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THE IMPACT OF CLIMATE CHANGE ON DEVELOPING ECONOMIES: A COMPARATIVE ANALYSIS OF VULNERABILITY INDICES

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ABSTRACT

In order to make informed decisions on climate finance and policies, there is an increasing need to develop an index to assess countries' vulnerability to climate change. However, differing concepts and methodologies have led to varied views on which countries are most vulnerable and deserve more international financial support. This Working Paper examines whether key indices in climate science consistently classify countries' vulnerability to climate disruption. It begins by reviewing literature on the impact of climate change on developing countries, followed by a comparative analysis of the EVI, ND-GAIN, INFORM, and WRI indices from 2014 to 2020. The findings indicate that while these indices are valuable for understanding and monitoring vulnerability, their differing components lead to divergent results. This research underscores the importance of a holistic approach to vulnerability assessment and calls for informed selection of indices based on specific objectives and contexts.

Keywords CLIMATE CHANGE; VULNERABILITY; INDICES; DEVELOPMENT; IMPACT.

RESUMO

Para se tomarem decisões no âmbito do financiamento e políticas climáticas, reconhece-se cada vez mais a necessidade de se desenvolver um índice para avaliar o grau de vulnerabilidade dos países às alterações climáticas. No entanto, a existência de conceitos e metodologias diferentes tem conduzido a opiniões divergentes sobre quais os países mais vulneráveis e que merecem mais apoio financeiro internacional. Este estudo tem como objetivo compreender se os principais índices da ciência climática classificam de forma consistente a vulnerabilidade dos países às perturbações climáticas. Começa-se por caracterizar o impacto das alterações climáticas nos países em desenvolvimento através de uma revisão de literatura de referência, seguindo-se uma análise comparativa dos índices EVI, ND-GAIN, INFORM e WRI de 2014 a 2020. Os resultados indicam a sua relevância como ferramentas para compreender e monitorizar a vulnerabilidade dos países, no entanto, a diversidade na composição das componentes da vulnerabilidade dos índices leva a resultados divergentes. Esta investigação sublinha a importância de uma abordagem holística da avaliação da vulnerabilidade às alterações climáticas e apela ao uso de índices de vulnerabilidade com base em objetivos e contextos específicos.

Palavras-chave ALTERAÇÕES CLIMÁTICAS; VULNERABILIDADE; ÍNDICES; DESENVOLVIMENTO; IMPACTO.

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Introduction

In economic theory, climate change is treated as a global public good, which requires collaborative international efforts for an effective response (Harris et al., 2007). In recent years, cooperation in the fight against climate change has been directed towards the creation of funds and other international economic structures to financially support the countries most affected by this global problem (Kocharekar, 2023; Michonski & Levi, 2010). Thus, understanding the consequences of climate change on the development trajectory of the various regions of the planet, as well as the measures and policy alternatives to address this phenomenon, is becoming increasingly important for the public and private sectors (Miola & Simonet, 2014). That said, the need to develop multidimensional indices to assess the vulnerability of the various regions of our planet to climate change has been increasingly recognized, in order to make decisions in the field of climate finance and policies (UN-OHRLS, 2021).

However, the debate surrounding the criteria and methodologies used to produce this type of evaluation has resulted in a lack of consensus on which countries are most vulnerable to the impact of climate change and, therefore, who should receive support from the international community (Birkmann et al., 2022; Edmonds et al., 2020; Garschagen et al., 2021; Malone & Engle, 2011; Miola & Simonet, 2014; UN-OHRLS, 2021). Due to this controversy, it is vital to clarify which nations would be most affected by the climate crisis, but also to understand whether the indices recognized by climate science and international institutions consistently classify countries in terms of their vulnerability to climate disruption. The research question that this work aims to answer is presented below:

- *To what extent are the multidimensional indices used to assess climate vulnerability consistent with each other in classifying the vulnerability of developing countries?*

This research has three objectives: firstly, (1) to characterize the impact of climate change on economies, as well as to describe the factors that contribute to increased vulnerability in developing regions, by reviewing the literature on this subject; then, (2) to study the statistical relationships of the vulnerability dimensions of the selected indices by analyzing the behavior of the distributions of scores and vulnerability classifications for developing countries; and, finally, (3) to study the dispersion of vulnerability classifications and the factors that most contribute to the divergence of results.

Having explained the most relevant points of this research, it is important to describe some concepts within the scope of the object of study. Climate change is defined in Article 1 of the United Nations Framework Convention on Climate Change (1992) as "A change in climate attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that adds to the natural climate variability observed over comparable time periods" (p. 3). Global climate change is the result of the high concentration of greenhouse

gases in the atmosphere (GHG) and can be seen in precipitation, temperature, changes in carbon cycles, and finally, the frequency and intensity of storms (Harris et al., 2007).

According to the IPCC (2022), vulnerability is defined as the "propensity or predisposition to be adversely affected" (p.43), encompassing a variety of elements. Vulnerability varies within and between civilizations, regions, and nations, as well as over time (J.B. Smith et al., 2001). This variation is evident in how rising sea levels expose coastal communities like Kiribati, threatening to submerge parts of the country by 2100 (Haner, 2016). The IPCC report emphasizes the vulnerability of agricultural communities in Africa to changing rainfall patterns, which could disrupt food production and threaten food security in these regions (IPCC, 2021). The three fundamental elements of vulnerability are adaptation, exposure, and sensitivity (Brooks, 2003). Adaptation refers to a system's ability to reduce its exposure and vulnerability to climate change through "actions that help reduce vulnerability to current or expected impacts of climate change, such as extreme weather and natural disasters, sea level rise, loss of biodiversity, or food and water insecurity" (UNDP, 2023). According to the I.P.C.C. (2014), in human systems "adaptation aims to moderate or avoid damage or exploit beneficial opportunities" (p. 5). In natural systems, it refers to the process of adapting to current climate conditions and their impacts, and in certain natural systems, "the human context can facilitate adaptation to future climate conditions and their effects" (Field et al., 2014, p.5; Laitonjam, 2018). Adaptation strategies address the vulnerabilities created by climate change. Sea walls in the Netherlands (Rijkswaterstaat, n.d.) directly combat rising sea levels, while farmers can adapt to changing rainfall patterns by using drought-resistant crops (IITA, 2016). In the same vein, early warning systems, as highlighted by the World Meteorological Organisation (WMO, n.d.), play a crucial role in giving communities time to prepare for extreme weather phenomena, ultimately reducing the risk of disasters. On the other hand, exposure is defined as "the presence of people, livelihoods, species or ecosystems, environmental functions, services and resources, infrastructure or economic, social or cultural assets in locations and settings that could be adversely affected" (IPCC, 2014, p.5). Exposure is the occurrence of events or stimuli in a system, and therefore refers to the extent and intensity of the system's exposure to major damage from climate change, measuring the degree to which a system is exposed to climate fluctuations, such as precipitation, temperature, for example. The way climate change exposes different regions to unique challenges can be seen in how rising sea levels directly threaten coastal communities (Oppenheimer et al., 2019), while melting glaciers and permafrost expose mountainous regions to increased flooding and landslides (Huggel et al., 2021). Small Island Developing States (SIDS) face increased exposure due to limited resources and frequent extreme weather events (UNFCCC, n.d.). The sensitivity component is the response of the system as it is affected, that is to say, the magnitude of having been affected after exposure to the impact, assessing the degree to which a system is positively or negatively affected by climate variability (Brooks, 2003; Gumel, 2022; Luers, 2005; Paavola, 2008). In fact, coral reefs, forests, and the Arctic are highly sensitive to climate change due to rising water temperatures and acidification (UNESCO IOC, 2020). In the same vein, the rapid

warming of the Arctic is disrupting the habitats of polar animals due to the melting of permafrost and sea ice (Bintanja et al., 2018).

This research contributes to a new holistic view of vulnerability associated with climate change by explaining the conceptual and methodological aspects that most contribute to the divergence of the indices' results. To achieve this, the study is structured as follows: Chapters 1 and 2 present the theoretical framework on the impact of climate change on the environment, economy, and society, and the determinants of vulnerability in developing countries. Chapter 3 maps the most relevant multidimensional indices for the object of analysis in this work. Chapter 4 explains the methodology adopted for this research and then analyzes the results in order to compare the selected vulnerability indices. The final remarks of this study are presented in the Conclusion Chapter.

1. THE IMPACT OF CLIMATE CHANGE ON THE ENVIRONMENT, ECONOMY, AND SOCIETY

Climate change implies a greater frequency and intensity of extreme weather phenomena or, in other words, an increase in climate risk, which translates into serious socio-economic consequences. The universal impact of these phenomena has given rise to various social and political debates, which recognize the importance of systematizing the present and future effects of the climate crisis. The climate crisis has led to a general deterioration in the natural resilience and adaptive capacity of ecosystems, jeopardizing access to basic elements and livelihoods for all the inhabitants of our planet.

In fact, some extreme weather events, such as tropical cyclones, landslides, droughts, floods or long-term fires, have reduced short-term economic growth in several countries (IPCC, 2022). The losses caused by extreme weather events are reflected in various spheres, including labor productivity, where it is estimated that there will be an increase in working days lost due to high temperatures in several African regions, and above all in the basic living conditions of human beings (Baarsch et al, 2020). The sectors most exposed to the climate, such as agriculture, forestry, fishing, energy, and tourism, will suffer the most. On the other hand, there are some positive economic effects in regions that benefit from lower energy demand, as well as relative advantages for certain agricultural and tourism activities in specific geographies (IPCC, 2022). Although there are positive effects on agricultural activities in some high latitude regions of the planet, and although the level of global agricultural productivity has increased over the last five decades, climate change has slowed down this growth, with the negative effects hitting mid and low latitude regions the hardest (IPCC, 2022).

With the increase in climate variability, there is also an increasing direct degradation of key infrastructures, including transport, water, sanitation, and energy systems, not only due to extreme weather events, but also to gradual climate change, resulting in negative cyclical impacts, mainly on the well-being of populations. For example, climate change negatively affects the physical and mental health of populations, directly killing and injuring people and increasing the spread of disease (McMichael et al., 2012), particularly in more urban regions, where climate change has had the greatest impact on human health. Observing the increase in health

expenditure, this problem also ends up indirectly influencing social welfare due to the adverse financial impact on families (IPCC, 2022).

Finally, the increase in extreme weather events has exposed millions of people to acute food insecurity and reduced water availability, with the greatest impact on communities located on the African and Asian continents and also in certain areas of Central and South America, small islands and the Arctic region (IPCC, 2022). In this way, climate change can be expected to reinforce existing inequalities and boost the dynamics and incentives that lead migrants to move to urban and coastal locations (Castells-Quintana et al., 2018). Many of the migratory flows to large cities in developing countries are directed towards areas with precarious living conditions, limited access to drinking water and basic sanitation, and housing in areas prone to flooding, which reinforces the vulnerable situation of these people. In fact, climate change is contributing to humanitarian crises, as extreme weather events, combined with the high vulnerability of certain populations, force them to move and become part of involuntary migratory flows (IPCC, 2022).

1.1. DEVELOPMENT STATUS: GUIDING THE RESPONSE TO THE CLIMATE CRISIS

The effects of climate change vary enormously around the world. The specificities of each country – its geography and climate characterization, socio-economic conditions and growth prospects - determine the scale of the impact on society, the economy and the environment. The relationship between vulnerability and economic development is complex. On the one hand, Tol (2018) argues that, in general, the relative impacts of climate change decrease as GDP per capita increases. Arent et al. (2015) argues that in an advanced economy characterized by economic activities that take place mainly under controlled conditions – such as manufacturing and services – these are not significantly affected by climate change, while agriculture, forestry and fishing – examples of weather-dependent economic sectors – are consequently more susceptible to climate change. Similarly, more advanced societies are not only able to maintain well-being, but also have higher productivity in the agricultural sector due to technological innovation and are able to import the necessary food reserves in case of shortages. Wealthier communities are also better able to ensure a social safety net for the most vulnerable groups in society (Ward & Shively, 2012). However, more developed countries are not exempt from the consequences of climate change. On the contrary, it is important to consider that the use of energy is directly necessary for the functioning of industry, services, and commerce. Consequently, if energy production has to decrease in order to mitigate the impacts of global warming – by reducing the use of fossil fuels – GDP will also decrease (Keen, 2022).

From a different starting point, developing countries will adapt to climate change as much as their resources allow. Some key factors for effective adaptation and response capacity include infrastructure conditions, the innovative and technological capacity of an economy, increased disaster preparedness and the existence of crisis funds (UNDP, 2015). Many nations lack the infrastructure, financial means and efficient public services that would help them in the aforementioned process (Stern, 2006). In this sense, the most impoverished regions

are structurally more vulnerable to climate change because they have a greater dependence on the resources available in their ecosystems, from the supply of subsistence products and market incomes to food security and health services. For example, more than half of extremely poor people live in sub-Saharan Africa, have no education and depend essentially on natural resources and forest products to meet their daily needs (Sarkodie & Strezov, 2019).

Climate vulnerability is therefore strongly associated with poverty. In fact, according to Ward & Shively (2012), the effects of climate change are not evenly distributed worldwide, and most studies predict that the poorest regions will bear the brunt of the increasing frequency of these phenomena. Nicholas Stern (2006), in his work on the economics of climate change, even states that the most vulnerable populations, especially in the poorest countries, will suffer the most from climate change due to their high sensitivity, exposure and low capacity to adapt. It is therefore considered that the negative effects of climate change occur predominantly in the poorest countries and have a disproportionate impact on disadvantaged people (Castells-Quintana et al., 2018) – despite the fact that these are the regions of the world that have contributed the least to its causes – reinforcing the negative cycle between the incidence of poverty and climate vulnerability (Castells-Quintana et al., 2018; Sarkodie & Strezov, 2019).

Due to the structural vulnerability of the world's poorest regions, there are aspects that pose more immediate threats compared to the current risks caused by climate change. Currently, due to the uncertainty associated with future climate, the potential adverse effects of climate change may not even be recognized as the most pressing environmental hazards to human health and well-being in developing countries (Ward & Shively, 2012). Due to the scarcity of resources to adapt to climate change, which leads to the low capacity of governments in developing countries to provide social security support or invest in basic disaster preparedness and relief infrastructure, citizens in these countries recognize that economic development is the main political priority (Beckerman, 1992).

