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Measuring physical vulnerability to climate change: The PVCCI, an index to be used for international development policies

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Introduction

Many donors, international agencies and national policy makers, have called for the development of vulnerability to climate change indices which would make it possible to prioritize the recipients of financial support for adaptation to climate change. Indeed, despite the complexity of the phenomenon, there has been a proliferation of indices of vulnerability to climate change. However, these indices do not break down what is due to exogenous factors and what is due to the factors linked to policy (which mainly have an impact on resilience). What is needed for international policy design is a measure of vulnerability independent of domestic policy.

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…/… The lack of a clear and unambiguous model explains why no index of vulnerability to climate change has so far been used for the allocation of resources for financing adaptation to climate change in the poorest countries, nor for the identification of the Least Developed Countries (LDCs). The search for an appropriate index of vulnerability to climate change can draw lessons from the experience with the Economic Vulnerability Index (EVI), which was designed to reflect structural economic handicaps faced by poorer countries, and is used as one of the three criteria of identification of LDCs, and more recently as a criterion for the allocation of resources (Guillaumont, 2009b; Guillaumont, 2013).

In this document, with the aim of improving the allocation of resources for the adaptation to climate change, and the domestic policies for climate change, we present the Physical Vulnerability to Climate Change Index (PVCCI) built on principles similar to those of the EVI. A first version of this index was presented in Guillaumont and Simonet (2011). It has since been progressively refined (the last version being Closset *et al.*, 2018). This brief shows the limitations of the existing indicators and why they cannot be used for the allocation of aid. Then, it gives a simple presentation of the latest version of the PVCCI, its rationale, its main features, its evolution, and some uses. Finally, the brief presents the main results and the lessons which emerge.

Limitations of existing vulnerability to climate change indices

There is a lack of precision on how to identify the countries most vulnerable to climate change. This can be observed in the various international agreements[1], and is mainly due to two reasons. The first reason is related to the vague nature of the concept of vulnerability and its multiple interpretations in the literature. The second reason is related to the difficulty of establishing an index to capture the multiple manifestations of climate change and to determine if one country is more vulnerable than another.

The indices developed to date have been primarily used for awareness-raising purposes[2]. The majority of these indices have been developed on a country scale, which facilitates country-to-country comparisons. In the absence of commonly accepted methods for assessing, measuring, expressing and comparing the vulnerability of countries, the majority of indices are based on the IPCC's three key

1. For example, the 2007 Bali Action Plan, the Copenhagen Accord, the Cancun Agreements, the Paris Agreement, and so forth, mention the prioritization of "particularly vulnerable" countries in the process of resource allocation. LDCs and SIDS are permanently mentioned as groups of countries without ranking the countries of which they are composed.
2. These indices include UNDP's Disaster Risk Index), Maplecroft's Climate Vulnerability Index, DARA's Climate Vulnerability Monitor, ICRISAT's Quantitative Assessment of Vulnerability to Climate Change Index, and GAIN's Index of Vulnerability and Readiness.

aspects of vulnerability[3]. They aggregate a wide variety of variables which combine economic, social, physical, and political dimensions, and so they cannot influence the allocation of funding for climate adaptation in a suitable manner. The IPCC's specification does not establish a clear relationship between the three elements of vulnerability. Furthermore, there is an overlap between sensitivity and adaptive capacity. The distinction between the two elements is not easy to implement in the construction of indices because they use similar variables. The concept of adaptive capacity remains particularly vague. Adaptive capacity refers to resilience, and combines institutional, governance, infrastructure, food security, health, water resources, economy, human resources, and environmental variables. Indices of adaptive capacity are often different from one study to another, confusing decision makers. In addition, the methodology used may lack transparency, which can make it difficult to reproduce the outcomes. In the same way, the social data used to measure adaptive capacity come from household surveys that are subject to significant errors, especially in developing countries.

Beyond the technical aspect, the conceptual framework of existing indices is problematic. These indicators are not designed for guiding the allocation of adaptation resources. For example, using two vulnerability indices, DARA and GAIN, Fransen *et al.* (2013) show that there is only a weak correlation between the level of vulnerability of countries and the financial resources received in support of adaptation.

For a fair resource allocation process, an index needs to take into account the structural vulnerability of countries, and for the adaptation funds the "structural" vulnerability to climate change. It must reflect the truly exogenous vulnerability that results from exogenous shocks which hit the country and for which it is not responsible (Guillaumont, 2015). A vulnerability index built for resource allocation must be independent of the country's present policies. Such an index should provide a balance to the aid allocation approach of institutions such as the World Bank, which uses a formula whose main criterion is performance in implementing policies that support economic growth and poverty reduction. Such a performance-based approach may be considered unfair since financial resources do not reflect the adaptation needs of the recipient countries (apart from their level of income and their capacity to effectively use the funds).

