African Climate Hazard Assessment

A Composite Index Assessing National Vulnerability to Climate Change

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Abstract

The study is compiled into a composite index for assessing the climate vulnerability of African nations. By employing a multidimensional approach, the index comprises nine distinctive hazards to examine a country's sensitivity to climate change. These hazards are divided into three categories; acute physical hazards, chronic physical hazards and systemic hazards. This index structure is based on the established three dimensions of vulnerability; expected exposure to hazards, sensitivity to said hazard, and the ability to adapt and cope with the implied effects. The final index was composed of 61 indicators all scaled from 0 to 1, with the final hazard scores and the aggregated total employing higher scores to denote greater climate vulnerability.

The results revealed the significant influence of a country's systemic robustness when responding to climate change impacts, as the inclusion of systemic hazards had a considerable effect on the final aggregated score. The aggregated total score demonstrated how the risk profiles of vulnerable countries vary greatly, and that severe vulnerability to one or few hazards can amount to similar levels of risk as a widespread vulnerability to many different hazards. The index highlights that while some nations may endure more perilous climate change impacts, other nations with lower physical exposure may lack the necessary resources and organisational capacities to handle the risks, rendering them more susceptible. Somalia and South Sudan appeared the most vulnerable, primarily due to the current and historical burden experienced in all three systemic dimensions combined with high hazard exposure. Liberia faced the highest aggregated vulnerability to physical hazards, but its systemic efficiency allows them to better cope with these risks. Meanwhile, countries such as Cabo Verde and Tunisia showcased strong and more resilient systems, making them better placed to respond to climate change impacts.

The index fills a vital role in offering valuable insights into the factors that render African nations vulnerable to climate change which provides guidance on allocating resources for adaptation and mitigation initiatives. It strives to convey the complex and intricate climate change impacts in a transparent and easy to understand manner while remaining relevant and actionable for policymakers. Lowering the threshold for assessing and comparing the vulnerability to climate change can act as a call to action and help further initiate the dialogue on climate change adaptation in Africa. The indicators used in the index can help guide policy-makers and other stakeholders in assessing future risks, find suitable adaptation efforts and track their progress towards climate resilience.

Key words: Composite Index, Climate Vulnerability, Assessment, African Nations, Acute Physical Hazards, Chronic Physical Hazards, Systemic Hazards, Exposure, Multidimensional Approach, Sensitivity, Adaptation, Indicators

Abbreviation list

ACHA	African Climate Hazard Assessment
AIDI	African Infrastructure Development Index
AR5	IPCC's Fifth Assessment Report
AR6	IPCC's Sixth Assessment Report
CMIP	Coupled Model Intercomparison Project
CO2	Carbon Dioxide
COP27	2022 Conference of the Parties of the UNFCCC
DRMKC	European Commission´s Disaster Risk Management Knowledge Centre
DRR	Disaster Risk Reduction
ENSO	El Niño Southern Oscillation
FAO	The Food and Agriculture Organisation
GDP	Gross Domestic Product
GHG	Greenhouse Gas
ICT	Information Communication Technology
IDP	Internally displaced people
ILO	International Labour Organization
IPCC	The Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
JRC	Joint Research Centre (The European Commission)
LECZ	Low-Elevation Coastal Zone
MDG	Millennium Development Goals
NDC	National Determined Contributions
ND-GAIN	Notre Dame Global Adaptation Index
NGFS	Network for Greening the Financial System
OECD	The Organisation for Economic Co-operation and Development
RCP	Representative Concentration Pathway
SDG	Sustainable Development Goals
SIDS	Small Island Developing States
SLR	Sea Level Rise
SPEI	Standardised Precipitation Evapotranspiration Index
SSP	Shared Socioeconomic Pathway
SRTM	The Shuttle Radar Topography Mission (international research
UN	The United Nations
UNDP	United Nations Development Programme
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNHCR	United Nations High Commissioner for Refugees

WGI	World Governance Indicators
WHO	World Health Organisation
WMO	World Meteorological Organisation
WRI	World Resources Institute
WSS	Water and Sanitation Systems

Preface

The research presented in this thesis was carried out at Lund University, Sweden, between January and June 2023. The study was conducted at the Faculty of Environmental and Energy Systems, which is designated to explore the interactions between technology, natural resources, economics, politics, security and development. The thesis was part of a master's in industrial engineering and management.

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André Månberger (Examinator) Associate Senior Lecturer at Lund University.

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1. Introduction

This first section of the report gives a short introduction to the relevance of the subject that is being investigated. It begins by providing a background on the climate change impact of loss and damage, focusing on Africa. The later part of the chapter will introduce climate finance and the current insufficiencies in allocating resources for developing countries to adapt to the impacts of climate change.

1.1 Loss and Damage

As global warming unfolds, the changes in climate will lead to negative impacts and disruptions commonly referred to as *loss and damage*. The term includes economic and non-economic impacts on material and non-material systems (Schäfer, Jorks, Seck, Koulibaly & Diouf 2021). These impacts emerge from unavoidable onset events such as increasing temperatures, rising sea levels and flooding (United Nations Environmental Programme [UNEP] 2022). The effect that climate change has will vary between different regions, both based on the extent of climate changes they are exposed to and the sensitivity to a specific change. This sensitivity is an aggregation of several interacting non-climatic processes and macro trends that shape the ability to respond to the consequences of climate change (Trisos et al. 2022).

