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

Dans quelle mesure les pays africains sont-ils rendus vulnérables au changement climatique? Leçons d'un nouvel indicateur de vulnérabilité physique au changement climatique

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Abstract

This paper examines the vulnerability of African countries to climate change, they are not responsible for. It relies on an index of structural or physical vulnerability to climate change at the country level, noted below by the acronym PVCCI, recently set up by the authors and made available on the Ferdi website.

The design of this index draws both on the environmental literature and some principles applied at the United Nations to measure the structural economic vulnerability through the Economic Vulnerability Index (EVI) for the identification of the Least Developed Countries (LDCs). As an environmental index, the PVCCI index relies on components reflecting only physical consequences of climate change that 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 the vulnerability that does not depend on the present will of the African countries. In other words this index refers to a "structural" or "physical" vulnerability, keeping aside resilience, usually integrated in vulnerability assessments, but largely depending on policy factors. The components of the index respectively capture two kinds of risks related to climate change: the risks of increasing recurrent shocks (such as droughts) and the risks of progressive and irreversible shocks (such as flooding due to higher sea level). Moreover the components refer either to the likely size of the shocks or to the country exposure to these shocks.

The study evidences a high heterogeneity among countries in the level of physical vulnerability to climate change, even within a same regional area or continent. On average African countries, already found to evidence a relatively high economic vulnerability (with regard to the UN Economic Vulnerability Index); also show a high physical relative vulnerability to climate change, but with significant differences among those countries, mainly due to the risk of drought. The index permits to characterize the climate change vulnerability for developing countries, particularly African countries, laying some foundations to improve the 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 enlightens the challenges of climate change for African countries. In particular the PVCCI is likely to be considered as one of the relevant criteria for the geographical allocation of resources devoted to adaptation.

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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. En particulier 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 evidenced that African countries face a higher structural economic vulnerability than other developing countries (Guillaumont, 2007).The purpose of this paper is to give some new evidences that African countries also face a relatively high vulnerability to climate change. It should be remained that climate change associated to global warming is due in large part by the destruction of the ozone layer, which is mainly due to the industrial activity in developed countries and to lesser extend of large emerging countries, but nearly not to the expansion of the African activity.

Most of the 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 affect particularly poor countries and a growing concern is that climate change worsens 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 to 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 consequences of climate change. The impacts of climate change are likely to be considerable in tropical regions. Overall, crop yields may fall by 10 to 20% to 2050 because of warming and drying, but there are places where yield losses may be much more severe (Jones and Thornton, 2003). As consequence there is a considerable and increasing activity of development agencies and governments to support the development of appropriate adaptation strategies. A good knowledge of the vulnerability to 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 of resources for financing mitigation and adaptation. Raising funds meets similar problems for mitigation and adaptation, 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 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 quite below what would be required. This make all the more needed to allocate these resources according to criteria reflecting the countries’ needs of adaptation, as well as their capacity to effectively use the resources to this aim. In 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. An appropriate indicator of vulnerability to climate change available for all the countries concerned is then 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 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 lead to a quantitative and comparative assessment. This work proposes a first assessment of the vulnerability to climate change focusing on the vulnerability which only depends 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. The "Physical Vulnerability to Climate Change Index" presents various results for the African continent, and confirms the importance of vulnerability to drought and desertification in this region. Moreover the study lay out a first step to the design of criteria for the allocation of adaptation resources.

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

The index used in this work only reflects physical components of the vulnerability to climate change. Moreover, it relies on a few components, relevant, reliable, available for the whole set of developing countries and 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 in vulnerability, as done in this research stream. Second, the endeavour to measure a 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, named Economic Vulnerability Index, (EVI) (United Nations CDP 2008, Guillaumont 2009a and 2009b). The EVI, which does not ignore the environmental vulnerability, indeed 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 a low population size). But it is not focused on the long term vulnerability to climate change, and only captures the likelihood that they re-occur in a near future through the recurrent shocks.

The study evidences a high heterogeneity among countries in the level of physical vulnerability to climate change, even within a 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 index permits to characterize the climate change vulnerability for developing countries, particularly African countries, laying some foundations to improve 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 enlightens the challenges of climate change for African countries. In particular the PVCCI is likely to 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 in 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 results this index on developing countries, more specifically for African countries.

What is Vulnerability About?

Starting from the main definitions of vulnerability to climate change, this section tries to design a physical vulnerability to climate change. The "vulnerability of systems to climate change" is examined in a fast expanding 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 diverse researchers in 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). Relying on a several decades of literature (in particular on export instability), this macro vulnerability is considered as an impediment to growth. The economic vulnerability can be seen as formed by three main components: *shock, exposure and resilience***.** Shocks are exogenous and generally unforeseen events (external, such as the instability of exports, or natural, such as typhoons, hurricanes, earthquakes, droughts …). The exposure corresponds to factors upon which the direct impact of shocks depends. The resilience is the capacity to react to shocks, then considered, when it is weak, as a part of the general vulnerability (Miller et al. 2010)

Assessments of vulnerability retain all these three components or only one or only two of them. 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. Indeed resilience, even if it may include some structural elements, is mainly related to policy factors. The structural economic vulnerability is the kind of vulnerability captured by the Economic Vulnerability Index (EVI) used at 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 rather parsimonious and transparent manner (seven indicators). It mainly refers to the vulnerability in the low-income countries (see UN CDP web site and Guillaumont 2009a, 2009b, 2011). By the same way, this paper tries to design an index of structural vulnerability to climate change, retaining only a small number of indicators related to the size of the climate shocks and to the exposure to these shocks.