2. DETERMINANTS OF VULNERABILITY IN DEVELOPING COUNTRIES

A country's economic, social and environmental vulnerability to climate change varies depending on its exposure and capacity to adapt (Ward & Shively, 2012). It is therefore important to describe the importance of variables such as economic growth, investment, demographics and the degree of urbanization, among others, in determining vulnerability to climate risk in these regions.

Regarding environmental factors, poorer countries tend to be located in geographies that are more exposed to climate risk. In recent decades, while the world's population grew by 87% between 1970 and 2010, the population in floodplains increased by 114%, and in cyclone-prone coastal areas by 192% (Hallegatte et al., 2016). Recent World Bank studies have also found that the poorest populations are disproportionately exposed to the risk of flooding, particularly in urban areas or areas where the average temperature is high (Castells-Quintana et al., 2018). Developing economies are highly dependent on water – the most climate-sensitive

economic resource – for their growth and development. As water is essential for agriculture, industry, energy, transportation and domestic purposes, its management has not been effective in these regions, with relatively little investment in irrigation systems, dams and groundwater (Stern, 2006). Consequently, the dynamics inherent in poverty and climate vulnerability are even more incisive in semi-arid countries. In fact, the world's poorest populations live in areas that are already limited in terms of climate and agricultural productivity (with very low levels of rainfall), and many of these areas are precisely those most affected by climate change (Castells-Quintana et al., 2018).

In addition, the study by Baarsch et al. (2020) predicts that the most severe effects will occur more frequently in regions with high social vulnerability, mostly characterized by high poverty rates and population density. The climate vulnerability of the poor is further exacerbated by inequality and marginalization in various social spheres, including gender, ethnic, political, and geographical discrimination. With regard to individual livelihoods, these have been affected by changes in agricultural productivity, human health, food security, the destruction of housing and infrastructure, loss of assets and income, with effects varying according to gender and social strata. For example, a large proportion of citizens in rural regions of the African continent live in dry pastoral and agro-pastoral areas, where the incidence of poverty in these regions is attributed to climate variability and vulnerability to drought (Turrall et al., 2011). Thus, various measures of human well-being have also deteriorated with aridity, such as infant mortality, child malnutrition, maternal care, adult literacy and access to education (Castells-Quintana et al., 2018). On the other hand, an efficient adaptive response depends on informed decisions by society. Citizens respond appropriately to changing conditions when they have adequate information, incentives and an environment conducive to investing in the necessary changes (Castells-Quintana et al., 2018). Given the importance of climate change awareness, poorer communities may lack the capacity and sometimes the political will to mobilize resources for large-scale infrastructure.

Regarding economic determinants, the poorest countries are more vulnerable to extreme weather events due to the central role of agriculture and water resources in their economies (Castells-Quintana et al., 2018). Many developing states lack crop insurance to protect farmers against extreme weather events, which, when they occur, have a catastrophic impact on livelihoods (Baloch et al., 2020; Ward & Shively, 2012). According to Nicholas Stern, the concentration of activities in one sector also limits flexibility to switch to less climate-sensitive activities, such as industry and services. For example, a large percentage of the population in the poorest countries depends on economic activities in the primary sector, mostly characterized by specialization in agricultural production. The agricultural sector, besides being associated with low-income levels, is one of the most threatened by climate change in developing countries (Stern, 2006). In Sub-Saharan Africa, most employment is in the agricultural sector, accounting for about 57% of the workforce but only 16% of the region's GDP. This discrepancy underscores the vulnerability and endemic poverty of the sector, which has a per capita value added 6 to 7 times lower than other sectors of the economy (World Bank, 2018). This context is further compounded by the fact that these economies have "fragile" connections to global financial markets, limiting

their ability to diversify risk or obtain or redistribute financial resources (Stern, 2006). Access to financing is still very limited in most least developed countries. The poorest populations not only lack their own resources but are also often excluded from credit markets, as they lack the necessary collateral to obtain loans, limiting their ability to face risk. The lack of financial reserves makes countries more vulnerable to shocks to household incomes, resulting in direct consequences for health, education, investment, and productivity (Castells-Quintana et al., 2018). It is important to highlight that the poorest countries tend to have limited adaptive capacity, depending on various factors such as the availability of innovative technology and the ability to pay for patents (Tol, 2018). These countries often lack access to financial means and technological advancements that can help protect against adverse weather conditions, including air conditioning, malaria drugs, and crop insurance.

Finally, there is a stark contrast between the quality of infrastructure and urbanization in developed countries and the poorest societies, with the lack of adequate housing being one of the most critical barriers to positive adaptation and sustainable development. While most citizens in industrialized countries have well-reinforced housing structures made from more resistant materials, access to basic infrastructure is still very limited in developing countries. Cities in developed countries have high levels of sanitation and water filtration, while developing nations have unprotected and unreliable water supplies and often lack adequate sanitation. Additionally, supporting infrastructure for transportation, communication, and health is often extremely weak (Ward & Shively, 2012). Compared to the rest of the world, access to basic services in low-income countries is still very deficient. For example, basic sanitation and electricity cover less than a third of the total population in these countries (Castells-Quintana et al., 2018). In 2000, the World Health Organization attributed 1.7 million deaths to the consumption of non-potable water and the lack of sanitation and hygiene, with most deaths occurring in the poorest and most vulnerable regions of the world, mainly in Africa and Southeast Asia (Ward & Shively, 2012).

3. CLIMATE CHANGE INDEX MAPPING

As society grapples with the complexities of mitigating and adapting to climate change, policymakers, academic researchers, and international organizations seek reliable and comprehensive tools to assess countries' vulnerability levels to this issue (Garschagen et al., 2021; Miola & Simonet, 2014; UN-OHRLLS, 2021). Most studies dedicated to the scientific analysis of vulnerability have focused on using indices as a methodological approach to quantify the structural and exogenous factors that contribute most to countries' vulnerability to extreme weather events (Blasiak et al., 2017; Debortoli et al., 2019; Nguyen et al., 2016; Roukounis & Tsihrintzis, 2022). In general, constructing an index relies on the operationalization and weighting of a series of components that aggregate a set of observable variables, allowing for the translation of various aspects of a country's, area's, or region's vulnerability into a single value (Ahsan & Warner, 2014; Below et al., 2012; Hinkel, 2011; McIntosh & Becker, 2019).

However, the use of representative indicators has some drawbacks, such as the possibility that the conditions they intend to measure may not be accurately reflected, the potential overlap of variables, the formation of gaps due to data scarcity, and the fact that indicator sets often omit interactions that characterize real-world systems (Malone & Engle, 2011; Nelson et al., 2007). For these reasons, it becomes crucial to understand the procedure for integrating factors — the weighting and aggregation method — to determine a country's vulnerability level (Angeon & Bates, 2014).

The quantity and diversity of multidimensional indices associated with climate change available in the scientific community represent both a challenge and an opportunity for research on countries' vulnerability to it, thus requiring a methodical and rigorous selection process (Miola & Simonet, 2014; Nguyen et al., 2016). Therefore, this chapter begins by proposing a set of criteria for researching and selecting indices of economic and environmental vulnerability associated with climate change, ensuring the adequacy and effectiveness of the chosen indices to address the research question at hand and provide a basis for objective and coherent comparisons (Miola & Simonet, 2014; Roukounis & Tsihrintzis, 2022). The indices are intended to take into account the multidimensional nature of vulnerability (Edmonds et al., 2020; Roukounis & Tsihrintzis, 2022; UN-OHRLLS, 2021), capture its dynamics at the national scale (Birkmann et al., 2022; Garschagen et al., 2021), rely on databases with wide availability and free access (Malone & Engle, 2011; Miola & Simonet, 2014; Sheehan et al., 2023; UN-OHRLLS, 2021), be updated periodically (Birkmann et al., 2022), have universal applicability (Malone & Engle, 2011; Miola & Simonet, 2014; Sheehan et al., 2023; UN-OHRLLS, 2021), and finally, be widely used in research on climate change (Garschagen et al., 2021).

In the first phase, a survey of the most frequently referenced vulnerability indices in the literature associated with climate change was conducted. The analysis of the indices revealed limitations in addressing the multidimensional nature of vulnerability, with various examples focusing narrowly on specific dimensions. For example, the Climate Change Performance Index (Burck et al., 2019) mainly focuses on mitigation and adaptation measures, while the Climate Vulnerability Index (Sullivan & Meigh, 2005) is based on specific indicators for coastal areas, excluding other regions. The Economic Vulnerability Index (Briguglio & Galea, 2003) addresses only the economic dimension, neglecting important aspects, and the Environmental Performance Index (Yale Center for Environmental Law and Policy and Columbia University, 2001) measures environmental performance without directly assessing vulnerability to climate change. Additionally, the Environmental Sustainability Index (Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network (CIESIN), 2001) prioritizes environmental sustainability over climate vulnerability, while the Livelihood Vulnerability Index (Shah et al., 2013) and the Livelihood Effect Index (LEI) (Khajuria & Ravindranath, 2012) mainly focus on livelihoods, with little consideration for other vulnerability dimensions. Furthermore, indices such as the Composite Climate Change Vulnerability Index (Edmonds et al., 2020) and the Composite Socio-Economic Index (Sahana et al., 2021) have inadequate methodologies to capture diversity, emphasizing specific indicators at the expense of other socio-economic and institutional aspects.

Given the above, out of the thirty-five mapped indices (see Table III in Annex I), four indices were selected that satisfy all the selection criteria presented earlier, ensuring a coherent and transparent assessment of the dynamics associated with the vulnerability of developing countries. It is important to note that the selected models do not exclusively focus their applicability on the phenomenon of climate change but are used in this context by the scientific community and various institutions. Table I (below) summarizes the main characteristics of each of these indices.

Table I - Climate Change Index Mapping

Index	Source	Rationale	Ranking	Dimensions	Indicators	Data
Index of Economic and Environmental Vulnerability (EVI)	<i>United Nations Committee on Development Policy (CDP)</i>	Measurement of structural vulnerability to economic and environmental shocks.	[0-100]	Economic Vulnerability	8	143 countries
			A higher value represents higher vulnerability.	Environmental Vulnerability		2000-2023
Notre Dame Global Adaptation Index (ND-GAIN)	<i>Notre Dame Global Adaptation Initiative (ND-GAIN)</i>	Assessment of a country's vulnerability to climate change and other global challenges, considering its resilience capacity.	[0-1]	Vulnerability - exposure, sensitivity, and adaptive capacity	45	192 countries
			The top of the ranking is the most prepared and least vulnerable country.	Preparedness Capacity - Economic, governance, and social preparedness		1995-2023
INFORM Risk Index	<i>European Commission's Joint Research Centre (JRC)</i>	Assessment of the dimensions of hazard and exposure, on one hand, and vulnerability and lack of response capacity, on the other.	[0-10]	Hazard & Exposure	54	191 countries
			Higher values represent greater risk and vulnerability.	Vulnerability Lack of response capacity.		2014-2023
WRI Risk Index	<i>Institute for Environment and Human Security, UNU-EHS & IFHV, Ruhr-University Bochum</i>	Evaluation of risk as an interaction between hazards and vulnerability, with a focus on the importance of social capacities in disaster preparedness.	[0-100]	Exposure	100	193 countries
			At the top of the ranking, the country with the highest global disaster risk.	Susceptibility		2000-2021
				Lack of response capacity. Lack of adaptive capacity.		

Source: CDP & UN DESA, 2021; ND-GAIN Country Index Technical Report, 2023; Marin-Ferrer et al., 2017; World Risk Report, 2022

The Economic and Environmental Vulnerability Index (EVI), developed by the United Nations Committee for Development Policy (CDP), considers the economic and environmental dimensions of vulnerability in its assessment. The EVI focuses on structural vulnerability to economic and environmental shocks, using normalization techniques such as the Min-Max procedure to ensure a consistent distribution of indicators. This index assigns equal weights to the indicators, and its aggregation method involves calculating the simple arithmetic average of the indicator values (see Table IV in Annex I). The EVI has data available from the year 2000 for 143 developing countries (Assa & Meddeb, 2021; CDP & UN DESA, 2021). The calculation of the EVI score is based on summing the score of the "economic vulnerability index" with the score of the "environmental

vulnerability index" for each country, resulting in a vulnerability score between 0 and 100 (CDP & UN DESA, 2021), according to formula (1):

- $EVI = \frac{1}{2} \text{Economic Vulnerability Index} + \frac{1}{2} \text{Environmental Vulnerability Index}$

The Notre Dame Global Adaptation Index (ND-GAIN) is the second index selected for this study. The ND-GAIN index assesses the adaptation capacity to climate change of 192 UN countries, considering the dimensions of "exposure," "sensitivity," and "adaptive capacity" for the "vulnerability" component. It also presents a "readiness" component, observing "economic readiness," "governance readiness," and "social readiness." Both composite constructions use Min-Max linear normalization procedures to compare indicators for each country. The index weighting method relies on equal weights, and the aggregation method is the arithmetic mean. The calculation (2) of the ND-GAIN score corresponds to subtracting the "vulnerability" score from the "readiness" score for each country, resulting in a value from 0 to 1 (ND-GAIN Index Country Index Technical Report, 2023):

- $(2) \text{ND-GAIN} = (\text{Readiness Score} - \text{Vulnerability Score} + 1) * 50$

Finally, the INFORM Risk Index and the WRI Risk Index are two examples of risk-based indices. These indices strongly emphasize determining vulnerability based on the risks associated with hazard and exposure. To normalize the indicators, these indices use Min-Max linear normalization approaches, as well as equal weights for indicator weighting methods. The WRI Risk Index includes 193 countries, and the INFORM Risk Index includes 191 countries (Marin-Ferrer et al., 2017; World Risk Report, 2022). The INFORM index establishes a balance between the dimensions of "hazard," "exposure," "vulnerability," and "lack of response capacity." The calculation of this analytical tool (3) focuses on multiplying the scores of the "hazard and exposure," "vulnerability," and "lack of response capacity" dimensions for each country, resulting in scores from 0 to 10, using the formula below (Marin-Ferrer et al., 2017):

- $(3) \text{INFORM} = \text{Hazard and Exposure } 1/3 * \text{Vulnerability } 1/3 * \text{Lack of Response Capacity } 1/3$

The WRI Risk Index assesses "exposure," "susceptibility," "lack of response capacity," and "lack of adaptive capacity." To calculate its score, the "exposure" score is multiplied by the "vulnerability" score (resulting from the sum of the scores of the "susceptibility," "response capacity," and "adaptive capacity" dimensions) for each country, resulting in a value from 0 to 100, using the formula below (World Risk Report, 2022):

- $(4) \text{WRI} = \text{Exposure} * [\text{Susceptibility } 33\% + \text{Response Capacity } 33\% + \text{Adaptive Capacity } 33\%]$

As initially presented, this work focuses on studying vulnerability associated with climate change in developing countries. Thus, considering the object of study under analysis, this research uses only the dimensions related

to the concept of vulnerability from each mapped index. Figure 1 (below) represents the process of extracting vulnerability dimensions from each index analyzed in this research.

