,06	115	35,25	11	40,58	80
Comoros	2,84	109	40,70	119	25,00	7	77,04	197	21,77	83	51,02	160	45,34	106
Congo	0,05	41	22,52	17	46,01	139	47,52	122	11,29	9	46,77	128	34,94	38
Congo, The Dem. Rep. of	0,01	40	25,96	37	45,22	135	58,03	172	12,98	22	51,63	164	39,01	72
Côte d'Ivoire	0,80	63			51,34	163	44,81	86			48,07	135		
Djibouti	5,87	135	62,34	158	32,63	44	48,67	134	34,11	120	40,65	64	42,88	95
Egypt	2,66	103	30,89	73	41,40	112	48,94	137	16,78	54	45,17	112	35,60	44
Equatorial Guinea	0,38	52	25,51	34	39,47	92	49,51	140	12,95	21	44,49	103	34,13	33
Eritrea			62,39	159	57,84	187	42,59	50			50,21	153		
Ethiopia	3,29	119	51,28	139	31,03	30	44,12	78	27,28	100	37,57	34	37,25	61
Gabon	0,76	61	24,74	29	50,55	160	48,77	136	12,75	17	49,66	147	37,24	60
Gambia	5,31	133	79,80	180	54,86	181	55,96	160	42,56	139	55,41	184	55,99	139
Ghana	1,60	87	59,18	152	16,18	1	57,20	168	30,39	113	36,69	25	41,95	86
Guinea	0,82	65	36,57	105	53,60	178	62,30	177	18,69	66	57,95	191	44,98	104
Guinea-Bissau	3,08	118	33,90	88	65,07	199	49,78	143	18,49	65	57,43	189	44,36	100
Kenya	0,16	48	57,13	150	47,43	145	52,66	152	28,64	107	50,05	151	45,52	109

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[12] In grey, countries not usually classified as Sub-Saharan Africa

[13] The ranking presented are based on all the countries in the world but are differing according to the index components due to data availability. The number of ranked countries is indicated in the rank column of each component.

[14] The mean value of the PVCCI considering all the countries in the world (147) is 40,76.

	Risks related to								Index of the risk of progressive shocks		Index of the risk intensification of recurrent shocks		**PVCCI** quadratic average	
	progressive shocks due to				intensification of recurrent shocks due to									
countries	Sea level rise		Intensification of aridity		Rainfall shocks		Temperature shocks							
	Value	**Rank/ 155**	**Value**	**Rank/ 188**	**Value**	**Rank/ 201**	**Value**	**Rank/ 201**	**Value**	**Rank/ 146**	**Value**	**Rank/ 201**	**Value**[14]	**Rank/ 147**
Lesotho	0,00	1	17,94	4	43,53	120	44,03	77	8,97	2	43,78	94	32,23	23
Liberia	0,42	53	26,82	46	49,00	153	58,38	174	13,62	26	53,69	175	40,40	77
Libyan Arab Jamahiriya	2,74	105	43,74	127	30,25	27	47,29	119	23,24	90	38,77	43	35,61	45
Madagascar	0,78	62	36,99	106	59,15	190	63,82	180	18,89	69	61,48	195	47,28	120
Malawi	0,00	1	34,64	91	58,17	188	42,74	51	17,32	56	50,46	156	40,03	75
Mali	0,00	1	69,63	170	56,35	184	51,83	150	34,82	122	54,09	177	51,74	133
Mauritania	2,77	107	51,92	141	44,41	132	48,11	126	27,34	101	46,26	125	41,80	83
Mauritius			22,11	14	45,87	137	45,09	93			45,48	116		
Mayotte	3,80	123	40,70	119	25,00	7	77,04	197	22,25	85	51,02	160	45,36	107
Morocco	1,00	70	71,81	174	37,28	73	39,02	18	36,40	128	38,15	40	44,92	103
Mozambique	0,54	55	46,19	135	59,23	192	39,85	23	23,37	91	49,54	145	42,51	92
Namibia	0,26	49	81,67	183	63,60	197	64,84	187	40,97	133	64,22	198	61,07	144
Niger	0,00	1	61,47	156	50,09	158	47,82	125	30,73	114	48,95	142	46,30	113
Nigeria	0,29	50	55,58	147	39,62	94	55,12	159	27,93	105	47,37	132	43,87	98
Rwanda	0,00	1	31,11	74	38,46	87	76,99	196	15,55	43	57,73	190	45,75	111
Sao Tome and Principe	2,78	108	49,77	138	63,23	195	47,50	121	26,28	98	55,37	183	46,74	118
Senegal	3,34	121	80,22	182	48,57	152	70,71	191	41,78	137	59,64	193	58,75	142
Seychelles	44,00	147	15,70	1	47,07	144	42,33	47	29,85	109	44,70	106	39,34	73
Sierra Leone	1,39	80	34,85	92	47,70	149	76,22	194	18,12	63	61,96	196	48,22	123
Somalia	0,36	51	65,37	163	35,46	61	56,23	162	32,86	116	45,85	122	46,62	116
South Africa	0,08	43	57,24	151	39,62	94	46,46	112	28,66	108	43,04	89	41,85	84
Sudan	0,08	45	65,96	165	52,23	168	58,03	171	33,02	118	55,13	182	51,10	130
Swaziland	0,00	1	55,00	145	30,76	29	44,39	79	27,50	102	37,58	35	38,54	68
Tanzania, United Rep. of	0,07	42			52,90	170	48,11	126			50,51	157		
Togo	0,75	60	41,86	123	50,77	162	57,14	167	21,30	81	53,95	176	43,57	97
Tunisia	4,33	132	80,17	181	33,37	45	42,74	51	42,25	138	38,06	38	48,44	124
Uganda	0,00	1	32,80	80	39,62	94	57,96	170	16,40	50	48,79	140	38,75	69
Zambia	0,00	1	37,44	108	68,97	200	66,64	188	18,72	67	67,81	201	51,48	131
Zimbabwe	0,00	1	60,16	154	59,88	193	46,74	114	30,08	110	53,31	171	48,45	125