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

The vulnerability to climate change is designed here as a vulnerability to environmental shocks resulting from climate change. These shocks are supposed to be physical consequences of climate change. They appear through more droughts, floods, storms as well as through the rise of 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 in the heart of the 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 announced the goal is to “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 biophysical condition, and between vulnerability and political economy.

There has been a profuse although recent literature on vulnerability to environmental change and more specifically to climate change, and on vulnerability to natural hazards as well, which partly overlaps with the former ones. Not surprisingly, there is no universally accepted definition of vulnerability to climate change (and even a different definition for each IPCC report, as noted by Downing and Patwardhan 2005). Beyond the semantic issue, a definition of the vulnerability is obviously needed to make explicit the theoretical concept. The choice of the definition influences the orientation of the vulnerability analysis (O’Brien et al. 2007). Main references to this 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, as for the vulnerability to natural hazards, Birkmann (2006a and 2006b), Cardona et al. (2003) or Thywissen (2006).

Actually, the definition and then the assessment of vulnerability have met two difficulties. First, the notions have been used with different meanings according to the scientific area (Hinkel 2008, Bruckner 2010). Second, within each area various conceptual frameworks have been designed. 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 blur 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 the 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 briefly review the literature on the vulnerability to climate change with the aim to see 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 the vulnerability.

Main current approaches to the vulnerability to climate change

Let us call *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 outcomes' 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 (by a rise in the sensitivity of the environment for instance). This vulnerability is affected by social and economic dynamics, and by political and institutional characteristics. The starting point vulnerability is linked to 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 end point vulnerability is a vulnerability the assessment of which is subject of studies; for instance O'Brien et al. (2007) uses the similar distinction. The authors deal with an outcome vulnerability and contextual vulnerability whose definitions are closed 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 the 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 a *matriochkas approach* consists of elaborating on 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 closest to the largest definition: "multi dimensional vulnerability encompassing physical, social, economic, environmental and institutional features" (Birkmann 2006a). A similar analysis lays in the "onion framework" proposed Bogardi and Birkmann (2004). It is an enlightening approach, but not adapted to our purpose as far as policy factors may interfere at each step of the concept enlargement.

A *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. The biophysical vulnerability is defined by the 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 is 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) previously examined. This is also, according to Brooks, the definition of social vulnerability. Social vulnerability depends on the biophysical factors but also includes the set of socio-economic factors that determine people's ability to cope with stress or change (Allen, 2003). It can be seen as including what has been called above 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 the social and biophysical vulnerability (see also Füssel and Klein 2006). This concept must be distinguished from climate hazards assessments. Moreover, in the conceptual framework of "eco-sociological system, the distinction between social and biophysical vulnerability could be discussed (see part 1). Adger (2006) proceeds in the same way: after distinguish two mainstreams, entitlements and natural hazards; he gathers these two streams in a global framework named: "socioecological system".

Let us end with the *IPCC's approach.* The IPPC (….) has a precise definition of vulnerability often used in the vulnerability to climate change analysis. The IPCC's definition is (IPCC 2007b) "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". This definition is close to the definition the analysis of economic vulnerability, previously presented with the three components of shock, exposure and resilience. The scheme given by Füssel (2010), see figure 1, helps to better understand, what in the IPCC definition is about structural vulnerability and what is not: the sign (+/-) next to factor indicates the direction of this factor 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).