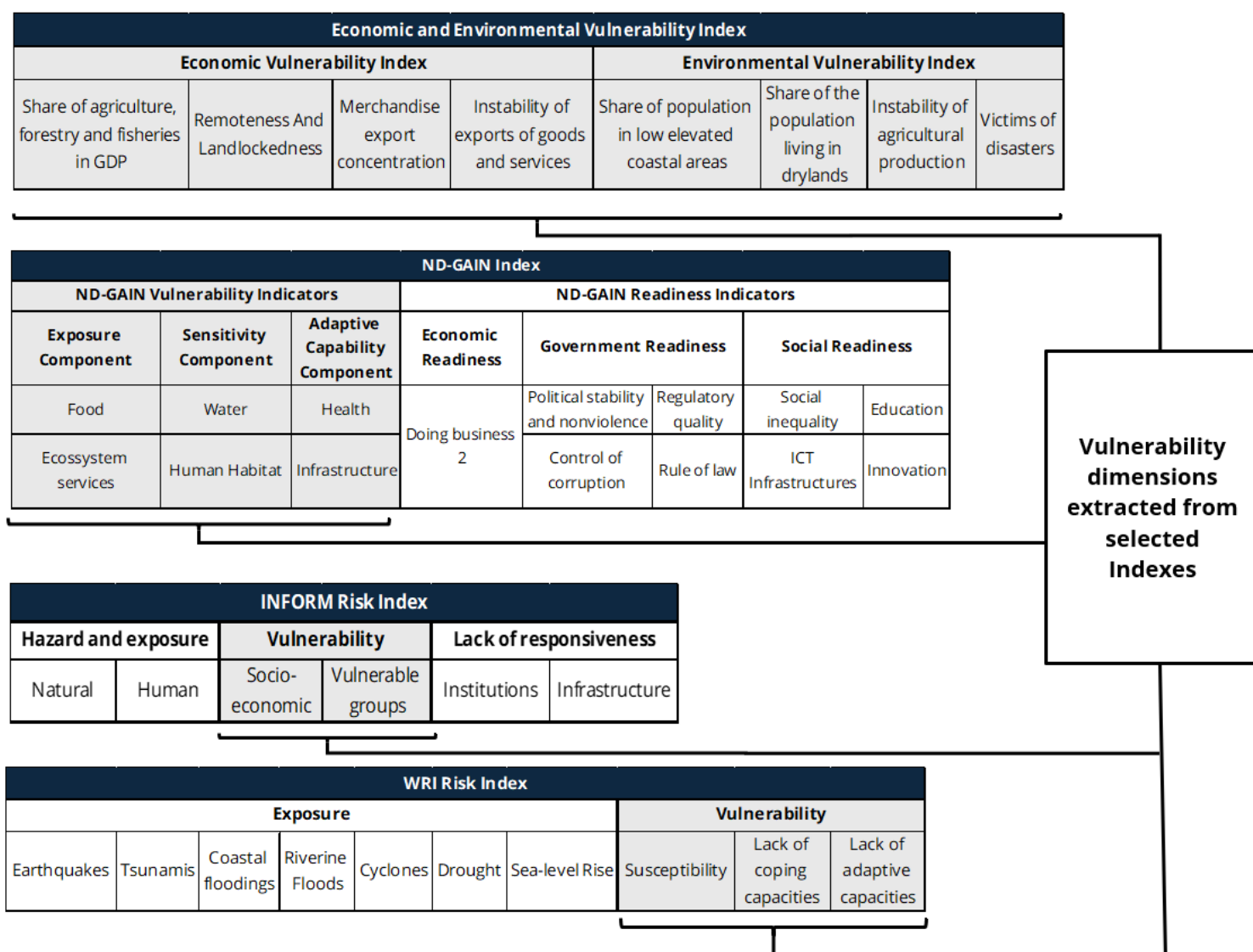


Figure 1 - Composition of vulnerability indices

Source: Adapted from CDP & UN DESA, 2021; ND-GAIN Country Index Technical Report, 2023; Marin-Ferrer et al., 2017; World Risk Report, 2022

For the EVI, the "economic vulnerability index" and "environmental vulnerability index" were extracted. These dimensions comprise the structural vulnerability of countries, such as the risk of being harmed by exogenous shocks. In other words, the extent to which a country is exposed to these shocks and how quickly it can recover from them determines its vulnerability. These factors also depend on the size and frequency of the shocks in question. Resilience is not analyzed in the EVI, as some aspects of resilience are related to the implementation of policy measures and, therefore, are not treated as structural factors (CDP & UN DESA, 2021). Table V (see Annex II) presents the composition of the EVI index, from which it can be observed that its structure focuses on

commercial impacts regarding economic shocks, and, regarding environmental shocks, the EVI focuses on natural hazards such as weather events and climate change (CDP & UN DESA, 2021). These shocks potentially affect economic activity, consumption, employment, population welfare, and the natural resource base of economic and social development. Although the frequency and magnitude of commercial shocks and environmental shocks (such as climate change) are sometimes influenced by international policy decisions, they are largely exogenous, at least from the perspective of less developed countries (CDP & UN DESA, 2021).

In the case of the ND-GAIN index, which comprises vulnerability as the "propensity or predisposition of human societies to be negatively impacted by climate risks" (Chen et al., 2023, p.3), indicators of vulnerability related to the sectors "food," "water," "health," "ecosystem services," "human habitat," and "infrastructure" were selected. As can be observed in Table VI (see Annex II), each sector consists of six indicators representing the three cross-cutting dimensions: the sector's exposure to climate-related risks or risks exacerbated by climate, the sensitivity of that sector to the impacts of risk, and the sector's adaptive capacity to cope with or adapt to those impacts (Chen et al., 2023, p.3).

Regarding the INFORM index, which analyzes the vulnerability dimension as "the intrinsic predispositions of a population exposed to be affected or susceptible to the harmful effects of a hazard, even if the assessment is made through hazard-independent indicators" (Marin-Ferrer et al., 2017, p. 30), the categories "socioeconomic aspects" and "vulnerable groups" that compose the vulnerability dimension of this index were considered (see Table VII, in Annex II). In contrast to the first category, which focuses more on the demography of a nation as a whole, the "vulnerable groups" category includes social groups with limited access to social and health systems (Marin-Ferrer, 2017).

Finally, for the WRI index, vulnerability is interpreted as "the predisposition of populations to be vulnerable to damage caused by extreme natural phenomena or negative impacts of climate change" (World Risk Report, 2022, p. 40). The dimensions "susceptibility," "lack of response capacity," and "lack of adaptive capacity" were used for this research (see Table VIII, in Annex II). Thus, the vulnerability component of this climate index considers the capacity of individuals, households, and societies to be destabilized, harmed, or even destroyed by catastrophic events, encompassing economic, political, social, and environmental aspects in this analysis (World Risk Report, 2022).

Observing Figure 1 and Annex II, it is understood that, unlike the ND-GAIN, INFORM, and WRI indices, the EVI index does not assess vulnerability resulting from non-structural endogenous factors, such as the impact of public policies, innovation, restrictions on international financial aid, social instability, or public health crises. The EVI index only considers factors that determine a country's structural vulnerability to exogenous shocks, whether economic or environmental (CDP & UN DESA, 2021). On the other hand, the ND-GAIN, INFORM, and WRI indices also incorporate a set of factors based on a wide range of economic, political, and social aspects that determine a country's vulnerability, making it impossible to distinguish between concerns of structural

vulnerability and variables related to current politics (Chen et al., 2023; World Risk Report, 2022; UN-OHRLLS, 2021; Marin-Ferrer et al., 2017).

4. COMPARATIVE ANALYSIS OF VULNERABILITY INDICES

4.1. METODOLOGY AND DATA

In this chapter, the methods used in the research and selection of data, the definition of the sample, and finally, the methodology adopted in the statistical analysis are presented. After selecting the indices used in this work, the verification of the update of their construction methodologies over the years was carried out. This assumption was fulfilled, with retroactive updates of classifications in relation to previous years by the authors, based on existing baseline data. This data treatment by the entities that publish them is essential to understand the impact of methodological changes on the results and to ensure their temporal coherence. Next, the data were selected through the statistical databases of each entity responsible for publishing the index (publicly accessible), properly identified in this work. The database that gathers the statistical information processed in this research is called "Database | Vulnerability Index Statistics," which can be consulted in Table IX (available in Annex III).

Regarding the definition of variables, data related to the results of the vulnerability dimensions of the EVI, ND-GAIN, INFORM, and WRI indices were extracted. In order to simplify their interpretation, four quantitative variables were created:

- The scores of the Economic and Environmental Vulnerability Index (EVI) are represented by the variable "EVI Index".
- The scores of the vulnerability dimension of the Notre Dame Global Adaptation Index (ND-GAIN) are represented by the variable "ND-GAIN Index".
- The scores of the vulnerability dimension of the INFORM Risk Index are represented by the variable "INFORM Index".
- Finally, the scores of the vulnerability dimension of the WRI Risk Index are represented by the variable "WRI Index".

Next, the sample definition procedure is described. With the aim of maximizing the number of cases under analysis and obtaining a viable and representative sample to achieve the research objectives, all years and countries with data in common for the four multidimensional indices were used. This method resulted in a study population composed of 135 developing countries (ODC) and least developed countries (LDC). Developing countries represent a heterogeneous group of nations with an intermediate level of per capita income and social indicators. According to the World Bank, in 2023, the average per capita income of developing countries was \$7,696, below developed countries but above LDCs (World Bank, 2023). These countries share characteristics such as average to low per capita income and progressing social indicators, but they differ based on specific criteria reflecting their challenges and particular needs. While developing countries have

intermediate per capita income and rising social indicators, LDCs represent the most precarious socio-economic conditions, with extremely low per capita income, high poverty rates, and heavy reliance on external assistance (United Nations, 2023). Subsequently, data were selected for a period of seven years – 2014, 2015, 2016, 2017, 2018, 2019, and 2020. The main reason behind this temporal interval was the concern to obtain a sample with a reasonable size capable of achieving the research objectives.

In order to enable a proper comparison between the results of the vulnerability dimensions of each index, which have different construction methodologies and aggregation methods, a Min-Max linear normalization of the four distributions under study was performed. Through this technique, country rankings were normalized on a scale from 0 to 100, where 0 is the minimum vulnerability result and 100 is the maximum. This normalization procedure allows for a more insightful comparison of vulnerability scores associated with climate change of the population and the time frame under analysis. The formula (5) used in normalizing the vulnerability results of the four indices under study is presented below:

- $normalized_value = (original_value - minimum_value) / (maximum_value - minimum_value) * 100$

The research uses a quantitative methodology, supported by statistical methods. The empirical analysis was primarily conducted using the IBM SPSS Statistics software and Excel. Firstly, a descriptive analysis was performed, calculating measures of central tendency and dispersion to explore the data and understand its distribution. To assess the normality of the data, the Kolmogorov-Smirnov (K-S) normality test was applied. In addition, bivariate analyses were conducted to compare the results of the different indices, using statistical tests such as Spearman correlation analysis and the production of scatter plots. This step allowed verifying if there are statistically significant associations between variables and identifying possible outliers. Finally, to complement the analysis and address the research questions proposed in this work, a discrepancy analysis of the vulnerability index rankings was conducted, a method used by authors Miola and Simonet (2014) in the study "Concepts and Metrics for Climate Change Risk and Development - Towards an index for Climate Resilient Development" and by researchers Garschagen et al. (2021) in the article "Global patterns of disaster and climate risk—an analysis of the consistency of leading index-based assessments and their results." This analysis identifies countries with significant differences in rankings between indices and highlights inconsistencies in their results, while also considering contextual factors that may influence them.

4.2. RESULTS ANALYSIS

Firstly, the main characteristics regarding the behaviour of the variables related to the vulnerability indices mapped in this study are presented, namely, the variables "EVI Index," "ND-GAIN Index," "INFORM Index," and "WRI Index." Each of the four quantitative variables presents 945 valid cases considered for the development of the study. The values of each distribution represent the degree of vulnerability of a country, where 0 can be assumed to represent the minimum vulnerability classification and 100 the maximum vulnerability classification. The values correspond to a group of 135 countries belonging to developing geographic regions for the years 2014 to 2020.

Observing the statistics of the four variables under analysis, it can be inferred that concerning the EVI index, its mean is 34.05, and it is observed that the distribution is positively skewed (0.37), meaning the distribution of statistical units is slightly biased to the left side of the histogram. The kurtosis is -0.73, indicating a platykurtic distribution, meaning a relatively flat distribution compared to the normal distribution. Similarly, the mean of the ND-GAIN Index is 47.64. The skewness is 0.40, indicating slight positive skewness, meaning that the distribution of statistical units is slightly concentrated on the left side of the histogram. The kurtosis is -0.58, indicating a platykurtic distribution, relatively flat compared to the normal distribution. The mean of the INFORM Index is 42.36. The skewness value is close to 0, indicating it is irrelevant, with an almost symmetric distribution. The kurtosis is -0.74, indicating a platykurtic distribution, relatively flat compared to the normal distribution. Finally, the WRI Index has a skewness of 0.98, indicating more pronounced positive skewness, that is to say, the distribution of statistical units is concentrated on the left side of the histogram and then a long tail is observed to the right. Therefore, analyzing the median as a measure of location is privileged. It has a value of 24.51 and an interquartile range of 17.17, meaning half of the countries in our sample have a relatively low vulnerability classification. The kurtosis coefficient presents a value of 0.19. This value is greater than 0, indicating leptokurtic distribution (see Table X, Annex III). These statistics reveal that there is a highly concentrated frequency at certain values which graphically have higher bars in the considered histogram, indicating a relatively sharper distribution compared to the normal distribution. Thus, it is observed that high vulnerability scores represent a significantly small proportion of the total in the four distributions. Therefore, it is considered that in the four indices under analysis, the majority of country rankings regarding their vulnerability have relatively low values (<60). Thus, the statistics characterizing the shapes of the distributions reveal that there are fewer vulnerability observations as higher vulnerability is considered (see Figures 7 and 8, Annex III).