Africa faces a unique situation in their socioeconomic, political and environmental context that exacerbate their vulnerability to these climate change impacts. A greater reliance on agriculture, strong urbanisation trends and fragile food and water security makes the region particularly exposed, and the observed loss and damage surpass current and projected adaptation efforts. Climate change is anticipated to negatively affect the well-being of a country, escalate governmental instability and increase the risk of conflicts (Busby, Smith, White & Strange 2013). Meanwhile, existing vulnerability deriving from weak constitutional structures and ongoing conflicts are also critical drivers of climate vulnerability. Armed conflicts destroy livelihoods and economies, making successful climate adaptation impossible (Buhaug 2022). An example of this is the intensifying armed conflict in Sudan, destabilising existing institutions and safety networks for its inhabitants and diluting resources and efforts that deal with the risks caused by climate change. The conflict is also negatively affecting the stability of Sudan's neighbouring countries, which all have been in conflict or serious civil unrest for the past decade (United Nations [UN] 2023a). These large scale disruptions affect the entire region, leaving them more fragile to the damaging effects caused by climate change.

The IPCC emphasises that a greater understanding of the regional climate change impacts in Africa is necessary to assess the required undertakings in adaptation. Table 1 below outlines some of the most crucial impacts of climate change on different sectors in Africa, posing a threat to the health and well-being of millions of people (Trisos et al. 2022). 8 out of the 10 most climate-vulnerable countries in the world are in Africa, each burdened with significant exposure to climate change impacts and low adaptive capacity (O. Somorin, personal communication, March 2023). This severe vulnerability is particularly upsetting, considering that the continent contributes the least to climate change in emissions (United Nations [UN] 2022).

Table 1: Loss and Damage for African Nations divided into sectors (Trisos et al. 2022).

Sector	Loss and damage from climate change
Ecosystems	Local, regional and global extinction Reduced ecosystem goods and services Declining natural coastal protection and habitats Altered ecosystem structure and declining ecosystem functioning Nature-based tourism Biodiversity loss
Water	Declining lake and river resources Reduced hydroelectricity and irrigation Disappearing glaciers Reduced groundwater recharge and salinisation Drought
Food systems	Reduced crop productivity and revenues Increased livestock mortality and price shocks Decreased fodder and pasture availability Reduced fisheries catch and fisher livelihoods
Human settlements and infrastructure	Loss or damage to formal and informal dwellings Damage to transport systems Damage to energy systems Water supply, sanitation, education and health infrastructure Migration
Health	Loss of life Loss of productivity Reduced nutrition
Economy, poverty and livelihoods	Loss of livelihoods, jobs and income Reduced productive land Reduced economic growth and increased inequality Community and involuntary displacement Reduced labour productivity and earning potential Delayed and poorer education progress Reduced tourism Increased urban in-migration
Heritage	Loss of traditional cultures and ways of life Loss of language and knowledge systems Damage to heritage sites

While many studies are performed on a global scale, it is crucial to recognise that the effects of climate change will significantly vary between regions. In general, developing countries will be more vulnerable than their developed counterparts, leading to further exacerbations of inequality between nations. This difference in vulnerability is threefold; developing nations experience different impacts from climate change than developed counterparts, often concentrated on their key sectors. Additionally, the loss and damage from exposure to these climate onsets are, in general, more severe than for developed countries. Finally, more stable and advanced nations show bigger preparedness against changes in temperature, disease spread, food security, and overall resource management allowing stronger adaptive capacity (Fankhauser et al. 2001). For example, several studies point to global averages in food production being shifted by a combination of decreases in food production in low-latitude countries and an increase in high-latitude countries as colder climates become more temperate. This is further aggravated by the fact that these low-latitude countries tend to be less developed and depend more on subsistence farming (Kane, Reilly & Toby 1992).

1.2 Climate Adaptation

In March 2023, the IPCC unveiled their AR6 synthesis report drawing attention to the insufficient adaptation action taken globally compared to the national and international commitments and aspirations. Evaluating the adaptation process is a part of the Paris Agreement and is mandated in SDG 13 (Jia, Chen & Du 2021). Despite the increase in adaptation initiatives, most projects focus on short-term risk reduction, with little regard being paid to the transformative adaptation needed long-term to live on a progressively warmer planet (Lee et al. 2023). There is an urgent need to adapt both short- and long-term to new climates to save ecosystems and human populations. However, there are soft and hard limits to how much adaptation is possible for certain regions, sectors and hazards (Thomas et al. 2021), placing many countries under additional pressure. Countries failing to adapt to climate threats in an estimated time frame may face irreversible damage. This loss and damage are unequally distributed across nations, regions and sectors. It is constrained by systemic limitations, for instance inadequate funding, lack of climate education and compounding humanitarian crises. The systemic hindrances are making it particularly difficult for developing countries to finance adaptation to climate change (Lee et al. 2023).