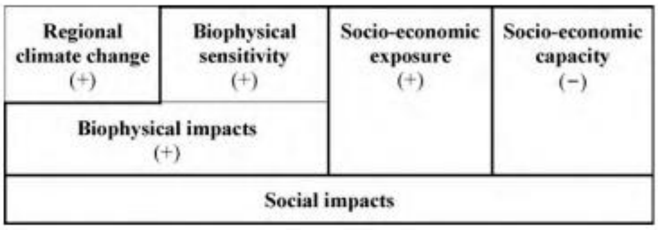
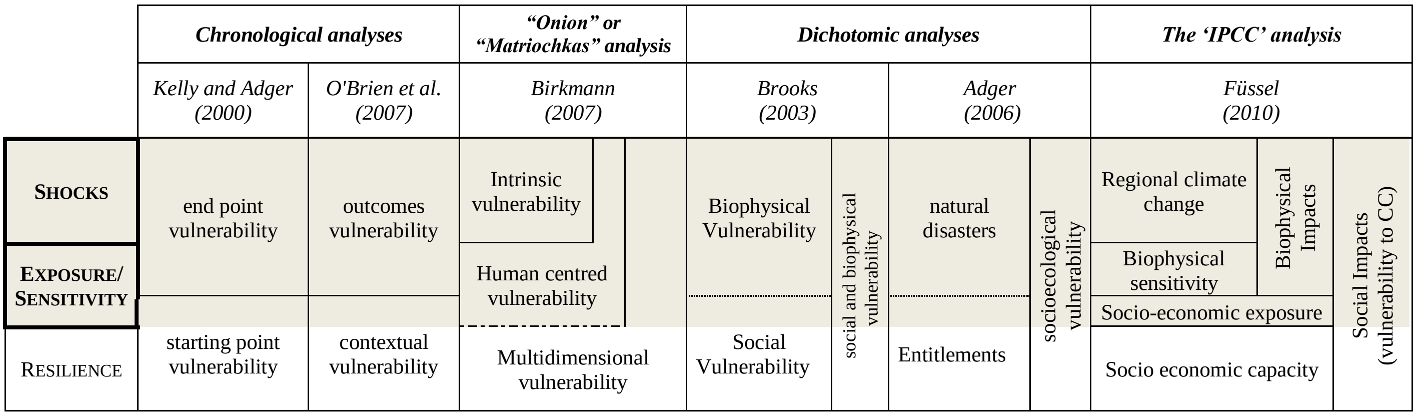


Figure 1: Vulnerability to climate change framework, the reading of IPPC definition by Füssel (2010)



	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 Shock, exposure and resilience definition

In any case, referring to the environmental vulnerability to climate change, the distinction established about macroeconomic vulnerability between shock, exposure and resilience should be kept in mind. This can help to put aside those components of vulnerability to climate change that are not structural, in other words those depending to a large extent on the present policy of countries and making 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 putting aside 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 the structural vulnerability

The authors of the existing indices point out the growing need of such an index (a need also expressed by the international community and organizations), while often underlining the confusion resulting of 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 note that some indices only try to reflect the evolution of climate change without assessing an impact of vulnerability. Such are the Climate Change Index of Baettig et al. (2007) or 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 the exposure and resilience. Moreover, these indices don't 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 the last years. The aim of the authors is to approach a measure of vulnerability to climate change and to highlight the differential impact of climate change between socio-economic units (state, collectivity). Among these indices we note for instance: 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 calculation 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 (SoVI Cutter et al. 1996), works of Downing et al. (1995) and Buys et al. (2007). However these indices present often the same advantages and weaknesses than the theoretical frameworks they refer to and previously presented. Thus, they capture a global (or “generic”, Füssel 2010) vulnerability to climate change and not only a structural vulnerability as we propose[3].

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 not relevant to assess effects of a phenomenon which doesn’t follow borders (Eakin and Luers 2006). Also noted, the substitutability of components in building the index (Tol and Yohe 2007). The generic indices of vulnerability to climate change are criticized greatly because they present “methodological flaws or severe doubts regarding their validity” (Füssel 2010 for a good review of major lacks of these indices).

About the relevance of the measurement of an index at the country level

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

As noted at the beginning of this paper, the index we propose should be used as a criterion of the allocation resources for adaption between countries, leading to allocate more resources to countries more vulnerable to climate change. Of course it doesn’t capture others factors to be taken into account in the resource allocation (such as population size and poverty level). For this reason the choice of scale analysis is the

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[3] When this paper has been written we had not the opportunity to take in consideration the stimulating paper written by D.Wheeler although different from our index.

country[4]. Thus, even if some authors express reservations about such a scale analysis (Eakin and Luers 2006); others choose the national level for the same reasons developed by Barr et al. (2010) or 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 obtain a vulnerability to future shocks? Components can be calculated rather as ex-ante or ex-post it seems possible to rely on forecasting when available and reliable (as likelihood of sea level rises). Other components can be calculated ex post from past trend.

The demand for an index of vulnerability to climate change has become more and more important. This growing demand leads international institutions and researchers to provide related frameworks and indices. But within a wide literature on vulnerability to climate change, there seems to bet neither common framework nor universally accepted definition. It can be seen as the result of a lack of connection between the design of frameworks and indices and the goal they are expected to reach. This why we are trying to design a vulnerability to climate change with the aim to guide the allocation of the adaptation funds; derived from literature, this design allows us to combine various existing frameworks Based on the split of vulnerability of climate change into three elements: shocks, exposure and resilience, this framework permits to assess this part of the vulnerability to climate change which can be considered as physical or structural, and essentially relies on shock and exposure components[5].

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[4] The paper of D.Wheeler pursues a similar goal

[5] 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 to guide the aid allocation is controversial.

The analysis of vulnerability to climate change undoubtedly meets 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 on the vulnerable system by reducing system sensitivity or by reducing the consequent level of damage. The mitigation consists in limiting the number and the magnitude of potential climate hazards due to climate change through reducing the emissions of greenhouse gases, for instance. Both are likely to lower the vulnerability to climate change, but not in the same way. The 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. Looking 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) or Buob and Stephan (2010).