The linear relationship between the variables and the normality of their distribution were also assessed using the Kolmogorov-Smirnov (K-S) normality test (see Table XI, Annex III). In this case, all test statistics are positive and low, suggesting a discrepancy between the observed distributions and the theoretical distributions of normality. In all cases, the significance values are less than 0.001 (sig. < 0.001), indicating that the data of the variables do not follow a normal distribution. Thus, it is considered more appropriate to proceed with data analysis using non-parametric tests, which do not assume normality in the data. In this sense, Spearman correlation tests were performed to measure the correlation between the vulnerability indices analyzed in this research. Observing the results in Table II, the p-values are below the significance level of 0.01, indicating that the correlation coefficients are statistically significant. These results indicate that there is a significant and positive relationship between the vulnerability indices, suggesting a direct linear relationship between them. That is, in all statistical tests, the relationship between the indices means that the higher the vulnerability values of the index located on the Y-axis, the higher the vulnerability values in the index on the X-axis. However, it is important to remember that correlation does not imply causality and that other factors may influence this relationship. Regarding the linear relationship between the variables, scatter plots demonstrate that it is

evident, with two exceptions – the scatter plots between the variables "EVI Index" and "INFORM Index" and the one corresponding to the relationship between "EVI Index" and "WRI Index."

Table II. Correlation Analysis between Vulnerability Indices for the period 2014-2020.

SPEARMAN'S CORRELATION COEFFICIENTS	EVI INDEX	ND-GAIN INDEX	INFORM INDEX	WRI INDEX
EVI INDEX	1	0,451**	0,275**	0,153**
ND-GAIN INDEX	0,451**	1	0,710**	0,533**
INFORM INDEX	0,275**	0,710**	1	0,759**
WRI INDEX	0,153**	0,533**	0,759**	1

** THE CORRELATION IS SIGNIFICANT AT THE 0.01 LEVEL (2 ENDS).

Source: Database | Vulnerability Index Statistics

The intensity of correlation varies between the pairs of indices, with the highest between the INFORM index and the WRI index: 0.759**, which, according to the correlation interpretation grid proposed by Cohen and Holliday (1983), means that the correlation is positive and high. That is, the higher the vulnerability scores of the INFORM index, the higher the vulnerability scores of the WRI index.

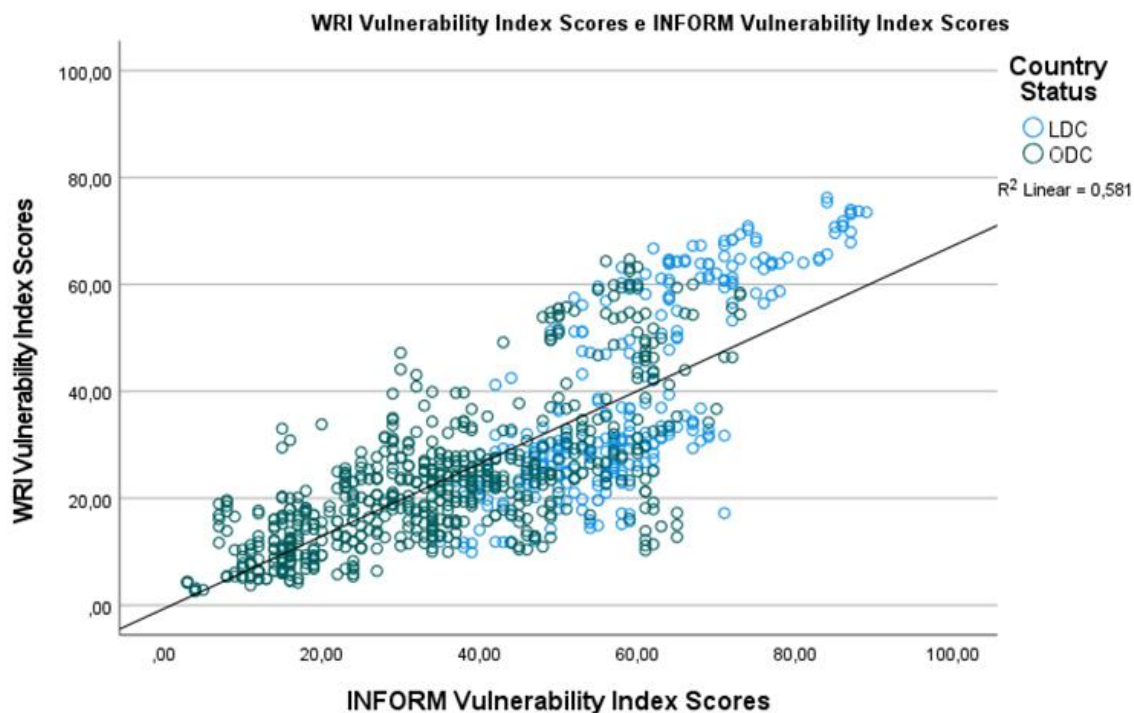


Figure 2 - Scatter plot between the WRI index (y-axis) and the INFORM index (x-axis) for the period 2014-2020.

Source: Database | Vulnerability Index Statistics

Next, in order of intensity, follows the correlation between the ND-GAIN index and the INFORM index (0.710**), a positive and equally high correlation.

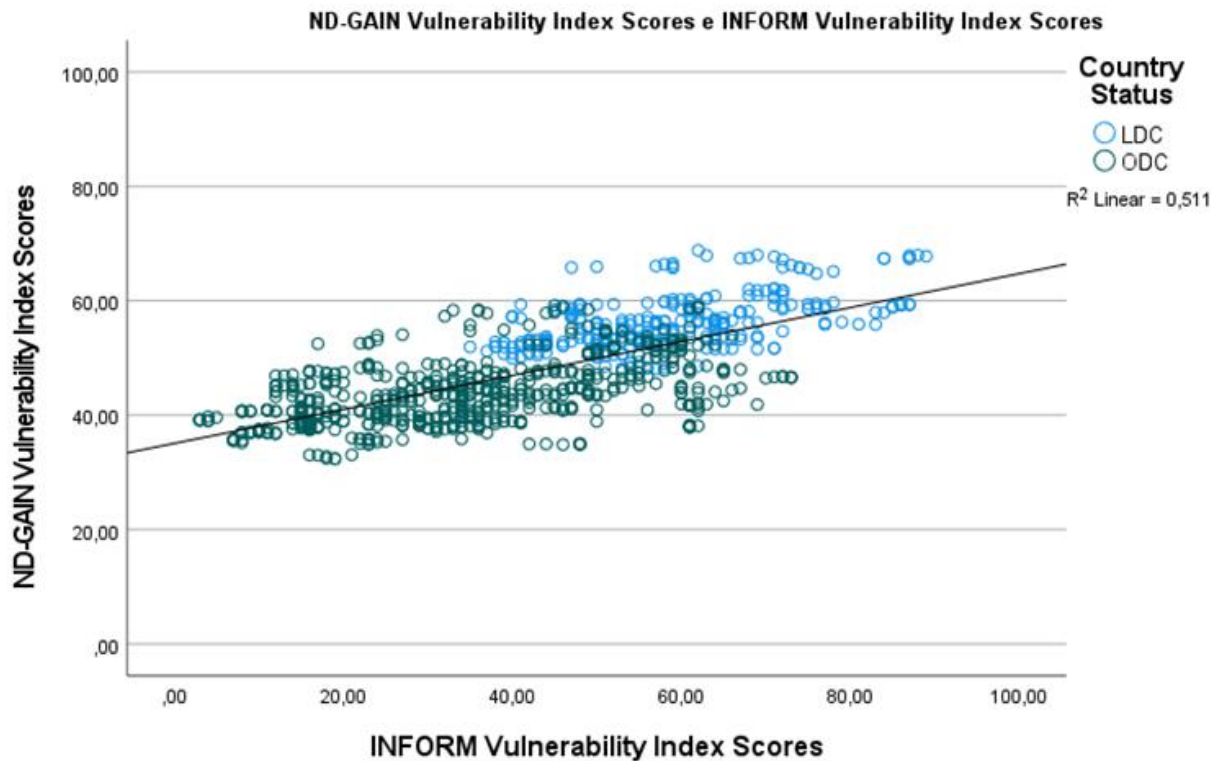


Figure 3 - Scatter plot between the ND-GAIN index (y-axis) and the INFORM index (x-axis) for the period 2014-2020.

Source: Database | Vulnerability Index Statistics

Regarding the analysis of the remaining bivariate relationships, the correlation test between the ND-GAIN index and the WRI index results in a Spearman coefficient of $r = 0.533$. According to the interpretation grid proposed, the correlation is positive and moderate. Thus, the higher the vulnerability scores of the ND-GAIN index, the higher the vulnerability scores of the WRI index, although the relationship between these two indices is moderate. Similarly, the correlation between the EVI index and the ND-GAIN index ($r = 0.451$) is positive and moderate. Next, the correlation between the EVI index and the INFORM index has a value of $r = 0.275$, meaning that the correlation is low or weak. Finally, the correlation between the EVI index and the WRI index ($r = 0.153$) is very low. Next, we aim to measure the discrepancy between the vulnerability scores of each of the four indices. For this purpose, the average of the rankings of the seven years (2014 to 2020) for each country was calculated to obtain an aggregated measure of vulnerability over time. This simplifies the analysis and provides a more general view of each country's average vulnerability ranking. In a subsequent phase, the average vulnerability values were sorted in descending order, and rankings were assigned to each country, identifying the countries with the highest and lowest vulnerability rankings (1st to 135th), where 1st represents the most vulnerable country to climate change and 135th the least vulnerable country in the sample.

Figure 4 (page 25) represents the cartographic distribution of the average vulnerability rankings of each of the vulnerability indices for the 135 developing countries in the sample. In each of the maps, countries are grouped into five categories defined by vulnerability level based on the quintile calculation of each distribution under analysis. In this first stage of cartographic analysis, it is possible to identify some regional clusters of vulnerability on a global scale from Figure 4. Considering the results of the four indices, a significant portion of the countries in the African continent, particularly in the Sahel region and western and eastern Africa, are highlighted. Most of the countries in these regions of Sub-Saharan Africa are highly vulnerable to climate change due to their high sensitivity and exposure to climate variability and related hazards, considering their dependence on climate-sensitive sectors such as agriculture and hydropower for energy production, as well as the increasing irregularity of precipitation and temperature levels across the African continent. From the observation of each of the individual maps, it is concluded that the EVI index highlights a group of countries located in Southern Africa, Central Asia, and certain island states in Central America and Oceania as highly vulnerable, while the ND-GAIN, INFORM, and WRI indices map countries situated in Central Africa and South Asia as highly vulnerable.

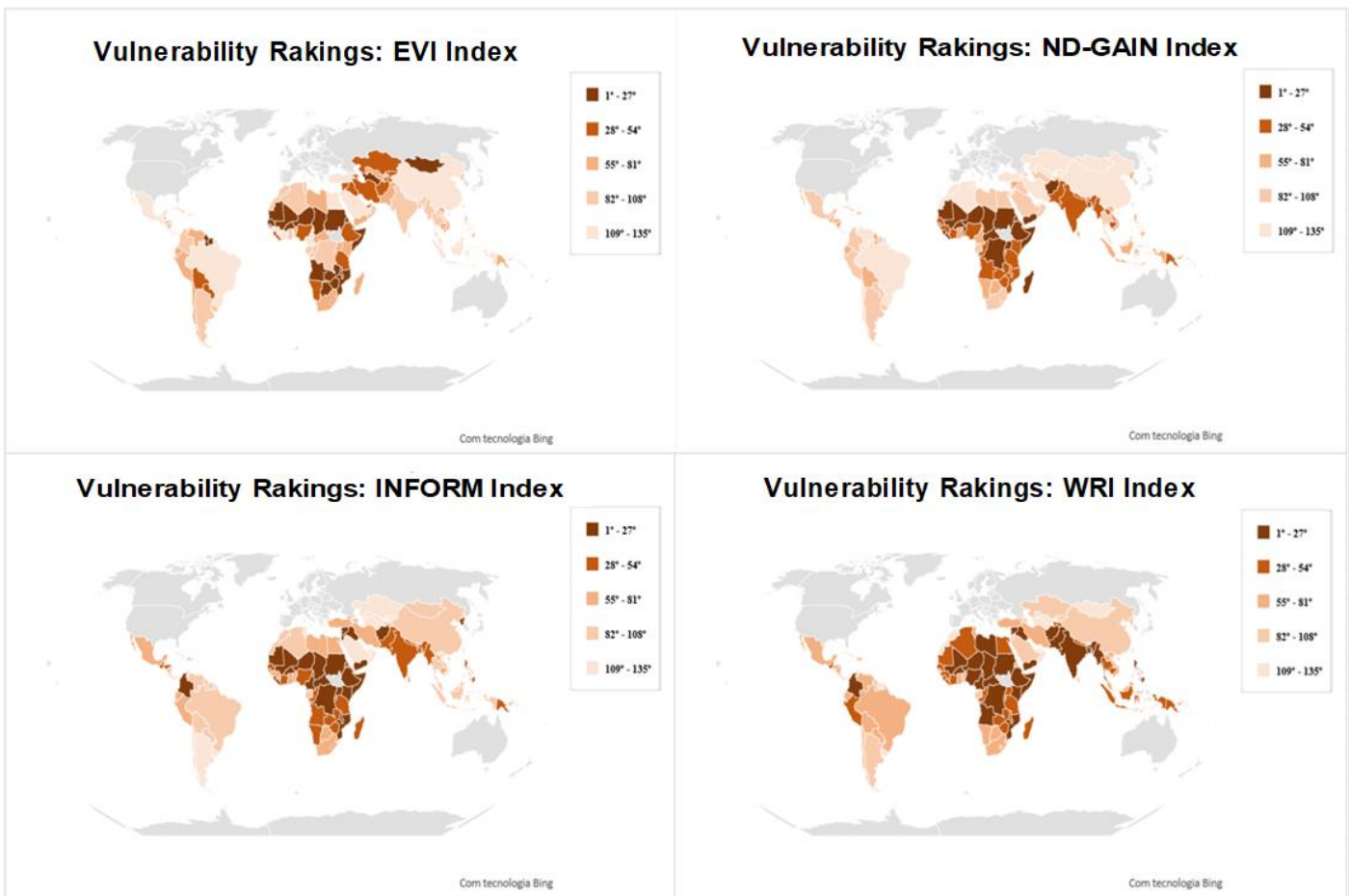


Figure 4 - Mapping of vulnerability rankings for the EVI, ND-GAIN, INFORM, and WRI indices.