1.2.1 Adapting to Climate Hazards

The increase in frequency and intensity of climate hazards will adversely affect economies and human health, necessitating adaptation initiatives. For instance, developed regions with an increase in flooding are adapting through resistant infrastructure and nature-based solutions such as floodplains which are both examples of adaptation measures (European Environment Agency [EEA] 2023). Hazards will require different approaches for adaptation and preparedness for their impacts on communities. Over-time chronic hazards, such as changes in precipitation patterns will for instance require long-term planning to avoid severe water scarcity (Conway & Schipper 2011), while acute hazards such as tropical cyclones will require developed early warning systems and education in disaster preparedness (Wouterse 2023). To meet the different adaptation requirements, countries must assess and evaluate their anticipated exposure and corresponding risk to each hazard.

1.2.2 Climate Finance in Africa

African countries face severe challenges in both securing the necessary funding to support adaptation measures as well as effectively accessing and utilising available funds. The establishment of concrete adaptation activities is often limited by substantial institutional barriers. Meanwhile, the current structure of multilateral climate funds makes it harder for sub-national actors to partake, locking out potential core agents in delivering domestic adaptation resources (Omari-Motsumi, Barnett & Schalatek 2019). Moreover, the cost of adaptation is likely to increase as the global mean temperature rises rapidly (Chapagain, Baarsch, Schaeffer & D’Haen 2020).

Although African countries receive financial support for climate adaptation from multilateral and bilateral sources, the amount received falls short compared to the estimated requirements. The currently allocated funding from multilateral and bilateral sources for adaptation is illustrated in Figure 1 below. The financing currently committed is mainly dedicated to mitigation efforts, with some estimates suggesting only 38% of the funding is allocated to adaptation (Savvidou, Atteridge, Omari-Motsumi & Trisos 2021). The African Development Bank (AfDB) has utilised countries' National Determined Contributions (NDCs) to project the finance needed for adaptation across the region. However, the AfDB acknowledges that the adaptation components of the NDCs need to better evaluate national vulnerabilities and financing gaps (African Development Bank [AfDB] 2019).

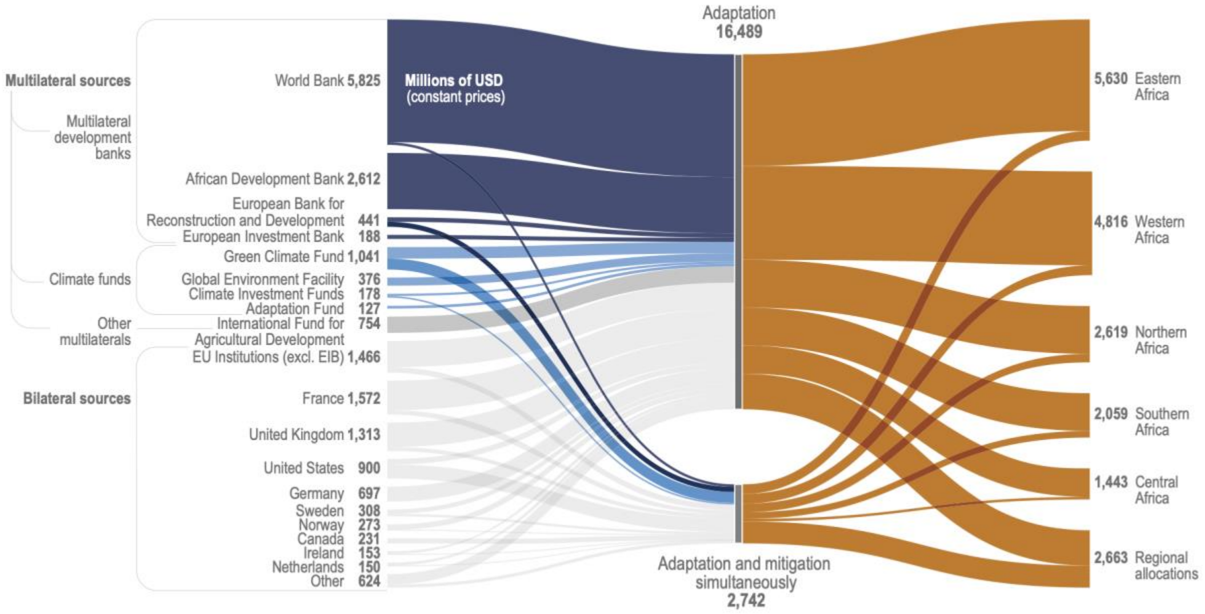

Figure 1: Total multilateral and bilateral aid for adaptation to African regions by source and recipient 2014-2018 (Trisos et al. 2022).

The adaptation cost has been estimated to be around 7-15 billion USD annually for African countries (Schaeffer et al. 2013). However, in an adaptation gap analysis conducted by the United Nations Environment Programme (UNEP), it suggests that the numbers are likely to be substantially underestimated and may potentially be 4-5 times higher by 2030 (Puig, Olhoff, Bee, Dickson & Alverson 2016).

Insufficient climate finance is recognised as a significant obstacle to effective climate action. The finance flow from developed countries to developing countries, mandated by the United Nations Framework Convention on Climate Change (UNFCCC) and committed internationally in the Paris Agreement, is not representative. Following the limited attention given to adaptation initiatives, vulnerable developing countries are being left behind. The annual target for finance flows for Africa is billions of USD less than the actual costs for adaptation short- and long-term. Inadequate climate risk assessments and a severe absence of sufficient and updated data for the region further compound the challenges for effective financing (Lee et al. 2023).