Adaptation credits could be used with accredited financial institutions to which they would submit their adaptation projects or programs. However, existing indicators which include resilience factors, such as the quality of institutions, penalize countries that do not have sufficient institutional capacity to submit a request for funding for adaptation funds. These countries are particularly vulnerable

3. Exposure, sensitivity and adaptive capacity are the IPCC's three aspects of vulnerability. Exposure refers to the nature, magnitude, and rhythm of climatic variations to which a country is or will be exposed, according to IPCC scenarios. Sensitivity refers to the size of the effects (both negative and positive) of climate stimuli in a given country. Adaptive capacity refers to the intrinsic ability of a country's authorities to adapt in order to mitigate the impacts of climate change.

to climate change. The exogenous shocks to which they are regularly subjected do not allow them to build solid institutions. Stadelmann *et al.* (2013), using a vulnerability index[4], highlight the fact that the majority of Adaptation Fund projects and Programs have so far been funded in relatively less vulnerable countries with relatively high GDP per capita.

In view of the limitations identified in the existing indices, FERDI proposes the use of the Physical Vulnerability to Climate Change Index, based exclusively on the physical characteristics of climate change. The index is independent of present and future country policy, and aims inter alia to be used for international allocation of adaptation resources.

The Physical Vulnerability to Climate Change Index (PVCCI)

The rationale and main features

Assessments of vulnerability use some or all of exposure, shock, and resilience. When the three components are considered, a general vulnerability is assessed; whereas when only the size of the exogenous shocks and the extent of exposure to these shocks are considered, the vulnerability considered is essentially a structural vulnerability. An index of structural vulnerability should therefore reflect the likely size of recurrent external or natural shocks, and the main structural factors of the exposure to these shocks, using a small number of indicators in a transparent manner. These aspects of vulnerability are at the heart of the Economic Vulnerability Index (EVI) designed by the United Nations' Committee for Development Policy (CDP). The EVI is used for the identification of LDCs and as a criterion for decisions on aid allocation between developing countries. As structural vulnerability contributes to making aid more effective (Chauvet and Guillaumont, 2009), the EVI is used as one of the criteria for the allocation of development assistance.

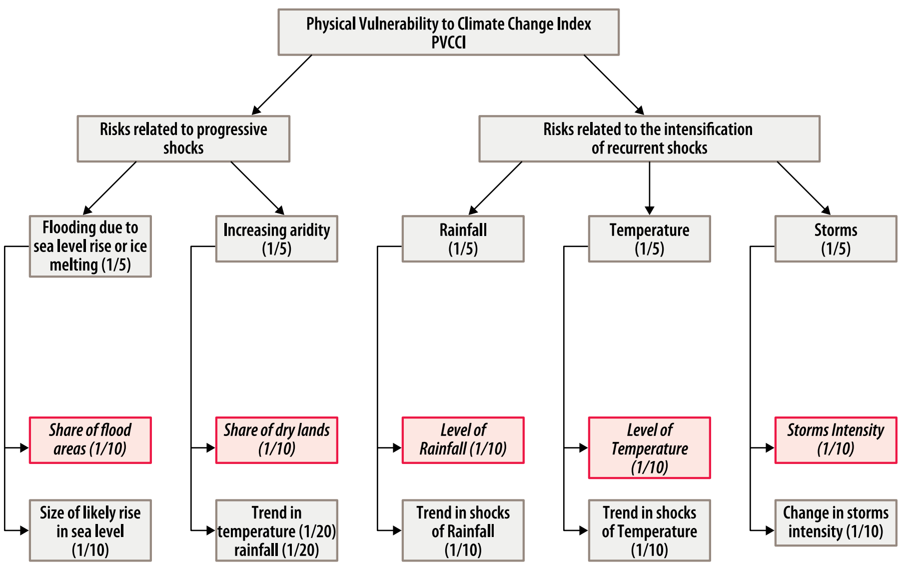
It is therefore logical that the search for an indicator of vulnerability to climate change for resource allocation should be inspired by the structure of the EVI and the conceptual basis behind it. As the EVI captures structural economic vulnerability and is assumed to be exogenous, an index of vulnerability to climate change should capture the "physical" vulnerability to climate change, and thus be exogenous. Such an index of vulnerability to climate change, independent of the present political policies of countries, is expected to identify countries needing the most adaptation assistance, regardless of their political choices, and could be used as a criterion for the allocation of adaptation resources.

4. An index of vulnerability to climate change built by Barr *et al.* (2010). This quantitative index consists of three pillars: physical impact, adaptive capacity, and implementation capacity.