Source: Database | Vulnerability Index Statistics

Subsequently, the standard deviation between the index rankings for each country was calculated to measure how dispersed they are relative to the mean. In Figure 5 (below), a map is presented showing the level of dispersion between the vulnerability index rankings. Although differing in definitions, indicators, methodologies, or the stages of development of the countries they refer to, this exercise allows finding "points of agreement" regarding geography.

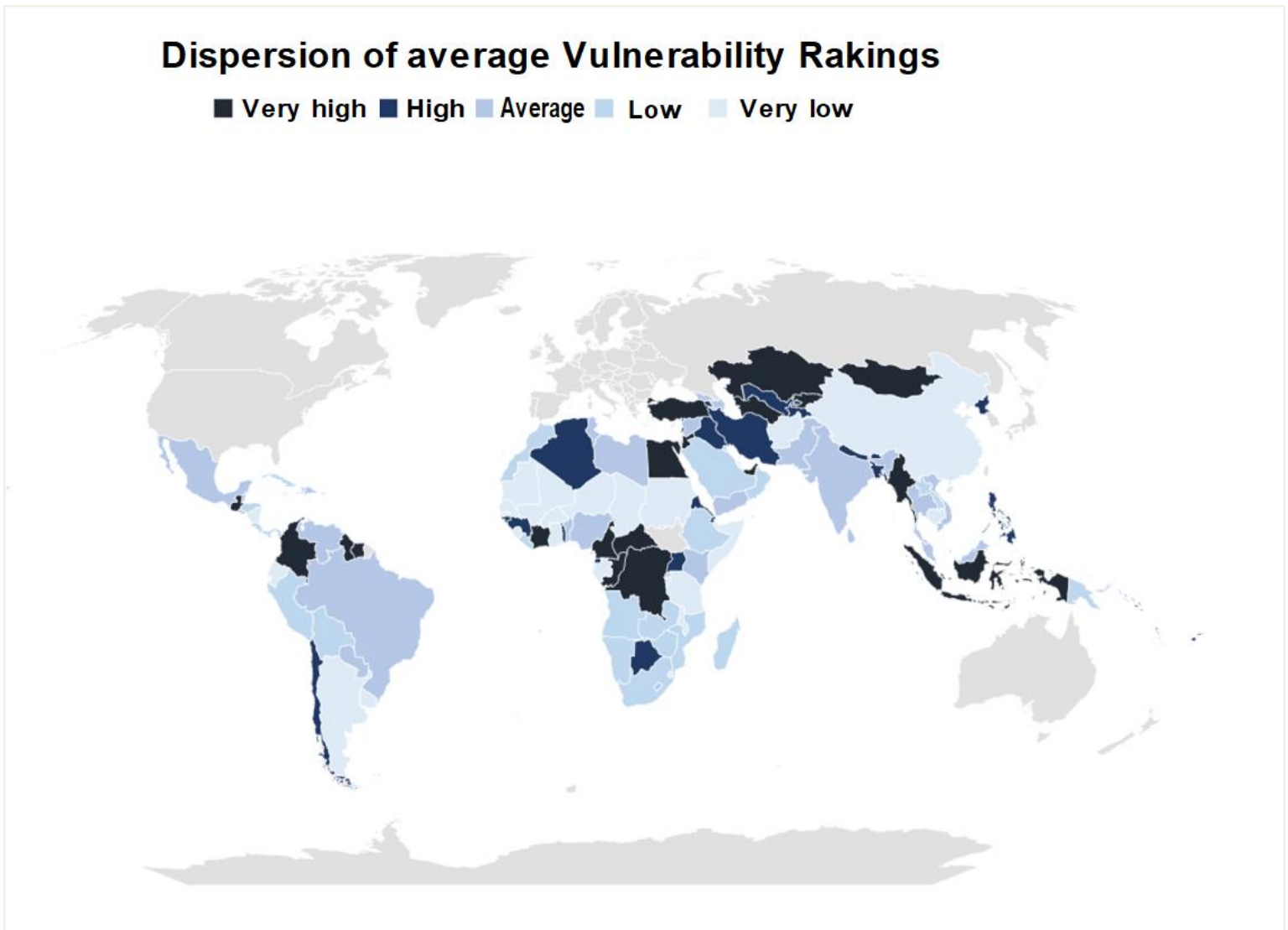


Figure 5 - Cartographic analysis of the dispersion of vulnerability rankings for the vulnerability indices.

Source: Database | Vulnerability Index Statistics

Interpreting the results of the two figures, the homogeneity of light colors on the dispersion map reflects the fact that there is unanimity among the various indices in classifying a large portion of least developed countries located in the African Sahel region – Chad, Niger, Sudan, Mali, Burkina Faso, Mauritania, and Senegal – as highly vulnerable to climate change. Still, in the African continent, it is possible to highlight the consensus of the four vulnerability indices in positioning least developed countries such as Somalia, Burundi, Malawi, Sierra Leone, and Tanzania as nations with a high level of vulnerability.

Observing the map, one can also identify cases like Afghanistan, a landlocked territory currently undergoing the largest and most severe humanitarian crisis in the world, and Cambodia, one of the least developed nations in Southeast Asia, as countries classified consensually as very vulnerable to the impacts of the climate crisis. Both states are highly vulnerable to the effects of climate change due to a combination of natural, social, and economic factors. Global warming has significantly increased annual maximum and minimum temperatures in both territories, resulting in ecosystem impacts, also affecting livelihoods in populations dependent on agricultural activity. Moreover, the context of enormous social and economic instability in Afghanistan has put pressure on outdoor workers, urban areas, the efficiency of the country's energy infrastructure, and, finally, human health, increasing the risk of heat-related diseases and mortality. In the case of Cambodia, this situation translates into an impact on food security and human health in a country characterized by low incomes, high mortality rates, and inefficient adaptation capacities. Regarding the countries considered consensually less vulnerable to climate change by the four indices compared to the rest of the study population, Qatar and China in the Asian continent can be highlighted. In the Central Africa region, characterized by high susceptibility to the hazards of global warming, it is possible to observe that Gabon is attributed low vulnerability. Moving to the western side of the map, in Latin America, Argentina and Uruguay emerge with small standard deviations. Finally, Nicaragua, Jamaica, Trinidad and Tobago, and Barbados in Central America and the Caribbean can also be distinguished.

Observing the dark-colored geographic areas, the map underscores the lack of consensus regarding the vulnerability of a block of countries located in Central Africa and the Congo Basin – Cameroon, Congo, Democratic Republic of the Congo, Central African Republic – as well as Ivory Coast, a nation located in the western African region. It is also possible to observe, with a similar pattern, the case of Myanmar in Southeast Asia. The significant standard deviation between the vulnerability rankings of this cluster of countries is due to the fact that the WRI, INFORM, and ND-GAIN indices attribute high vulnerability rankings, while the EVI index does not assign such a severe vulnerability scenario for the same region. Finally, the cluster consisting of Colombia and Guatemala, nations located in South America and Central America, respectively, and the cases of Lebanon and Turkey in the Middle East and Eurasia, can be identified. In these cases, the INFORM and WRI indices classify the countries as highly vulnerable, while the EVI and ND-GAIN do not express the same critical level of vulnerability.

In Central Asia, it is also possible to identify a group of countries with significantly discrepant vulnerability rankings, such as Turkmenistan, Kyrgyzstan, Kazakhstan, and, further east, Mongolia. It is also noteworthy, in the Arabian Peninsula, the case of the United Arab Emirates. Unlike the cases described for countries located on the African continent, the EVI index positions these economies in contexts of high vulnerability, while the other indices present in this study diverge from this scenario, considering that the Asian region is more prepared for various climate phenomena. In the same vein, the variation in rankings of two countries northeast of South America – Guyana and Suriname – with the EVI index attributing positions of high vulnerability. Finally, a group of countries stands out, such as the Island States like Micronesia, St. Kitts and Nevis, Antigua and

Barbuda, Maldives, Seychelles, and Tonga. The EVI index assigns high vulnerability rankings to these countries, while the INFORM and WRI place them among the least vulnerable developing countries in the sample. In the case of Maldives, Tonga, and the Micronesian archipelago, the ND-GAIN index also positions these states as highly vulnerable to the impacts of Climate Change.

In summary, from the analysis of the correlation test results and the study of the dispersion of rankings, a clear divergence between the EVI index and the ND-GAIN, INFORM, and WRI indices can be identified. Firstly, low correlation coefficients are observed between the EVI index and the other vulnerability assessment tools, compared to the high correlation coefficients between the other three indices. Regarding the analysis of dispersion of rankings, in cases where there is a significant standard deviation between vulnerability rankings, this is mostly due to the fact that the rankings assigned by the EVI index are very discrepant compared to the positions assigned by the other indices, namely, concerning the rankings of the INFORM and WRI. It is considered that the divergence of results between the indices essentially results from the composition of the vulnerability component of each index being constituted by different indicators, which determines that there are different factors to level and weigh the level of vulnerability of a country to climate change. Analyzing the case of Cameroon and Colombia, the INFORM and WRI classify these countries as highly vulnerable while the EVI index does not attribute the same severity, despite being extremely unequal countries from a social and economic standpoint, dealing with serious and complex migratory crises and suffering from armed conflicts. From another perspective, the EVI index positions the archipelagos of St. Kitts and Nevis and the Maldives as very vulnerable, two economies highly dependent on tourism, as well as Turkmenistan, an economy specialized in natural resources – such as natural gas and oil – which significantly depends on its export. However, the ND-GAIN, INFORM, and WRI indices indicate low or very low vulnerability for these three countries.

Conclusion

There is an increasingly recognized need for a cohesive and transparent global response to the problem of climate change, one that strengthens measures applied to date. The progressive accumulation of greenhouse gases in the atmosphere and the growing costs associated with global warming and other extreme weather phenomena demand that any strategy for climate change mitigation or adaptation includes economic policy instruments capable of changing industrial development patterns, income distribution, and long-term energy use. It also requires taking into account all the connections between scientific uncertainty, international political relations, and economic decision-making. For example, for an objective application of climate financing instruments, it is necessary to understand the relationships between the dynamic factors responsible for the degree of vulnerability of a country, region, or community to climate change impacts. Thus, international climate policy and economic aid decisions are increasingly based on information provided by multidimensional indices on a global scale, allowing for comparison and classification among the various countries of the world. However, several authors have identified a theoretical, practical, and political gap related to the inconsistency between

the results of the assessment of various indices, raising doubts about their applicability in determining the allocation of funding to high-risk or more vulnerable countries.

Therefore, this study contributed to clarifying how the main vulnerability indices recognized by the scientific and international community differ in terms of results. It also identified which components of climate indices influence this dispersion of vulnerability rankings among the countries in the sample. Regarding the research question "To what extent are multidimensional indices associated with climate change consistent with each other in classifying the vulnerability of developing countries?", the results of the statistical analysis show that the four vulnerability indices are relatively consistent in terms of their linear relationship. However, the intensity of correlations varies considerably between pairs of indices, suggesting that each index may emphasize certain aspects of vulnerability more strongly than others. Thus, it can be observed that the bivariate analysis between the INFORM and WRI indices, as well as the relationship between the distributions of the ND-GAIN and INFORM indices, show strong correlations, demonstrating that, in these pairs, the distributions of vulnerability scores behave more identically compared to the EVI index. Similarly, the dispersion analysis confirms the lack of consensus on the classification of the most vulnerable developing countries to climate change. The most noticeable cases, where the standard deviation is high, reinforce that the choice of index can have a significant impact on vulnerability rankings. These differences can be attributed to the different methodologies adopted by each index and the different emphasis placed on certain indicators. As was observed, the choice of indicators that constitute each index by each institution contributes to the divergence between the vulnerability rankings of the countries in the sample. While some indices consider the distinction between structural and non-structural factors that contribute to increased vulnerability associated with climate change, others include, without distinction, exogenous and endogenous factors. Another aspect that stands out is the fact that the representative component of vulnerability in each of the climate indices presents a distinct definition, as it is composed of different variables.

In conclusion, through the analysis of vulnerability indices associated with climate change, it can be considered that there are significant relationships between them, corroborating that they are relevant instruments for assessing and monitoring the vulnerability of developing countries. However, due to the enormous diversity in the vulnerability components of each index, it is essential to consider their limitations. It is inferred, therefore, that the most transparent and ethical method for analyzing the vulnerability of a country, region, or group of people involves, firstly, paying attention to the definition of the objectives, context, and vulnerability parameters to be analyzed, ensuring a good understanding of their conceptual and methodological foundations, and, secondly, selecting the index that best fits the objectives set. Regarding the limitations of this research, it can be highlighted the unavailability of data for all UN developing countries and for a longer period, which would allow for deeper research, producing more representative results and with a long-term perspective on the evolution of vulnerability. On the other hand, due to selection criteria and data availability, only four

multidimensional indices are analyzed. However, there are other vulnerability indices in the scientific literature and used by international institutions.

Finally, it is suggested as future research the development of an index that, in addition to incorporating overlapping dimensions between different indices, also considers structural and non-structural factors that stand out in weighting less consensual indices. Thus, it would be possible to overcome the lack of consensus and offer a more complete view of vulnerability associated with climate change. The characteristics of indices with higher correlations between their internal dimensions can be combined to create a more comprehensive and holistic measure of vulnerability. Furthermore, it is essential to consider regional particularities and country contexts, complementing vulnerability studies with qualitative analyses and case studies. This will allow for more informed and effective decisions to address the challenges posed by climate change in different regions of the world. Collaboration between experts, international organizations, and governments is essential to promote a robust and efficient index capable of guiding strategies to respond to the climate crisis.