1.2.3 Assessing Climate Vulnerability

A number of scientific initiatives are looking into the severity and sensitivity of climate change. Global indices such as ND Gain and INFORM have developed structures for measuring individual countries' climate risks and vulnerability. These indices integrate information on national climate hazard exposure, sensitivity, and adaptive capacity, offering policymakers and other stakeholders a comprehensive and comparable assessment of climate risks on a global scale (Chen et al. 2015; Poljansek et al. 2022). By combining the complex nature of climate change impact into a single aggregated score on a national level, decision-makers can more easily make operational and strategic decisions while accounting for the underlying drivers of the risk. The transformation of the complex and often spatial risks onto a national scale in these indices also prove useful for operators at administrative and political scales who often implement decisions on a country level (Luo, Young & Reig 2015). Another vital function of these indices is to advance and facilitate the conversations regarding climate change impact and to provide a foundation upon which further dialogues can progress (J. Hellmann, personal communication, April 2023). However, the global nature of these indices might overlook regional differences in suitable indicators and fail to highlight differences within regional contexts.

Looking at Africa in particular, it is evident that the entire continent is facing tremendous challenges related to climate change impacts. African countries and economies possess distinct characteristics that differentiate them from other, more developed nations, leading to additional critical risks. Climate-sensitive sectors such as agriculture dependence, water scarcity and widespread health problems are key factors making the region more fragile than other continents (African Development Bank [AfDB] 2023). Other societal conditions in the region, such as the lack of stable infrastructure, a high percentage of rural population, and fragile institutional and political systems, make the continent even more vulnerable to these changes in climate (David 2021). The region has unique enablers and barriers for strengthening institutional capacity for monitoring risk and establishing vulnerability reduction and adaptation measures (FAO & ECA 2018). Because of these unique traits across different geographical and economic contexts, global comparisons may fail to adequately capture driving risk factors in individual regions. Socioeconomic comparisons can be unfair to developing economies and label low-income countries similarly without providing insight into their contextual differences.

2. Objectives and Aim

This study digs deeper into the risk and sensitivity factors contributing to the vulnerability to climate change impacts for the African continent and its nations. The primary objective is to create a country-level index that assesses the differences in climate risk exposure, sensitivity and adaptive capacity across the region. The index is from this point onwards referred to as the African Climate Hazard Assessment [ACHA] Index. Focusing exclusively on African nations enables the index to capture the region's distinctive socioeconomic circumstances and allows fair comparison using relevant indicators. A more contextually relevant assessment of climate risks in Africa will provide decision-makers and other stakeholders with valuable insights to evaluate risks, identify efficient adaptation solutions and foster further discussion.

The index adopts a hazard-based approach to evaluate the individual risk associated with each hazard, shedding light on the most pertinent hazards for each country. Since different climate hazards require distinctive adaptation strategies this approach may differ from other index variants that apply a sector-based approach, and are more tailored to investment decisions for organisations (J. Hellmann, personal communication, April 2023). This index's hazard-based methodology allows comparisons between drivers of humanitarian risks as a consequence of climate change, which are more relevant for policy decisions that can help adapt to such risks.

The exposure is compiled with a national sensitivity assessment of each hazard using relevant indicators to measure associated risk. Additionally, a systemic sensitivity for each nation will be included to account for the adaptive capacity and proximity to potential breaking points. Through this structure, the index provides insights into the climate hazard vulnerability in African countries and supports scientific-based adaptation as well as loss and damage decisions and policy making. Ultimately, it hopes to guide the decision-making on financial allocation to address the specific necessities of the African region and act as a call to action for further attention on African climate change adaptation.

This study serves as a valuable addition to the existing science base by making progress towards addressing the deficiencies in focus and funding for African climate research and climate impact adaptation. The incorporation of regionally distinctive characteristics through an Africa-specific index helps highlight the needs of the region. Furthermore, by employing a hazard-based approach the index will be differentiated from existing indices such as ND Gain and INFORM Risk, bringing new perspectives into discussions.

2.1 Research Question

What are the key determinants of vulnerability to climate change impacts for different African nations, and how can such a vulnerability assessment be utilised to guide and support adaptation measures?

2.2 Limitations

The research has been primarily focused on the humanitarian aspects of climate change, investigating its impact on the livelihood and well-being of communities and ecosystems. It is therefore delimited from evaluating specific climate change impacts for companies, and does not include business-related and technological impacts. Additionally, the index does not include indicators for African mitigation efforts, as the region only accounts for 2-3% of global GHG emissions (World Meteorological Organisation [WMO] 2022). The study will use exposure data according to RCP8.5 and SSP5 scenarios with a time horizon of 2040-2100.

In the methodology chapter, the limitations of the ACHA Index structure are more extensively discussed, but a brief summary is provided below. Constructing an index is by default a subjective process of selecting indicators one believes accurately represents a risk and will always remain influenced by the authors' judgement. Indicators are used to approximate the true impact of a hazard and present it in a simplified and educative manner. Nonetheless, they will never be able to fully capture the full picture of a complex problem. While including a high number of indicators that cover less significant aspects may shed light on additional elements of climate impacts, it risks diverting attention from more severe issues. Thus, the number of indicators must be carefully balanced to attribute the different impacts fairly.