Components of the present Index of Physical Vulnerability to Climate Change.

An examination of the expanding literature on the economic consequences of the climate change leads to make 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 the author,, its assessment faces too high obstacles so that it has to be kept aside: it covers "discrete singular hazards, for example 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 that 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 actually 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 the vulnerability to climate change, 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 (see 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 assessment of the expected impact of climate change on socio-economic variables such as health, agriculture…And, as a consequence, it can be used to assess the link between climate change and these economic variables.

Anyway, 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. To be recalled, a good index should be parsimonious, transparent, and focused on the most relevant issues.

Risk of progressive and durable shocks

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

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

The vulnerability of a country to the sea level rise corresponds to the risk of this country to be flooded. Its assessment involves making a distinction between the size this shocks (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 components:

- the exposure to sea-level rise depends on the relief, since it influences the liability to 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 one to assess the likelihood of flooding resulting from the sea level rise (in t years).

The measurement of the exposure component does not raise the higher 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 the height of which is considered (all areas of the country or only arable areas or areas with a minimum population density?), and if the distribution of population is considered, it may be expected to change over time (but the *structural* vulnerability does not really depends on this change).

A more difficult issue arises for the assessment of the risk of sea level, for two reasons. The first one is that there is still some degree of uncertainty about the rise of the sea level at a given time horizon, the probability distribution being debated among climate specialists. The second reason is that this probability distribution is changing over time with a rising average sea level and an 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. Why to do so? For two reasons. One would be the increasing uncertainty of estimations as far as the time horizon is longer 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 alone reason. A second reason is the “pure time preference”: the disadvantage generated by a given sea level can be considered as all the higher that it occurs earlier; 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 share 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 seemed ungrounded or 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 and initial conditions

The literature on the consequences of climate change underlines the risk of some arid countries (in particular Sahelian countries) to be affected by the rise of temperatures and therefore to be 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 of 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 share of dry lands, which better fit the risk of desertification. The lower the rainfall level or the higher the dry lands share 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 retain the past trend in the annual average temperature in each country over two or three decades. The hypothesis is that the rise of the average world temperatures will be distributed over countries by the same way it has been so during the last 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 a decreasing trend of the average rainfall level. It supposes that the past trend in average rainfall is determined by climate change and will go on in each country following the same trend than the past one. At the country level, the permanent shock resulting from climate change and channelled by a rising trend in temperature or a decreasing trend in rainfall is thus assessed by an extrapolation of recent past trend. As far as more relevant and reliable projections of the temperature and rainfall would become available at the country level, it would be possible to use them instead of the (non linear) extrapolation here retained (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, floods… (World Bank, 2008) Here again the only variables to be considered should be unambiguously linked to climate and its change: such are supposed rainfall and temperature variability and its change.

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 (that reflects 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, supposing it is determined by climate change and likely to go on in the future. These two kinds of components are considered by the same way for rainfall and temperature.

Average present frequency as an indicator of exposure

When the Economic Vulnerability Index (EVI) has been built at the United Nations by the Committee for Development policy (CDP) for the identification of the Least Developed Countries, indirect and synthetic indicators have been used likely to capture natural shocks highly heterogeneous (flood, typhoons, droughts, hurricanes, earthquakes…) and of highly unequal intensity and consequences. Among the components of the Economic Vulnerability Index (EVI) the risks of natural shocks have been 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[6] (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 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

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

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.

As for the 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,

$$IR = \sum \frac{|\mathrm{R_t} - \hat{\mathrm{R}}_\mathrm{t}|}{\hat{\mathrm{R}}_\mathrm{t}}$$

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 to climate *change* is here assessed by a forward-looking manner. It is supposed 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 supposed to still increase. The proxies 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):

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

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

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

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

By 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 other. Making available the measure of 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 risks related to progressive and to more intense recurrent shocks, both considered as resulting of 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 shock index have been identified. The second way for 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 the sea level rise), it is not possible to draw weights from an econometric estimation of the expected respective impact on a socio-economic variable such as economic growth or poverty reduction, a method already difficult to apply for the EVI (Guillaumont, 2009a). Then a simple and usual, 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.