REFERENCES

- AghaKouchak, A., Chiang, F., Huning, L. S., Love, C. A., Mallakpour, I., Mazdiyasi, O., Moftakhari, H., Papalexioiu, S. M., Ragno, E., & Sadegh, M. (2020). Climate Extremes and Compound Hazards in a Warming World. *Annual Review of Earth and Planetary Sciences*, 48(1), 519–548. <https://doi.org/10.1146/annurev-earth-071719-055228>
- Ahsan, Md. N., & Warner, J. (2014). The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks—A case study in the south-western coastal Bangladesh. *International Journal of Disaster Risk Reduction*, 8, 32–49. <https://doi.org/10.1016/j.ijdrr.2013.12.009>
- Angeon, V., & Bates, S. (2014). Reviewing Composite Vulnerability and Resilience Indexes: A Sustainable Approach and Application (SSRN Scholarly Paper 2437980). <https://doi.org/10.2139/ssrn.2437980>
- Arent, D. J., Tol, R. S., Faust, E., Hella, J. P., Kumar, S., Strzepek, K. M., ... & Ngeh, J. (2015). Key economic sectors and services. *Climate change 2014 impacts, adaptation and vulnerability: Part a: Global and sectoral aspects*, 659-708.
- AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability—IPCC. (2014). Obtido 11 de janeiro de 2023, de <https://www.ipcc.ch/report/ar5/wg2/>
- Assa, J., & Meddeb, R. (2021). Towards a Multidimensional Vulnerability Index. <https://doi.org/10.13140/RG.2.2.17634.45763>
- Baarsch, F., Granadillos, J. R., Hare, W., Knaus, M., Krapp, M., Schaeffer, M., & Lotze-Campen, H. (2020). The impact of climate change on incomes and convergence in Africa. *World Development*, 126, 104699. <https://doi.org/10.1016/j.worlddev.2019.104699>

- Baloch, M. A., Danish, Khan, S. U.-D., & Ulucak, Z. Ş. (2020). Poverty and vulnerability of environmental degradation in Sub-Saharan African countries: What causes what? *Structural Change and Economic Dynamics*, 54, 143–149. <https://doi.org/10.1016/j.strueco.2020.04.007>
- Beckerman, W. (1992) Economic Growth and the Environment Whose Growth Whose Environment *World Development*, 20, 481-496. - References—Scientific Research Publishing.[https://www.scirp.org/\(S\(i43dyn45teexjx455qlt3d2q\)\)/reference/ReferencesPapers.aspx?ReferencelD=1901312](https://www.scirp.org/(S(i43dyn45teexjx455qlt3d2q))/reference/ReferencesPapers.aspx?ReferencelD=1901312)
- Below, T., Mutabazi, K., Kirschke, D., Franke, C., Sieber, S., Siebert, R., & Tscherning, K. (2012). Can farmers' adaptation to climate change be explained by socio-economic household-level variables? *Global Environmental Change*, 22, 223–235. <https://doi.org/10.1016/j.gloenvcha.2011.11.012>
- Bintanja, R., Oppenheimer, M., Casens, H., & Abspoel, R. (2018, December). Changing climate and the Greenland ice sheet. *Nature Climate Change*, 8(12), 1043-1052. [<https://www.nature>].
- Birkmann, J., Jamshed, A., McMillan, J. M., Feldmeyer, D., Totin, E., Solecki, W., Ibrahim, Z. Z., Roberts, D., Kerr, R. B., Poertner, H.-O., Pelling, M., Djalante, R., Garschagen, M., Leal Filho, W., Guha-Sapir, D., & Alegría, A. (2022). Understanding human vulnerability to climate change: A global perspective on index validation for adaptation planning. *Science of The Total Environment*, 803, 150065. <https://doi.org/10.1016/j.scitotenv.2021.150065>
- Blasiak, R., Spijkers, J., Tokunaga, K., Pittman, J., Yagi, N., & Österblom, H. (2017). Climate change and marine fisheries: Least developed countries top global index of vulnerability. *PLoS ONE*, 12(6), e0179632. <https://doi.org/10.1371/journal.pone.0179632>
- Brien, K., Eriksen, S., Schjolden, A., Nygaard, L., O'Brien, K., & Alfsen, K. (2004). What's in a word? Conflicting interpretations of vulnerability in climate change research. *Climate Policy*, 7.
- Brooks, N. (2003). *Vulnerability, Risk and Adaptation: A Conceptual Framework*. Tyndall Centre for Climate Change Research, Working Paper No, 38.
- Brown, W. G. (1998). Argument in the Greenhouse: The International Economics of Controlling Global Warming. *Environment: Science and Policy for Sustainable Development*, 40(7), 23–23. <https://doi.org/10.1080/00139157.1999.10544287>
- Castells-Quintana, D., Lopez-Uribe, M. del P., & McDermott, T. K. J. (2018). Adaptation to climate change: A review through a development economics lens. *World Development*, 104(C), 183–196.
- CDP, & UN DESA. (2021). *Handbook on the Least Developed Country Category: Inclusion, Graduation and Special Support Measures*, 4th ed. United Nations; United Nations. <https://www.un.org/en/desa/handbook-least-developed-country-category-inclusion-graduation-and-special-support-measures-4th>

- Chen, C., Noble, I., Hellmann, J., Coffee, J., Murillo, M., & Chawla, N. (2023). University of Notre Dame Global Adaptation Initiative: Country Index Technical Report. University of Notre Dame Global Adaptation Initiative.
- Convenção-Quadro das Nações Unidas sobre Alterações Climáticas (1992). Artigo 1. Nações Unidas. <https://unfccc.int/resource/docs/convkp/conveng.pdf>
- Debortoli, N. S., Clark, D. G., Ford, J. D., Sayles, J. S., & Diaconescu, E. P. (2019). An integrative climate change vulnerability index for Arctic aviation and marine transportation. *Nature Communications*, 10(1), Artigo 1. <https://doi.org/10.1038/s41467-019-10347-1>
- Edmonds, H. K., Lovell, J. E., & Lovell, C. A. K. (2020). A new composite climate change vulnerability index. *Ecological Indicators*, 117, 106529. <https://doi.org/10.1016/j.ecolind.2020.106529>
- Field, C. B., Barros, V. R., Dokken, D. J., & Mach, K. J. (2014). AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability — IPCC. <https://www.ipcc.ch/report/ar5/wg2/>
- Garschagen, M., Doshi, D., Reith, J., & Hagenlocher, M. (2021). Global patterns of disaster and climate risk—An analysis of the consistency of leading index-based assessments and their results. *Climatic Change*, 169(1), 11. <https://doi.org/10.1007/s10584-021-03209-7>
- Gumel, D. Y. (2022). Assessing Climate Change Vulnerability: A Conceptual and Theoretical Review (SSRN Scholarly Paper 4043765). <https://papers.ssrn.com/abstract=4043765>
- Hallegatte, S., Vogt-Schilb, A., Bangalore, M., & Rozenberg, J. (2016). *Unbreakable: Building the Resilience of the Poor in the Face of Natural Disasters*. World Bank Publications.
- Haner, J. (2016, July 3). Facing Rising Seas, a Pacific Island Nation Considers Retreat. *The New York Times*. <https://www.nytimes.com/2016/07/03/world/asia/climate-change-kiribati.html>
- Harris, J., Roach, B., & Codur, A.-M. (2007). *The Economics of Global Climate Change*. 70.
- Hinkel, J. (2011). «Indicators of vulnerability and adaptive capacity»: Towards a clarification of the science-policy interface. *Global Environmental Change*, 21, 198–208. <https://doi.org/10.1016/j.gloenvcha.2010.08.002>
- Huggel, C., Mueller-Janichen, D., Ibrahimov, M., Frey, H., Xu, J., Gruetzner, C., ... & Shulmeister, J. (2021, January). Ice loss and thermal effects in mountain regions: A global assessment. *Nature Geoscience*, 14(1), 74-81. <https://www.nature.com/collections/ababhihdce>
- Human Rights Watch. (2023, January 20). *World Report 2023: Rights trends in Colombia*. Retrieved September 4, 2023, from <https://www.hrw.org/world-report/2023/country-chapters/colombia>
- Intergovernmental Oceanographic Commission (IOC) of UNESCO. (2020). *Global Ocean Observing System (GOOS) Report on the State of the Ocean (2020)*. <https://gcrmn.net/2020-report/>

Intergovernmental Panel on Climate Change (IPCC). (2021). Climate Change 2021: The Physical Science Basis. <https://www.ipcc.ch/>

International Institute of Tropical Agriculture (IITA). (2016). Cassava in tropical Africa: A reference manual. https://www.iita.org/wp-content/uploads/2016/06/Cassava_in_tropical_Africa_a_reference_manual_1990.pdf

Keen, S. (2022). The appallingly bad neoclassical economics of climate change. In *Economics and Climate Emergency* (pp. 79-107). Routledge.

Kocharekar, R. (2023). The response of the international economic architecture to climate change. Royal Institute of International Affairs. <https://doi.org/10.55317/9781784135447>

Laitonjam, N. (2018). Vulnerability to Climate Change: Review of Conceptual Framework. *ECONOMIC AFFAIRS*, 63. <https://doi.org/10.30954/0424-2513.2.2018.25>

Light, J. G., & Warner, W. J. (1983). *Statistics for Social Scientists*. Obtido 21 de agosto de 2023, de <https://journals.sagepub.com/doi/abs/10.1177/002076408302900313>

Luers, A. L. (2005). The surface of vulnerability: An analytical framework for examining environmental change. *Global Environmental Change*, 15(3), 214–223. <https://doi.org/10.1016/j.gloenvcha.2005.04.003>

Malone, E. L., & Engle, N. L. (2011). Evaluating regional vulnerability to climate change: Purposes and methods—Malone—2011—WIREs Climate Change—Wiley Online Library. <https://wires.onlinelibrary.wiley.com/doi/abs/10.1002/wcc.116>

Marin-Ferrer, Vernaccini, & Poljansek. (2017). *INFORM > INFORM Risk > Methodology*. <https://drmkc.jrc.ec.europa.eu/inform-index/INFORM-Risk/Methodology>

Mastrandrea, M. D., Heller, N. E., Root, T. L., & Schneider, S. H. (2010). Bridging the gap: Linking climate-impacts research with adaptation planning and management. *Climatic Change*, 100(1), 87–101. <https://doi.org/10.1007/s10584-010-9827-4>

McIntosh, R., & Becker, A. (2019). Expert evaluation of open-data indicators of seaport vulnerability to climate and extreme weather impacts for U.S. North Atlantic ports. *Marine Affairs Faculty Publications*. <https://doi.org/10.1016/j.ocecoaman.2019.104911>

McMichael, C., Barnett, J., & McMichael, A. J. (2012). An Ill Wind? *Climate Change, Migration, and Health*. *Environmental Health Perspectives*, 120(5), 646–654. <https://doi.org/10.1289/ehp.1104375>

Mendoza, M. E., Naret, H., Ballaran Jr, V., & Arias, J. K. (2014). Assessing vulnerability to climate change impacts in Cambodia, the Philippines and Vietnam: An analysis at the commune and household level. *Journal of Environmental Science and Management*, 17(2).

- Michonski, K., & Levi, M. A. (2010). Harnessing International Institutions to Address Climate Change. Council on Foreign Relations. <https://www.jstor.org/stable/resrep00271>
- Miola, A., & Simonet, C. (2014). Concepts and metrics for climate change risk and development: Towards an index for climate resilient development. Publications Office of the European Union. <https://data.europa.eu/doi/10.2788/44142>
- Nelson, D., Adger, W., & Brown, K. (2007). Adaptation to Environmental Change: Contributions of a Resilience Framework. Annual Review of Environment and Resources, 32. <https://doi.org/10.1146/annurev.energy.32.051807.090348>
- Nguyen, T. T. X., Bonetti, J., Rogers, K., & Woodroffe, C. D. (2016). Indicator-based assessment of climate-change impacts on coasts: A review of concepts, methodological approaches and vulnerability indices. Ocean & Coastal Management, 123, 18–43. <https://doi.org/10.1016/j.ocecoaman.2015.11.022>
- Notre Dame Global Adaptation Initiative. (2023). Country Index // Notre Dame Global Adaptation Initiative // University of Notre Dame. Notre Dame Global Adaptation Initiative. Obtido 5 de janeiro de 2023, de <https://gain.nd.edu/our-work/country-index/>
- OCHA (2022, July 13). Saint Kitts & Nevis: Country Profile. Retrieved September 4, 2023, from <https://reliefweb.int/report/saint-kitts-and-nevis/saint-kitts-nevis-country-profile-may-2022>
- OCHA (2023, August 1). Afghanistan: The alarming effects of climate change. Retrieved September 4, 2023, from <https://www.unocha.org/news/afghanistan-alarming-effects-climate-change>
- Oppenheimer, M., Glavovic, B., Ragoonaden, V., & Leal, W. (2019, March 15). Sea level rise and implications for coastal settlements. Science Advances, 5(3), eaau3258. [invalid URL removed]
- Organization (WMO), W. M., & World Meteorological Organization (WMO). (2022). State of the Global Climate 2021 (WMO-No. 1290). WMO.
- Paavola, J. (2008). Livelihoods, vulnerability and adaptation to climate change in Morogoro, Tanzania. Environmental Science & Policy, 11(7), 642–654. <https://doi.org/10.1016/j.envsci.2008.06.002>
- Rijkswaterstaat. (n.d.). Water - Rijkswaterstaat. <https://www.rijkswaterstaat.nl/en/expertise/water>
- Roukounis, C. N., & Tsihrintzis, V. A. (2022). Indices of Coastal Vulnerability to Climate Change: A Review. Environmental Processes, 9(2), 29. <https://doi.org/10.1007/s40710-022-00577-9>
- Sarkodie, S. A., & Strezov, V. (2019). Economic, social and governance adaptation readiness for mitigation of climate change vulnerability: Evidence from 192 countries. Science of The Total Environment, 656, 150–164. <https://doi.org/10.1016/j.scitotenv.2018.11.349>