The theory mentions that the climate change impact research for Africa is disproportionately financed and insufficient, which is further limited by the lack of data availability in the region caused by insufficient investment. Data quality can also vary, especially for information gathered through self-reporting (J. Hellmann, personal communication, April 2023). The availability of nationally comparable data on complex issues of climate change impact is therefore scarce, and relevant indicator choices have been adapted to the available resources. Some aspects, such as the economic damages attributed to sea level rise, are heavily understudied in the region and can therefore not be accounted for in the creation of the index. Additionally, there are limitations in the quality and availability of projections based on climate change model scenarios, especially for extreme-weather events. The upcoming CMIP6 models will improve the accuracy and resolution of these projections, but these are not yet available during the construction of this study.

3. Theory

The purpose of the following chapter is to provide the theoretical research background of climate change impact in Africa and the information on composite indices that the index builds its theoretical framework. Through this theoretical overview, it helps the reader understand the use and design of the index.

3.1 Climate Change Updates 2023

In the first week of 2023, several countries experienced the warmest week of January ever recorded, signalling the intensifying impact of climate change (Fleck 2023). Estimates in November 2022 by the Global Carbon Project, shown in Figure 2Figure 2, indicated that the annual carbon emission from fossil fuels would hit the highest record ever tracked (Friedlingstein et al. 2022). At the same time, the latest report (AR6) from the IPCC, authored by 278 researchers representing 65 countries, stated that we are currently far off the target of limiting global warming to 1.5 degrees Celsius.

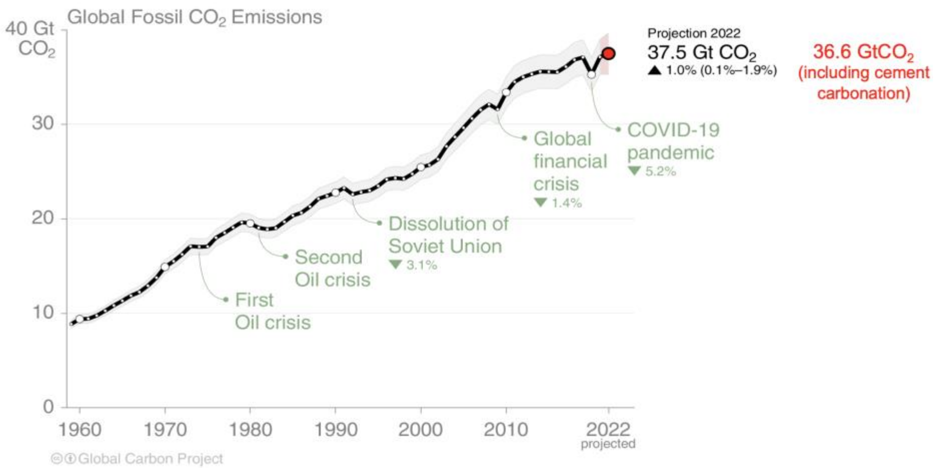

Figure 2: Historical and projected global fossil CO_2 emissions (Friedlingstein et al. 2022).

While the world is experiencing these record temperatures, the decade 2010-2019 recorded the highest annual anthropogenic GHG emissions in human history and emissions in all major sectors increased. The IPCC also stated with high confidence that current global greenhouse gas emissions will likely lead to a warming above 1.5°C. To limit warming below 2°C, it will be necessary to quickly accelerate mitigation efforts now and beyond 2030 (IPCC, 2022).

3.1.1 A predicted future with climate change scenarios

Climate models and scenarios play a crucial role in understanding how the climate has changed in the past and how it is predicted to change in the future. Generating future forecasts of different climate scenarios has required using some of the world's largest supercomputers. These models have simulated complex interactions between the atmosphere, land and oceans on a very granular level which is the base for the current scenarios (Hausfather 2019). In order to provide relevant insights and evaluate progress for major global commitments such as the Paris Agreement, different climate scenarios must be used. A rising and influential group of users and developers of scenario modelling are from the business and financial sectors. These groups require sufficiently credible climate change scenarios in order to conduct their risk assessments (Auer et al. 2021).

The RCP Scenarios
The Representative Concentration Pathways (RCP) scenarios, convened by the IPCC, quantify scenarios for the potential concentration of greenhouse gases (GHGs) in the atmosphere and the resulting temperature increase by mid-and-end of the century (IPCC, 2014b). These scenarios are primarily used for assessing different physical climate risks where the RCPs are converted into relevant potential temperature increases (Carlin, Falk, Johnson, Li & Workowski 2023). Figure 3 below illustrates the four pathways developed by the IPCC which describe different scenarios for the climate and their corresponding forcing values by 2100.