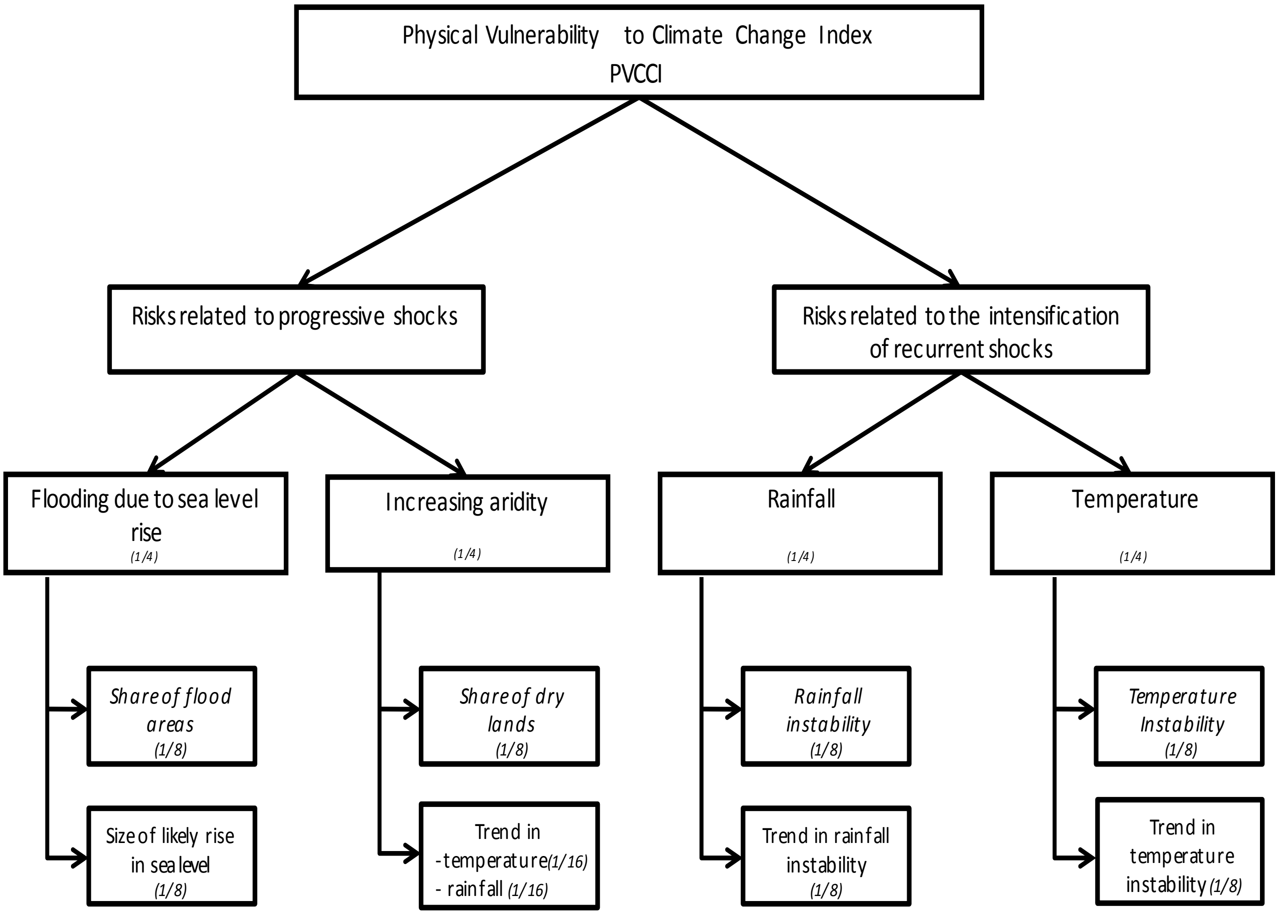
Finally, the way by which the values of the components are averaged is an important issue. The usual averaging practice for the calculation of synthetic indices is by arithmetic average (as done for the Human Development Index or for the EVI…). However, one should be aware that any of the main components 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'), designed 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, suppose an island with a very large share of area likely to be flooded or an arid country suffering from the most increasing trend the level of temperature. Each of these two countries, where one 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 graph respectively refer to exposure components *(in italics)* and to size of the shocks components

In the previous 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 an 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 the 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 data supplied by Dasgupta and al. (2009) give data for the calculation of the exposure to sea level rise, supposing a rise reaching one meter: so, a convenient proxy for the risk of flooding due to the sea level rise is the index of the "part of country affected by a raise of 1 meters of the sea level[7]" (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)[8].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 are similar but a discussion about this database could be opened.

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

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

With

Rj: monthly rainfall data

t : trend

θj : dummy monthly variable

$\mathcal{E}jt$: term or error

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[7] We supplement the database for 72 countries, in majority 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).

[8] 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 of 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 as the 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[9]:

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

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) has been 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) have been completed.

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 are well correlated with the arithmetic methods.

As for weights, comparing the arithmetic average results obtained with equal weights and with 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%)[10]. It may be seen as validating the choice of equal weights

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

[10] 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 later 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 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. 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 of African countries vulnerability to climate change should be taken into consideration.

First, African economies are very dependent on climate sensitive sectors as agriculture, forestry and fishery. Agricultural production in many African countries and regions is likely to be severely undermined by climate change. Number 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 on lower economic growth and on lower food security.

Second, extreme events, such as droughts, have major entailments for numerous African countries. The impacts of droughts are deeply reported through numerous studies, which evidence 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 impacts (World Water Forum, 2000). During the mid-1980s the economic losses due to droughts are assessed to 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 experimented also floods events which can entail important economic deprivation (Mirza, 2003).