- Sheehan, T., Min, E., & Hess, J. (2023). A Comparison of Hazard Vulnerability Indexes for Washington State. *Journal of Homeland Security and Emergency Management*. <https://doi.org/10.1515/jhsem-2021-0066>
- Smith, J. B., Schellnhuber, H. J., & Mirza, M. M. Q. (2001). Vulnerability to Climate Change and Reasons for Concern: A Synthesis — IPCC. <https://www.ipcc.ch/report/ar3/wg2/chapter-19-vulnerability-to-climate-change-and-reasons-for-concern-a-synthesis/>
- Smith, J. W., Anderson, D. H., & Moore, R. L. (2012). Social Capital, Place Meanings, and Perceived Resilience to Climate Change*: Social Capital, Place Meanings, & Perceived Resilience. *Rural Sociology*, 77(3), 380–407. <https://doi.org/10.1111/j.1549-0831.2012.00082.x>
- Stern, N. (2006). Stern review: The economics of climate change. <https://www.osti.gov/etdeweb/biblio/20838308>
- Tol, R. S. J. (2018). The Economic Impacts of Climate Change. *Review of Environmental Economics and Policy*, 12(1), 4–25. <https://doi.org/10.1093/reep/rex027>
- Turrall, H., Burke, J., & Faurès, J. M. (2011). Climate change, water and food security. *Water Reports*, No.36. <https://www.cabdirect.org/cabdirect/abstract/20133014321>
- UNDP (2023). The Climate Dictionary, from <https://www.undp.org/publications/climate-dictionary>
- UNHCR. (2021). West and Central Africa. *Global Focus*. Retrieved September 4, 2023, from <https://reporting.unhcr.org/globalreport/west-and-central-africa>
- United Nations Development Programme. (2015). Mapping Climate Change Vulnerability. Obtido 5 de janeiro de 2023, de <https://www.undp.org/publications/mapping-climate-change-vulnerability>
- United Nations Framework Convention on Climate Change (UNFCCC). (n.d.). <https://unfccc.int/>
- United Nations (2023). Least Developed Country Category. <https://www.un.org/en/conferences/least-developed-countries>.
- UN-OHRLLS. (2021). Report: Multidimensional Vulnerability Index: Potential Development and Uses | Office of the High Representative for the Least Developed Countries, Landlocked Developing Countries and Small Island Developing States. <https://www.un.org/ohrlls/news/report-multidimensional-vulnerability-index>
- Volkart, K., Mutel, C. L., & Panos, E. (2018). Integrating life cycle assessment and energy system modelling: Methodology and application to the world energy scenarios. *Sustainable Production and Consumption*, 16, 121–133. <https://doi.org/10.1016/j.spc.2018.07.001>
- Ward, P., & Shively, G. (2012). Vulnerability, Income Growth and Climate Change. *World Development*, 40(5), 916–927. <https://doi.org/10.1016/j.worlddev.2011.11.015>

WBG & ADB (2021). Climate Risk Country Profile: Afghanistan.
<https://www.adb.org/sites/default/files/publication/660566/climate-risk-country-profile-afghanistan.pdf>

WBG & ADB (2021). Climate Risk Country Profile: Cambodia.
<https://www.adb.org/publications/climate-risk-country-profile-cambodia>

WBG (2021). Climate Risk Country Profile: Colombia.
https://climateknowledgeportal.worldbank.org/sites/default/files/2021-07/15520-B_Colombia%20Country%20Profile-WEB%20%283%29.pdf

WBG & ADB (2021). Climate Risk Country Profile: Maldives.
<https://www.adb.org/sites/default/files/publication/672361/climate-risk-country-profile-maldives.pdf>

WBG & ADB (2021). Climate Risk Country Profile: Turkmenistan.
<https://www.adb.org/sites/default/files/publication/707601/climate-risk-country-profile-turkmenistan.pdf>

West and Central Africa. (2022). Global Focus. Obtido 21 de agosto de 2023, de
<https://reporting.unhcr.org/globalreport/west-and-central-africa>

World Bank Group (2023, September 4). The World Bank in the Caribbean: Overview. Retrieved September 4, 2023, from <https://www.worldbank.org/en/country/caribbean/overview>

World Bank Group (2023). World Development Indicators. <https://data.worldbank.org/>.

World Bank. (2023, September 4). The World Bank in Cameroon: Overview. Retrieved September 4, 2023, <https://www.worldbank.org/en/country/cameroon/overview>

World Health Organization, & Research, A. for H. P. and S. (2017). Primary health care systems (primasys): Case study from Cameroon: abridged version (WHO/HIS/HSR/17.20). World Health Organization. <https://apps.who.int/iris/handle/10665/341178>

World Meteorological Organization. (n.d.). Early Warning Systems. <https://wmo.int/topics/early-warning-system>

World Risk Report. (2022). WorldRiskReport 2022 - Focus: Digitalization - World | ReliefWeb. <https://reliefweb.int/report/world/worldriskreport-2022-focus-digitalization~>

Annex

ANNEX I - MAPPING OF INDICES ASSOCIATED WITH CLIMATE CHANGE

Table III - Survey of vulnerability indices associated with climate change.

<i>Index</i>	<i>Source</i>
Climate Change Performance Index	Burck, J., Hagen, U., Hühne, N., Nascimento, L., & Bals, C. (2019). <i>Climate change performance index</i> . Bonn: Germanwatch, NewClimate Institute and Climate Action Network.
Climate vulnerability index	Sullivan, C., & Meigh, J. (2005). <i>Targeting attention on local vulnerabilities using an integrated index approach: the example of the climate vulnerability index</i> . <i>Water Science and Technology</i> , 51(5), 69-78.
Climate Vulnerability Monitor	Scantlebury, B., & Ahmed, K. (2022). <i>Climate Vulnerability Monitor: A Planet on Fire Type: eBook Release date: 2 November 2022</i> .
Composite climate change vulnerability index	Edmonds, H. K., Lovell, J. E., & Lovell, C. A. K. (2020). <i>A new composite climate change vulnerability index</i> . <i>Ecological Indicators</i> , 117, 106529.
Composite socio-economic index	Sahana, M., Rehman, S., Paul, A. K., & Sajjad, H. (2021). <i>Assessing socio-economic vulnerability to climate change-induced disasters: evidence from Sundarban Biosphere Reserve, India</i> . <i>Geology, Ecology, and Landscapes</i> , 5(1), 40-52.
Economic and Environmental Vulnerability Index (EVI)	United Nations Committee for Development Policy (UNCDP)
Economic vulnerability index	Briguglio, L., & Galea, W. (2003). <i>Updating and augmenting the economic vulnerability index</i> .
Environmental Performance Index	Yale University (Yale Center for Environmental Law and Policy) and Columbia University (Center for the International Earth Science Information Network) in collaboration with the World Economic Forum and the Joint Research Centre of the European Commission.
Environmental Sustainability Index	Yale Center for Environmental Law and Policy and Center for International Earth Science Information Network (CIESIN). (2001). <i>2001 Environmental Sustainability Index (ESI): An Initiative of the Global Leaders for Tomorrow Environment Task Force</i> .
Environmental Vulnerability Index	South Pacific Applied Geoscience Commission
Global Climate Risk Index	Eckstein, D., Künzel, V., & Schäfer, L. (2021). <i>The global climate risk index 2021</i> . Bonn: Germanwatch.
Global Risk and Vulnerability Index	Peduzzi, P., Dao, H., & Herold, C. (2002). <i>Global risk and vulnerability index. Trends per Year (GRAVITY). Phase II: Development, analysis and results</i> . United Nations Development Programme. Bureau of Crisis Prevention & Recovery (UNDP/BCPR), Geneva.
Hoosier Resilience Index	Environmental Resilience Institute
Index of social vulnerability to climate change for Africa	Vincent, K. (2004). <i>Creating an index of social vulnerability to climate change for Africa</i> . Tyndall Center for Climate Change Research. Working Paper, 56(41), 1-50.
INFORM Risk Index	Joint Research Centre (JRC) of the European Commission
Livelihood vulnerability index	Shah, K. U., Dulal, H. B., Johnson, C., & Baptiste, A. (2013). <i>Understanding livelihood vulnerability to climate change: Applying the livelihood vulnerability index in Trinidad and Tobago</i> . <i>Geoforum</i> , 47, 125-137.
Livelihood Vulnerability Index (LVI) and the Livelihood Effect Index (LEI).	Khajuria, A., & Ravindranath, N. H. (2012). <i>Climate change vulnerability assessment: Approaches DPSIR framework and vulnerability index</i> . <i>J. Earth Sci. Clim. Chang</i> , 3, 109.

Maplecroft CCVI	Maplecroft
Multidimensional Vulnerability Index	<i>Assa, J., & Meddeb, R. (2021). Towards a multidimensional vulnerability index. United Nations Development Programme. Retrieved April, 14, 2023.</i>
Multidimensional Vulnerability Index	<i>Ram, J., Cotton, J., Frederick, R., & Elliott, W. (2019). Measuring vulnerability: a multidimensional vulnerability index for the Caribbean (No. 2019/01). CDB Working Paper.</i>
ND-GAIN Country Index	Notre Dame Global Adaptation Initiative
Predictive indicators of vulnerability	<i>Adger, W. N., & Agnew, M. (2004). New indicators of vulnerability and adaptive capacity (Vol. 122). Norwich: Tyndall Centre for Climate Change Research.</i>
Resilience Indicators Model (VRIM)	<i>Ibarrarán, M. E., Malone, E. L., & Brenkert, A. L. (2010). Climate change vulnerability and resilience: Current status and trends for Mexico. Environment, Development and Sustainability, 12, 365-388.</i>
Resilient Connecticut CCVI	Connecticut Institute for Resilience and Climate Adaptation
Retrospective Economic Vulnerability Index	Foundation for Studies and Research on International Development (FERDI)
Risk indicators for increasing weather-related disasters, sea-level rise, and loss of agricultural productivity.	<i>Wheeler, D. (2011). Quantifying vulnerability to climate change: implications for adaptation assistance. Center for Global Development Working Paper, (240).</i>
Set of indicators of vulnerability and capacity to adapt to climate variability	<i>Brooks, N., Adger, W. N., & Kelly, P. M. (2005). The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. Global environmental change, 15(2), 151-163.</i>
Social Vulnerability Index	<i>Cutter, S. L., Boruff, B. J., & Shirley, W. L. (2012). Social vulnerability to environmental hazards. In Hazards vulnerability and environmental justice (pp. 143-160). Routledge.</i>
Socioeconomic vulnerability index	<i>Ahsan, M. N., & Warner, J. (2014). The socioeconomic vulnerability index: A pragmatic approach for assessing climate change led risks—A case study in the south-western coastal Bangladesh. International Journal of Disaster Risk Reduction, 8, 32-49.</i>
Socioeconomic vulnerability indicator framework (SVIF)	<i>Jhan, H. T., Ballinger, R., Jaleel, A., & Ting, K. H. (2020). Development and application of a socioeconomic vulnerability indicator framework (SVIF) for local climate change adaptation in Taiwan. Sustainability, 12(4), 1585.</i>
The Commonwealth Universal Vulnerability Index	<i>Secretariat, C. (2021). The Commonwealth Universal Vulnerability Index For a Global Consensus on the Definition and Measurement of Vulnerability. The Commonwealth Secretariat, London.</i>
The Livelihood Vulnerability Index	<i>Hahn, M. B., Riederer, A. M., & Foster, S. O. (2009). The Livelihood Vulnerability Index: A pragmatic approach to assessing risks from climate variability and change—A case study in Mozambique. Global environmental change, 19(1), 74-88.</i>
Vulnerability index	<i>Binita, K. C., Shepherd, J. M., & Gaither, C. J. (2015). Climate change vulnerability assessment in Georgia. Applied Geography, 62, 62-74.</i>
Vulnerability Index	<i>Heltberg, R., & Bonch-Osmolovskiy, M. (2011). Mapping vulnerability to climate change. World Bank policy research working paper, (5554).</i>
World Risk Index	<i>Garschagen, M., Hagenlocher, M., Comes, M., Dubbert, M., Sabelfeld, R., Lee, Y. J., ... & Birkmann, J. (2016). World risk report 2016.</i>

Source: Comprehensive survey of vulnerability indices associated with climate change.

Table IV. Design and data processing methods for climate change indices.

Index	Missing Data Treatment	Outlier Treatment	Multicollinearity Treatment	Normalization of Components	Indicator Weighting	Aggregation Method	Validation Approach
Economic and Environmental Vulnerability Index (EVI)	-	Min-Max procedure to reduce the impact of outliers.	-	Min-Max procedure ensuring all indicator values range between 0 and 100	Equal weighting	Simple arithmetic mean	-
Notre Dame Global Adaptation Index (ND-GAIN)	1st Linear interpolation. 2nd The indicator is not considered in the averaging process.	Extraction of the 10th or 90th percentile of strongly skewed indicators	-	Linear Min-Max procedure [0-1] applied to all indicators (when using thresholds)	Equal weighting	Simple arithmetic mean	-
INFORM Risk Index (INFORM)	1st Introduction of data from the most recent year available within a 5-year period	1) Box Plot based on interquartile range	Correlation analysis	Linear Min-Max procedure [0-10] applied to all indicators	Equal weighting	Application of arithmetic and geometric mean	Sensitivity analysis
	2nd Introduction of more than one indicator for the same component	2) Interactive process based on skewness and kurtosis					
WRI Risk Index (WRI)	Application of an algorithm that efficiently estimates missing values	Transformation of Ordered Quantiles, requiring no further outlier post-treatment	Correlation analysis	Min-Max procedure ensuring all indices range between 0 and 100	Equal weighting	Unweighted geometric mean	Sensitivity analysis

Source: CDP & UN DESA, 2021; ND-GAIN Country Index Technical Report, 2023; Marin-Ferrer et al., 2017; World Risk Report, 2022

ANNEX II - COMPOSITION OF THE VULNERABILITY COMPONENTS OF THE INDICES

Table V. Composition of the EVI - Economic and Environmental Vulnerability Index.

Index	Dimensions	Indicators
EVI Index	Economic Vulnerability	Share of agriculture, forestry, and fisheries in GDP
		Remoteness and Landlockedness
		Merchandise export concentration
		Instability of exports of goods and services
	Environmental Vulnerability	Share of population in low-elevated coastal areas
		Share of population living in drylands
		Instability of agricultural production
	Victims of disasters	

Source: CDP & UN DESA, 2021

Table VI. Composition of the vulnerability dimension of the ND-GAIN Index.

	Sector	ND-GAIN Vulnerability Indicators		
		Exposure Component	Sensitivity Component	Adaptive Capacity Component
<i>ND-GAIN Index</i>	Food	Projected change of cereal yields	Food import dependency	Agricultural Capacity (Fertilizers, Irrigation, Pesticides, Tractor Use)
		Projected population change	Rural population	Child malnutrition
	Water	Projected change of annual runoff	Fresh water withdrawal rate	Access to reliable drinking water
		Planned change in annual groundwater recharge.	Water dependency ratio	Dam capacity
	Health	Projected change in deaths from climate change-induced diseases.	Slum population	Medical staff (doctors, nurses and midwives)
		Projected Change in Vector Borne Disease	Dependence on external resources for health services	Access to improved sanitation facilities
	Ecosystem Services	Projected change of biome distribution	Dependence on natural capital	Protected Biomes
		Expected changes to marine biodiversity	Ecological footprint	Engagement in international environmental conventions
	Human Habitat	Projected change of warm period	Urban concentration	Quality of trade and transport-related infrastructure
		Projected change of flood hazard	Age dependency ratio	Paved roads
	Infrastructure	Planned change in hydropower generation capacity	Dependence on imported energy	Electricity access
		Projected change of sea level rise impacts	Population living under 5m above sea level	Disaster preparedness

Source: ND-GAIN Country Index Technical Report, 2015

Table VII. Composition of the vulnerability dimension of the INFORM Index.