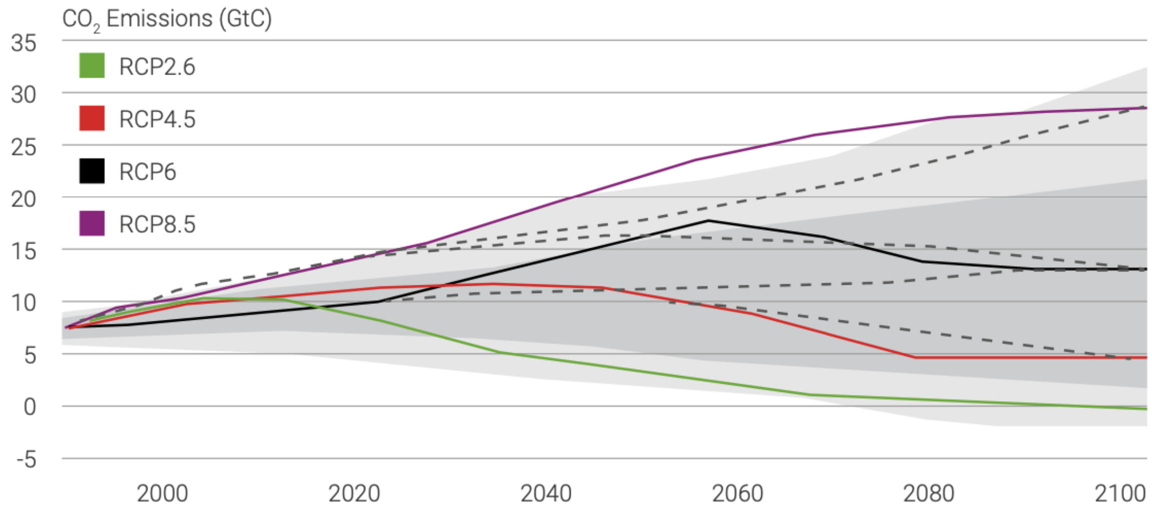

Figure 3: Carbon emissions until 2100 across the RCPs (van Vuuren, Edmonds, Kainuma et al. 2011).

The SSP Scenarios
To complement the RCPs, the Shared Socioeconomic Pathways (SSPs) are used to understand climate change by investigating different socioeconomic conditions and how they may influence GHG emissions. Five SSPs represent various pathways of socioeconomic development, taking into account factors such as population, economic growth, technological innovation, and global cooperation. The scenarios range from a sustainable, low-carbon future (SSP1) to a fossil fuel intensive future (SSP5) (O'Neill, Kriegler, Riahi et al. 2014).

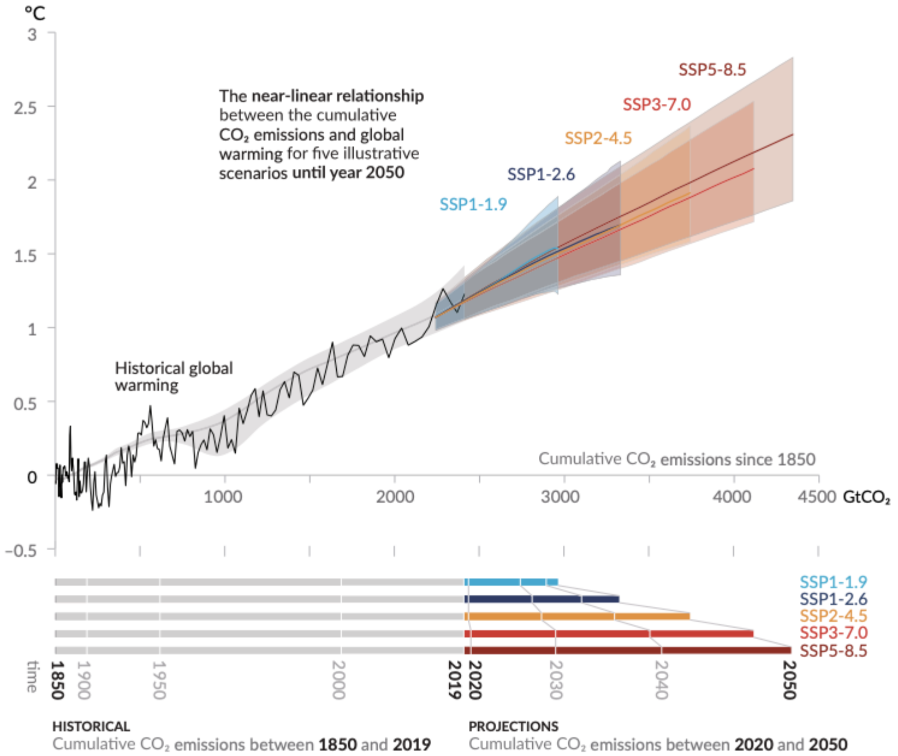

Figure 4: Global surface temperature increase since 1850-1900 in proportion to tonnes of CO_2 emissions (IPCC 2021).

Combining RCPs and SSPs allows for standardised comparisons of societal changes and resulting global warming. The SSPs set the stage for emissions reductions, with six Integrated Assessment Models (IAMs) utilising them to derive baseline and mitigation scenarios. Each SSP is compatible with multiple RCPs as long as it's plausible within the narrative (Hausfather 2018). The most recent version of SSP scenarios, developed in 2021 by the IPCC AR6, is expressed as SSPx-y, where "SSPx" represents the socioeconomic trends, and "y" is the approximate level of radiative forcing in 2100. The AR6 has explicitly mapped out the relationship between SSPs and temperature rises in the near, mid, and long term (Carlin et al. 2023). Figure 4 above, extracted from IPCC, outlines the five SSPs narratives and shows that global warming is proportional to CO_2 emissions in a near-linear manner. One such standardised comparison that uses both pathways is the Coupled Model Intercomparison Project (CMIP), which is an international effort to build granular climate models (Hausfather 2019). The latest one, called CMIP6, will be published in 2023 (S.Marzi, personal communication, April 2023).