With that in mind, FERDI has designed the Physical Vulnerability to Climate Change Index (PVCCI) in 2011[5]. This index captures the vulnerability to a specific shock which results from a risk in geophysical conditions, rather than from a growth handicap in the medium term. It differs from the other existing indices of vulnerability to climate change by considering only the part of the vulnerability which does not depend on present (and future) country policy. The PVCCI relies on components which are measured from observed long-term trends in physical (geo-physical) variables related to climate change, without any use of socioeconomic data. The lack of socioeconomic components in the PVCCI helps guard against the measurement errors that are often present in socioeconomic variables, and which create uncertainties in any assessment of future adaptation capacity (Guillaumont, 2017).

As shown in Figure 1, the components of the PVCCI capture two types of risk related to climate change: the risks of an increase in the intensity of recurrent shocks (in temperature, rainfall, and storms), and the long-term risks of progressive shocks (such as flooding due to higher sea level, or desertification). Like structural economic vulnerability, the risks related to climate change vulnerability use components referring both to the shock intensity due to climate change (for example rainfall instability or its trend), and the exposure to this shock (for example the share of dry lands). Each component is scaled between 0 (the least vulnerable) to 100 (the most vulnerable) using the min-max procedure.

Figure 1. Structure of the Physical Vulnerability to Climate Change Index (PVCCI)



Notes: The boxes corresponding to last rows of the graph respectively refer to exposure components (red boxes, in italics) and to size of the shocks components.

5. See Guillaumont and Simonet (2011).

Main changes in the PVCCI since 2011

Since its inception in 2011, the PVCCI methodology has been refined. The changes made are mainly of four types:

Taking into account the intensity of storms

A number of reports of the Intergovernmental Panel on Climate Change (IPCC) indicate that one of the likely consequences of climate change could be an increase in the frequency of storm events, or an increase in their intensity. In the first version of the PVCCI, only rainfall and temperature were used to measure the risks related to the intensification of recurrent shocks. Thanks to recent FERDI work on cyclone intensity at country level[6], it has been possible to add the risk related to the intensification of recurrent shocks due to cyclone activity.

Choosing a more consistent approach to measure the risk of increasing aridity

The literature on the consequences of climate change highlights the risk of the increasing temperatures to which arid countries are exposed. These countries face a risk of desertification and drought. In the first version of the PVCCI, exposure to increased aridity was estimated by the share of arid land[7] in a country. For consistency's sake, we exclude deserts (which are classified as hyper-arid areas) both in the arid land areas and in the country's total land area. By using the share of arid land of non-hyper-arid land, we assume that deserts are not considered to be an area at risk of increasing aridity. The degree of aridity is then calculated for land that is still "habitable" or "exploitable".

Using the quadratic mean rather than the arithmetic or geometric mean

The method by which the values of the components are averaged is an important issue, because any of the main components of the PVCCI may be of crucial importance for a country independently from the value of the other components. Either the reverse geometric average or the quadratic average method would allow a limited substitutability between components. We did not choose the geometric average because each component varies from 0 to 100, and the multiplicative nature of this type of average would reduce to zero the vulnerability of any country which had a value of zero for at least one component, irrespective of the values of the others components for the country.

The vulnerability of a country may depend on the levels of only one or two components, and the use of a quadratic mean enhances the impact of the

6. Feindouno *et al.* (2017).
7. This concerns UNEP definition of arid, semiarid and subhumid areas: areas, other than the polar and subpolar regions, in which the ratio of annual precipitation to potential evapotranspiration falls within the range from 0.05 to 0.65. The definition of dry lands is that of UNEP. According to UNEP, arid, semiarid and sub.

component(s) which reflect(s) higher levels of vulnerability. As an example, let us consider an island country with a very large share of area likely to be flooded and an arid country suffering from a high risk of increased aridity. Each of these two countries, due to a specific component close to 100, may be considered to be highly vulnerable, even if it is not vulnerable with respect to other components of the index. Thus, the quadratic mean shows the specific vulnerability of each country.

Taking into account the melting of glaciers as far as the risk of flooding is concerned

In the first version of the PVCCI, the risk of flooding was valued only by the country's exposure to sea level rise. The risk was estimated by the relative part of the country affected by a rise of 1 meter of the sea level. This measure implies that landlocked countries are not vulnerable to the risk of flooding; their score being equal to 0. However, some of the most devastating floods occur when glacial lakes overflow, in particular when so-called Glacial Lake Outburst Floods (GLOFs) occur. The retreat of mountain glaciers is one of the most reliable indicators of climate change. Glacier outburst floods represent the biggest and most far-reaching glacier risk with high potential for disasters and damage.

We have corrected for the countries concerned by using information on the world's glaciers[8]. Depending on the degree of vulnerability (number and volume of glaciers), we perform a rate of correction at the upper quantile. This approach allows some landlocked countries like Bhutan and Nepal not to have zero scores and so to appear relatively more vulnerable. Indeed, large parts of these two countries are covered by the Himalayas which have most of the outbursts from moraine-dammed lakes.