	Categories	Components	Indicators
<i>INFORM Index</i>	Socio-economic vulnerability	Development & Deprivation	Human Development Index
			Multidimensional Poverty Index
		Inequality	Gender Inequality Index
			Income Gini coefficient - Inequality in income or consumption
		Aid dependency	Public aid per capita
			Net ODA received (% of GNI)
	Volume of remittances as a percentage of total GDP (%)		
	Vulnerable Groups	Uprooted People	Refugees and asylum seekers by country of asylum
			Internally Displaced Persons (IDPs)
			Repatriated refugees
		Other Vulnerable Groups	Prevalence of HIV/AIDS (> 15 years)
			Prevalence of tuberculosis
			Malaria mortality rate
			Children under weight
			Child mortality
			Number of people affected by Natural Disasters in the last three years (& of total population)
			Prevalence of undernourishment
			Average dietary energy supply adequacy
Domestic Food Price Index			
Domestic Food Price Volatility Index			

Source: Marin-Ferrer et al., 2017

Table VIII. Composition of the vulnerability dimension of the WRI Index.

	Dimensions	Categories	Indicators
WRI Index	Susceptibility	Socio-economic development	Prospects for a healthy life
			Perspectives on education and training
			Prospects for high standards of living
			Perspectives of self-reliance
		Socio-economic deprivation	Lack of access to civilian infrastructure
			Lack of access to energy infrastructure
			Lack of access to communication technologies
			Lack of food security
		Social disparities	Economic disparities
			Demographic disparities
			Gender Disparities
		Vulnerable populations due to violence, conflicts and disasters	Refugees, asylum seekers, returnees and other displaced persons
			Internally displaced persons due to natural disasters
			Internally displaced persons due to violence and conflict
		Vulnerable populations due to diseases and epidemics	
	Lack of coping capacities	Recent societal shocks	Recent societal shocks due to natural disasters
			Recent social shocks due to violence and conflict
		State & Government	Democratic principles
			Government Responsibilities
		Healthcare capacities	Staffing Capacity
			Structural capacities
Lack of adaptive capacities	Research and Education	Education dimension	
		Research Dimension	
	Long-Term Health And Deprivation Effects	Long-term private effects	
		Long-term health effects	
	Investment Capacities		

Source: World Risk Report, 2022.

ANNEX III - ANALYSIS OF RESULTS

Table IX. Composition of the vulnerability dimension of the WRI Index.

Vulnerability Index Statistics database
https://docs.google.com/spreadsheets/d/1KzkGEi0NSLGpjtSNai7l_bXOeZ-LRD6f/edit?usp=sharing&ouid=105078304306562129146&rtpof=true&sd=true

Source: CDP & UN DESA, 2021; ND-GAIN Country Index Technical Report, 2023; Marin-Ferrer et al., 2017; World Risk Report, 2022

Table X. Descriptive statistics for the variables "EVI Index", "ND-GAIN Index", "INFORM Index" and "WRI Index".

Descriptive Statistics	EVI Index		ND-GAIN Index		INFORM Index		WRI Index	
	Statistic	Standard Test Statistic	Statistic	Standard Test Statistic	Statistic	Standard Test Statistic	Statistic	Standard Test Statistic
Mean	34,0508	0,30192	47,642	0,25273	42,3619	0,60866	28,1016	0,54221
95% Confidence Interval for Mean	Lower limit		47,1461		41,1674		27,0375	
	Upper limit	34,6433	48,138		43,5564		29,1656	
5% of trimmed mean	33,8627		47,3887		42,2034		27,1576	
Median	32,68		46,72		43		24,51	
Variance	86,143		60,36		350,091		277,819	
Standard Error	9,28132		7,76918		18,71073		16,6679	
Minimum	15,14		32,37		3		2,6	
Maximum	57,62		68,8		89		76,22	
Range	42,48		36,43		86		73,62	
Interquartile Range	13,74		12,33		29		17,17	
Skewness	0,369	0,08	0,398	0,08	-0,003	0,08	0,978	0,08
Kurtosis	-0,732	0,159	-0,576	0,159	-0,741	0,159	0,19	0,159

Source: Database | Vulnerability Index Statistics

Source: Database | Vulnerability Index Statistics.

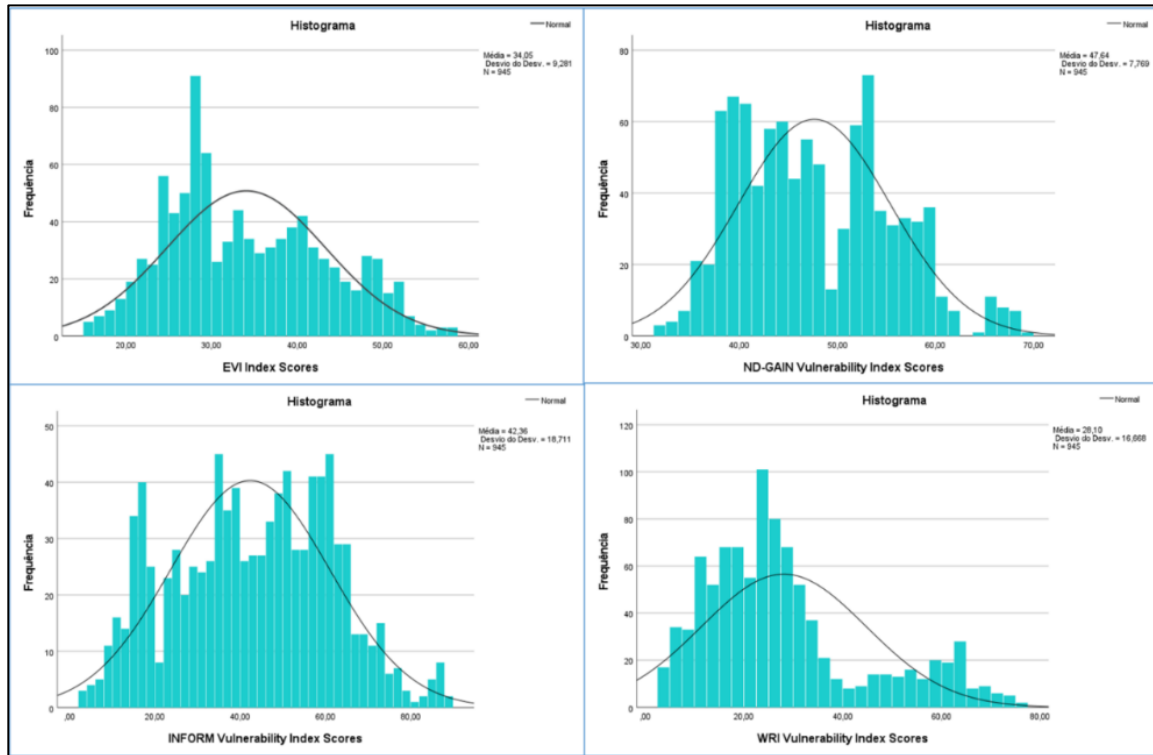


Figure 6 - Frequency distribution of the variables "EVI Index", "ND-GAIN Index", "INFORM Index" and "WRI Index".

Source: Database | Vulnerability Index Statistics.

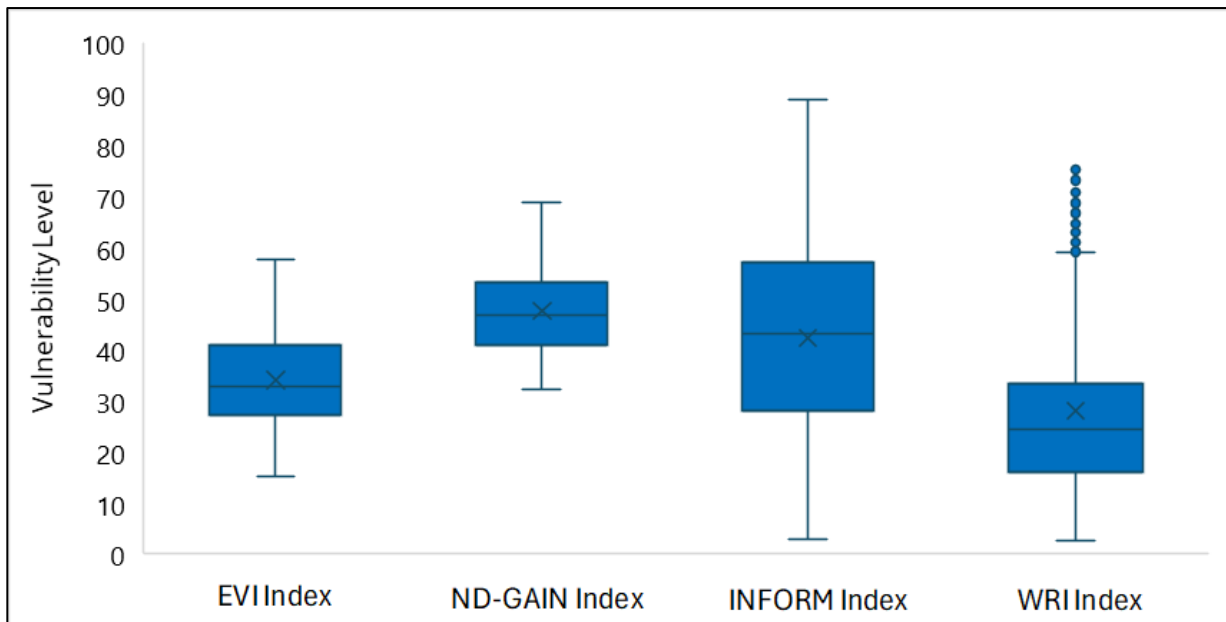


Figure 7 - Variation in the observed data for the "EVI Index", "ND-GAIN Index", "INFORM Index" and "WRI Index" variables.

Source: Database | Vulnerability Index Statistics.

Table XI. Kolmogorov-Smirnov Normality Test

Normality Test			
	Kolmogorov-Smirnov ^a		
	Statistic	gl	Sig.
<i>EVI Index</i>	,105	945	<,001
<i>ND-GAIN Index</i>	,070	945	<,001
<i>INFORM Index</i>	,055	945	<,001
<i>WRI Index</i>	,138	945	<,001

a. Lilliefors Significance Correlation

Source: Database | Vulnerability Index Statistics.

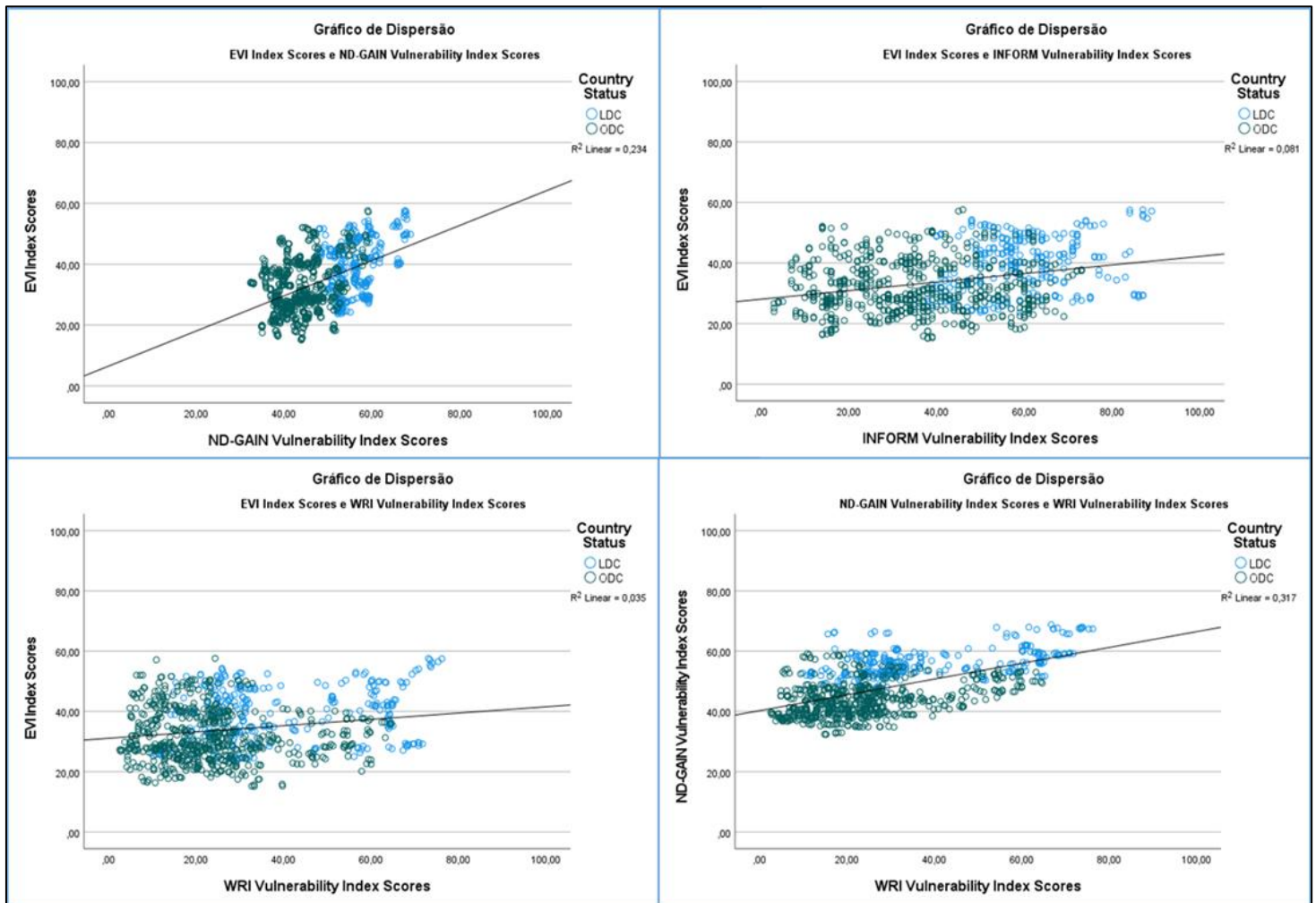


Figure 8 - Scatter plots between vulnerability indices

Source: Database | Vulnerability Index Statistics.