3.1.2 Climate Change Vulnerability

According to the IPCC, climate vulnerability refers to *"the degree to which a system is susceptible to, or unable to cope with, adverse effects of climate change, including climate variability and extremes"* (McCarthy et al. 2001, p. 995). Schneider and Sarukhan describe vulnerability as the potential for a natural or social system to suffer from loss and damage due to climate change (Schneider & Sarukhan 2001). Climate vulnerability is often measured and discussed as a function of three dimensions: (1) The exposure a system has to climate change or climate variability, (2) The system's sensitivity to these changes and ability to control them, and (3) Its adaptive capacity. These dimensions intersect to determine the overall climate vulnerability, as depicted in Figure 5.

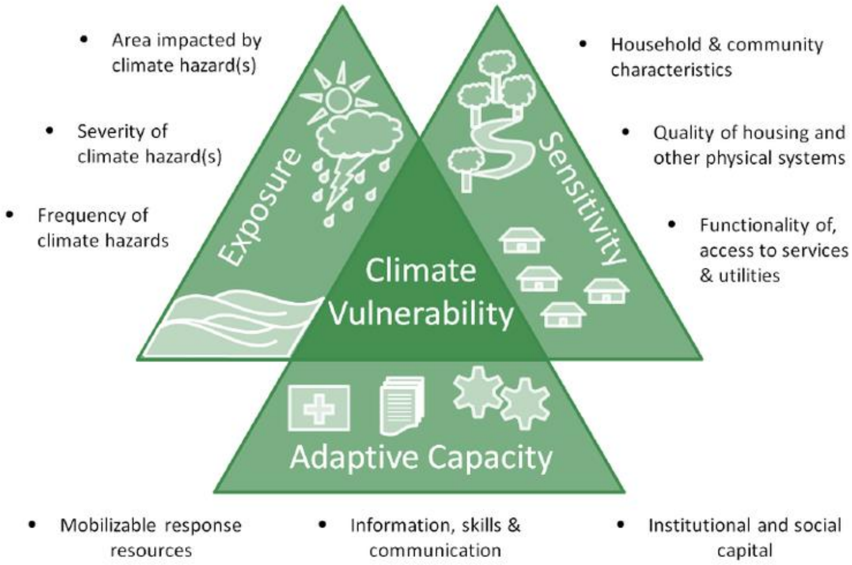

Figure 5: Three dimensions of climate vulnerability (Trundle & Mcevoy 2015).

The level of exposure is a function of the system's exposure to physical climate change and climate variation, such as temperature rise or flooding—including the exposure's character or direction, magnitude, rate of onset, and duration (Kay 2005). Sensitivity refers to the system's responsiveness to climate change, enclosing both positive and negative effects (Schneider & Sarukhan 2001). The level of sensitivity includes both direct effects, such as changes in crop yields due to changes in temperature or precipitation patterns, and indirect effects, such as coastal flooding caused by rising sea levels. These impacts can occur in different ways and levels, and vulnerability can appear immediately or over time, with varying degrees of severity (Kay 2005). Adaptive capacity is defined as the ability of a system to adapt to climate change, including extreme weather events and slow onset changes, in order to mitigate potential damages, seize opportunities and manage impacts (McCarthy et al. 2001). Social systems built by humans can adapt by changing their methods, infrastructures or processes for climate change adaptation. However, many natural systems may be limited in their ability to adapt. For example, ecosystems cannot adapt as a coordinated unit, and it is instead up to individual species to adapt. Some species may not be able to adapt quickly enough or may have difficulty finding suitable habitats due to the fragmentation and degradation of ecosystems that have already taken place (Kay 2005). In this study uses the term adaptive capacity to reflect on a country's ability to respond the climate change effects.

The vulnerability to climate change faced by Africa is multi-dimensional with socioeconomic, political and environmental factors playing a vital role in unlocking and hindering adaptation efforts (Perez et al. 2015). The latest IPCC report (AR6) affirms with high confidence that African countries are already experiencing widespread effects of anthropogenic climate change, despite having among the lowest per capita GHG emissions of any region globally (Trisos et al. 2022). A system with low vulnerability is generally referred to as resilient. Resilience refers to the ability of a system to withstand disturbances and shocks while maintaining its overall function. W. Neil Adger defines resilience as the power to persist and adapt (Adger 2003), and is further defined as a "measure of robustness or buffering capacity before disturbance forces a system from one stable equilibrium to another (Becker 2014). Therefore, it is incorrect to think of resilience as simply returning to the previous state after an impact. Resilience recognises that change is an essential quality of a system as it responds to new conditions, incorporates learning and makes adjustments (Kay 2005). Lastly, another term commonly used in the context of vulnerability, also in this study, is risk. According to Becker, risk can be conceptualised as uncertainty about what might happen and what the impact could be (Becker 2014).