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

All these consequences affect African economies, 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 percent 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 more important in lower income countries, as still are many African countries.

What the PVCCI shows

The Physical Vulnerability to Climate Change Index is then particularly useful to assess the degree and channels of this vulnerability in African countries. It should enlighten the characteristic 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 are to be recalled. Africa warming since 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 experiences decreasing trends in temperature. As for precipitations, 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 less important, and some other regions, such as Southern Africa, have no long-term trend 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 evidence 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 to progressive shocks, this is a result of a rather low impact of the sea level rise in Africa: difference of 3 points in the mean between DCs and African DCs. Compared to other developing countries Africa doesn’t include many small islands more threatened by this trend. This difference in the group composition explain the high level of standard deviation for sea level rise in the DCs group and the low level of the standard deviation for the African group which include more landlocked countries. This effect of less vulnerability concerning the sea level rise is limited by a more vulnerability to the 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 is more increasing in Africa. Finally, the index of the risk of progressive shocks is not significantly different in Africa and in other developing countries. Because of this two opposed effects. It should be noted that we are here comparing Africa and other developing countries through simple averages or median levels, consistently with the aim of our index. If the country indices of the risk of progressive shocks was 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 the sea level rise (as shown by the simple average for SIDS).

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

Country grouping 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 at the country level, it may exhibit a large heterogeneity in the levels and the kinds of vulnerability among countries (Annex 2). We have shown on average a large vulnerability to climate change in this region (Figure 5), but the level of the index is very different according to the country. The ranking of the PVCCI for African countries is from 23 (Lesotho) to 144 (Namibia) compare to all the countries of the world. The most vulnerable countries regarding the PCCVI in Africa are Botswana, Burkina Faso, Burundi, Comoros, Gambia, Namibia and Senegal. These countries present a high level of global physical vulnerability due to high level of different components of the index. Five main regions could be distinguished: North Africa (Tunisia, Morocco, Egypt,…) presents lower vulnerability than the rest of continent; West Africa (Senegal, Niger, Mali,…) and East Africa have a high vulnerability, mainly due to the risk related to progressive shocks; Central Africa exhibits low values of PVCCI; and finally South Africa seems to be more vulnerable to risks of recurrent shocks.

More precisely, Botswana, Chad, Comoros and Mali are African countries with the higher level of vulnerability to progressive shocks. Their rankings for this component are the most important of the world.

Obviously, this high level of vulnerability to progressive shocks is due to two different components: sea level rise and intensification of aridity. Generally, African DCs are not vulnerable to sea level rise but it's important to note the very high vulnerability to Seychelles and Comoros to this shock (the value of this component is very higher than the average of African countries which are mainly landlocked and so not exposed to sea level rise). The other countries which present a high level of vulnerability to progressive shocks are exposed to the intensification of aridity. This vulnerability seems to be more important for countries in desert areas as Sahelan zone: Mali, Burkina Faso or Sudan and Namib Desert: Namibia and Botswana. The rankings of African countries vulnerable to aridification are the most important of the world with Central Asian countries (Afghanistan, Turkmenistan …). We note that Senegal presents a high level of vulnerability to progressive shocks because of a high level of vulnerability to intensification of aridity due to Sahara in the north of the country but also because of the sea level rise at the delta of the river Senegal. Moreover, we can see that this difference in the standard deviation for the "increasing aridity" component is more important in African DCs group than in the DCs group.

The component "risk of intensification of recurrent shock" is globally high for all African countries. Its component is different between African countries (27 for Chad and three as large for Zambia). Angola. Burundi, Guinea, Madagascar and Sierra Leone are countries with the higher level of vulnerability to the intensification of recurrent risks. We note a higher vulnerability to this component for small countries of West Africa (Guinea, Senegal,…); South African countries and small center countries. The vulnerability of Madagascar is not a surprise due to the numerous typhoons which harm the country. We note a variation between the vulnerability to rainfall or temperature intensification of shocks even if mainly countries with high vulnerability of the components "intensification of recurrent shocks" are vulnerable to rainfall and temperature (Senegal, Gambia, Namibia).

African countries present a big heterogeneity in the PVCCI which confirm presence of various profiles of vulnerability climate change in the continent.

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[11] 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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[11] We consider here only Sub-Saharan –African countries following the World Bank classification