All of these changes are presented and reflected in the latest version of the PVCCI (Closset *et al.*, 2018).

Recent examples of uses of the PVCCI

Since 2011, the PVCCI has been used in several circumstances. It has been used in studies about the vulnerability of LDCs (Guillaumont and Simonet, 2014) and of African countries (Guillaumont, 2014), but also as part of a vulnerability assessment of Asian LDCs for the Asian Development Bank (Guillaumont, 2017). A series of studies[9] on small islands was carried out by Goujon *et al.* (2015a, b, c) at the request of the French Development Agency which consisted of in adapting and calculating vulnerability indicators (economic vulnerability, physical vulnerability to climate

8. Glacier database: GLIMS and NSIDC (2005, updated 2013): Global Land Ice Measurements from Space glacier database. Compiled and made available by the international GLIMS community and the National Snow and Ice Data Center, Boulder CO, USA.
9. These studies were conducted at a time when the cyclone component had not yet been integrated into the PVCCI.

change) and development indicators for small island economies, with particular attention to French overseas territories and their local authorities.

The PVCCI has also been used in more concrete situations. For example, to determine the allocation of funds for adaptation, Guillaumont (2015) uses the PVCCI in a simple formula alongside per capita income for developing countries. A simulation using parameters established in a transparent manner shows the relative share that each group of countries would receive (more than half for LDCs) and the amount of allocation per capita relative to the average for developing countries (highest for SIDS). In the same vein, the PVCCI has been used in a recent study requested by the African Development Bank which proposes new allocation criteria for concessional funds. Weiler *et al.* (2018), using the former version of the PVCCI, find that "physical vulnerability strongly influences both whether a country receives adaptation aid, and how much adaptation aid it receives…"

Finally, the index is used with structural economic vulnerability, to evaluate the sustainability aspect of the Sustainable Competitiveness Observatory (SCO) developed at FERDI.

Which countries (or country groups) have the highest score according to the PVCCI?

The PVCCI has a minimum value of 39.8 and a maximum value of 69.7, a statistical range of 29.9. This would mean that all countries are facing climate change in some way, being vulnerable with respect to one or other components of the PVCCI. According to the PVCCI, the most vulnerable countries are Oman, Marshall Islands, and Maldives and the least vulnerable are Georgia, Nauru, and New Zealand.

When looking closely at country groups or country categories of particular interest for policy makers, SIDS and African countries are very vulnerable to climate change. Already structurally handicapped in their development process, LDCs are also penalized by climate change. Of the 15 most vulnerable LDCs, 12 are in Africa (all in sub-Saharan Africa). Sudan, Mauritania, Niger, Chad, and Eritrea are the most vulnerable in both the LDCs group and the African countries group. This is not surprising when we consider the components used in the PVCCI.

Most African countries are among the most vulnerable in at least three of the five components. This, combined with the quadratic mean used in the aggregation procedure, increases the likelihood of finding African countries among the highest scores on the PVCCI. The PVCCI's average score for Small Island Developing States (SIDS) is also very high. Given their inherent physical characteristics (small country size, low elevation coastal zone), SIDS are very prone to natural disasters: floods, earthquakes, tropical and extratropical cyclones, tsunamis, and so on. In many SIDS, the majority of human communities and infrastructures are located in coastal zones. They are the most vulnerable countries for the components of storm intensity and flooding due to sea level rise or melting glaciers. The standard deviation values highlight a high heterogeneity across all country groups. The PVCCI is quite variable within the group of SIDS Non-LDCs, and the vulnerability is likely to be greatest where local environments are already under stress as a result of human activities.

Conclusion

The international community is looking for international policy measures to direct support to the countries which are most vulnerable to climate change. A major issue is related to the financing of climate change adaptation and its allocation between countries. Another important issue is how to take into account the vulnerability to climate change in the identification of LDCs.

This brief presents the Physical Vulnerability to Climate Change Index (PVCCI) developed by FERDI. The PVCCI is a simple, precise, objective, transparent, relevant, measurable, and clear. It is easy to understand. Due to these characteristics, it seems to be a suitable index for several development policies, in particular the identification of the LDCs and aid allocation. Combined with the income per capita, the PVCCI can be applied to determine the distribution of concessional adaptation funds, with greater funding going to more vulnerable areas or groups. A simulation has been proposed in order to illustrate the relative share that each group of countries would receive (see Guillaumont, 2015). From this simulation, it appears that LDCs would receive more than half of the adaptation resources. The SIDS would receive an average amount per capita close to the average because of the high level of per capita income of many of them. The outcome of this simulation is in line in the various reports of the United Nations Framework Convention on Climate Change (UNFCCC) which refers to LDCs and SIDS as 'particularly vulnerable countries' towards which the bulk of the adaptation resource should be flowing.

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