Figure 4: Map of PVCCI-Developing countries

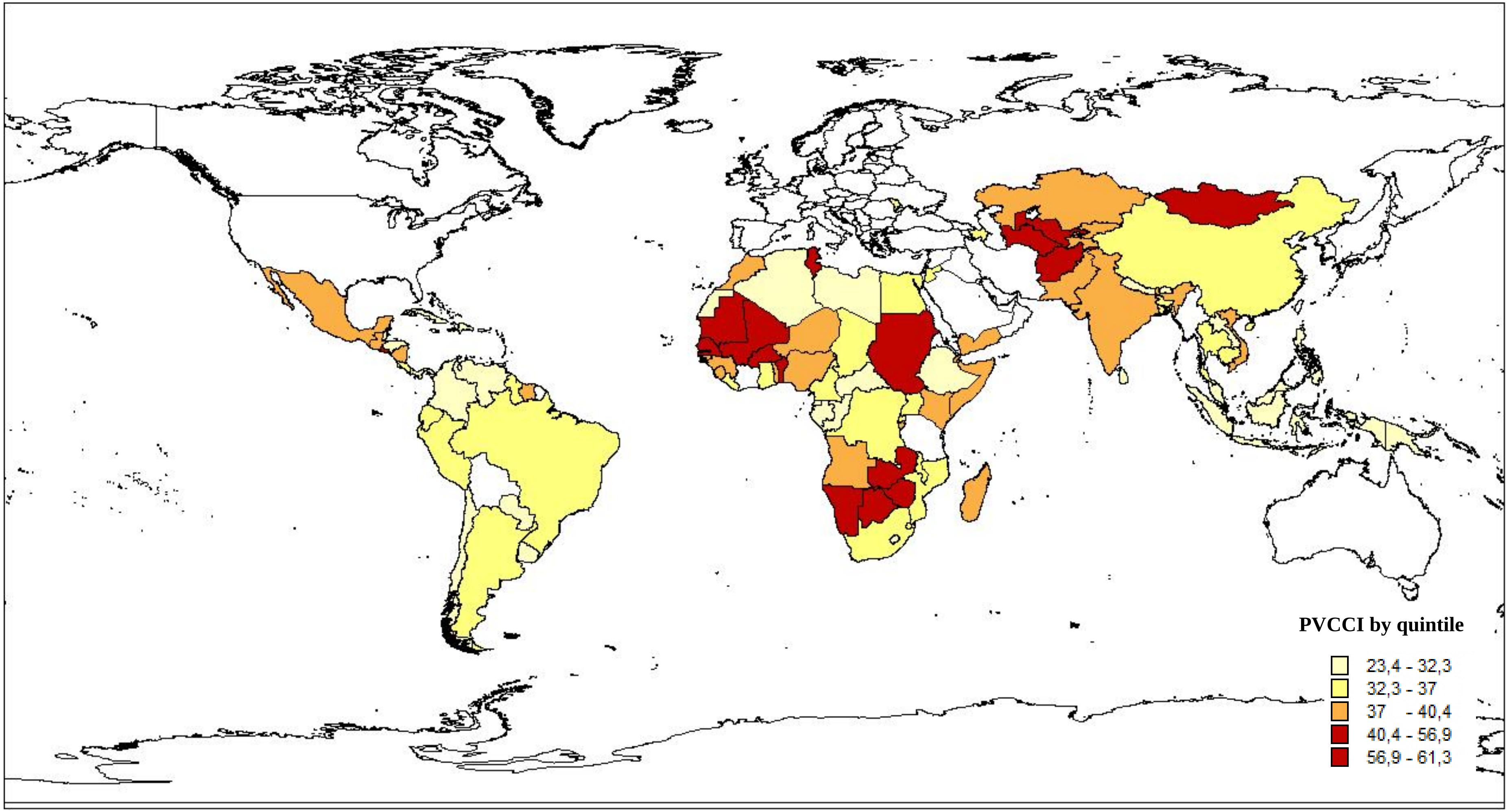
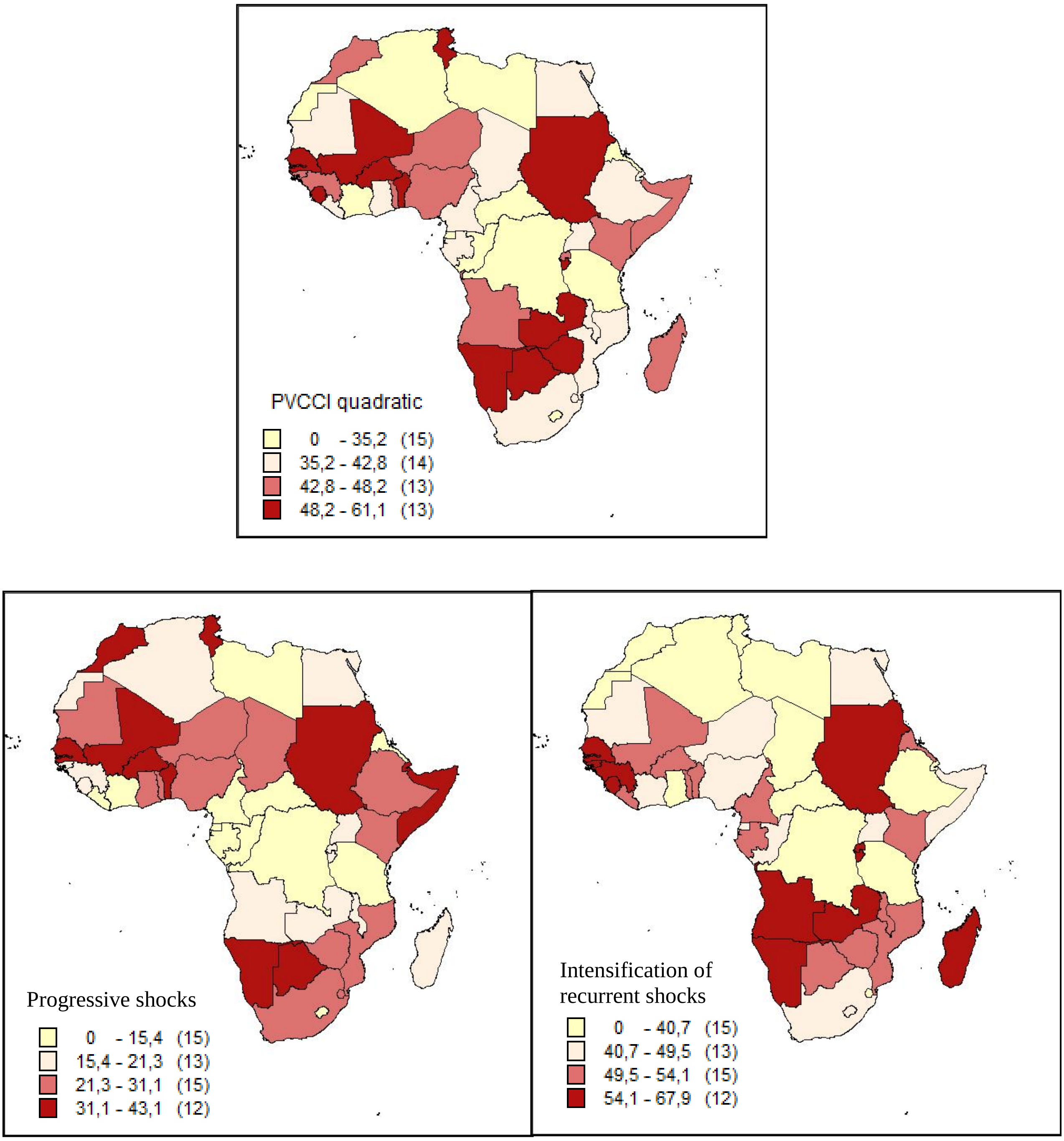


Figure5 : PVCCI in African Countries and by components



Conclusion

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 differs from the burgeoning and already rich literature on vulnerability to Climate Change by only considering this part of the vulnerability which does not depend on present policy and future policy as well. To this aim it relies only on physical components reflecting a likely impact of climate change, without any use of socioeconomic data. It is an index of 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 EVI is related only to structural vulnerability (independent from the present will of countries), as the PVCCI is related only to physical vulnerability, but it covers all kinds of exogenous shocks likely to affect economic growth, and not only those resulting from climate change.

The calculation of the index of physical vulnerability to climate change evidences both a higher average level for African countries than for the other developing countries and a strong heterogeneity among them. But this global vulnerability is moderated by uneven results. The “risks related to the intensification of shocks” indeed differ according to the countries. Five main regions could be distinguished: North Africa (Tunisia, Morocco, Egypt,…) presents lower vulnerability than the rest of continent; West Africa (Senegal, Niger, Mali,…) and East Africa have a high vulnerability, mainly due to the risk related to progressive shocks; Central Africa exhibits low values of PVCCI; and finally South Africa seems to be more vulnerable to risks of recurrent shocks.

The EVI has been proposed as a possible criterion for the allocation of development assistance between countries (Guillaumont, 2008; Guillaumont et al., 2010). By the same way, thanks to its features, the PVCCI could be used as a criterion of the allocation of the international resources available for the adaptation to climate change. It would be a relevant criterion precisely because it doesn’t depend on the present policy and only gives an indication of the need for adaptation. The two indices EVI and PVCCI can then have a complementary role in the allocation of international resources, as far as these resources are provided from separate windows. We will investigate later how the ranking of the PVCCI follow that of the EVI.

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Appendix 1: Elementary components of the PVCCI for African Countries[12]

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

Appendix 2: Aggregated components and overall level of CCVI for African countries[13] [14]

	Risks related to													
	progressive shocks due to				intensification of recurrent shocks due to				Index of the risk of progressive shocks		Index of the risk intensification of recurrent shocks		**PVCCI** quadratic average	
	Sea level rise		Intensification of aridity		Rainfall shocks		Temperature shocks							
countries	**Value**	**Rank/ 155**	**Value**	**Rank/ 188**	**Value**	**Rank/ 201**	**Value**	**Rank/ 201**	**Value**	**Rank/ 146**	**Value**	**Rank/ 201**	**Value**[15]	**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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[13] In grey, countries not usually classified as Sub-Saharan Africa

[14] 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.

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

	Risks related to													
	progressive shocks due to				intensification of recurrent shocks due to				Index of the risk of progressive shocks		Index of the risk intensification of recurrent shocks		**PVCCI** quadratic average	
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**[15]	**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