3.2 Climate Change Research

Research on climate change impact is advancing steadily, thanks to improved data access, enhanced computing power and more sophisticated statistical methods. The improvements enable researchers to identify couplings and correlations between complex natural and human systems, thus highlighting the consequences of climate change on environmental, economic and humanitarian aspects. Identifying the economic and social burdens imposed by climate change helps illustrate the importance of mitigating climate change and guiding adaptive measures (Carleton & Hsiang 2016).

In Africa, the access and availability of climate data remains severely limited, and the number of existing weather stations has dropped significantly during the last 20 years (Trisos et al. 2022). The remaining ones are sparse and unevenly distributed, with most stations situated along major roads. Moreover, the available data is often of lower quality (Dinku 2019). This issue poses challenges in generating precise and granular climate change projections, particularly for precipitation patterns and extreme weather events who are more heavily influenced by regional geographic features (Otto et al. 2020).

The possibility to attribute climate change impacts is further hampered by a scarcity of climate research in the region, particularly in North and Central Africa. Biodiversity and socioeconomic data are notably lacking (Meyer, Kreft, Guralnick & Jetz 2015) as are studies on marine ecosystems, agriculture, migration and health. Research on climate change impacts on low-income countries carries half as much robust evidence as research into high-income countries. These knowledge gaps are mainly attributed to limited data collection and access, as well as inadequate funding for African researchers (Callaghan et al. 2021).

From 1990-2020, only 3.8% of climate-related research funding was dedicated to projects focused on Africa (Overland et al. 2021). The research on climate change adaptation for individual countries is heavily skewed towards more developed countries (Sietsma, Ford, Callaghan & Minx 2021). Furthermore, within Africa, funding varies greatly (Overland et al. 2021). For over 75% of African countries, 60-100% of studies did not include a single locally-based author (Pasgaard, Dalsgaard, Maruyama, Sandel & Strange 2015). The unequal distribution of researchers and funding influences the design and participation of climate research, which may reduce the availability and relevance for African contexts and ultimately impede the adaptive capacity of African countries (Trisos et al. 2022).

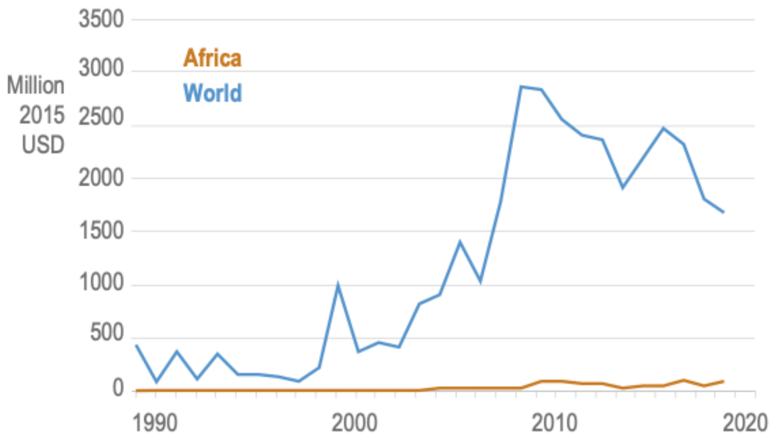

Figure 6: Funding for climate research on Africa versus total global funding (Trisos et al. 2022).

Since the data availability and funding is much stronger in developed countries, global studies tend to focus more on high-latitude risks. These studies often generate estimates of global averages who will be misleading if African impacts and risks are underrepresented. Consequently, current research struggles to statistically distinguish specific differences in impacts across African nations (Trisos et al. 2022). When assessing adaptation measures, the national circumstances and locally appropriate technologies are even more impactful, both in identifying the correct intervention and in monitoring and evaluating response effectiveness (Trisos et al. 2022).

Another difficulty in assessing socioeconomic impact is the additional factors that also affect the aspect outside of climate change. The mechanisms that drive socioeconomic changes are complex and multifaceted, encompassing for instance human behaviour, policy choices, technological advancements, and geopolitical developments. Attributing specific outcomes solely to climate change requires careful consideration of these other influencing factors (Collins et al. 2013).

3.3 Physical Climate Hazards

Loss and damage will be caused by two different physical climate-related hazards; *rapid onset events* or *slow onset events* (IPCC 2014b). Rapid onsets are short-term discrete events of weather anomalies caused by climate change and can severely impact human and natural systems. The events are naturally occurring but increase in frequency and severity as global warming progresses (Siegele 2012). In climate contexts, the term 'extreme weather events' is also used (Schäfer et al. 2021). Slow onsets are long-term incremental changes that gradually increase stress on human and natural systems. Another classification exists in the United Nations Framework Convention on Climate Change [UNFCCC] financial risk sphere which originates from the Bali Action Plan of 2007 (Schäfer et al. 2021), where climatic hazards are split into the three categories *Acute, Chronic* and *Second Order* (UNFCCC 2008). Siegele highlights that the differentiation of the two different onset types is somewhat vague, as the terms are used but never properly defined in the Cancun Agreements and UNFCCC papers. The term 'slow onset events' is used for both droughts and desertification and while these are processes that unfold over time, they are still one-off events (Siegele 2012). This paper will therefore use the classification of 'acute' and 'chronic', in line with the Bali Action Plan.

The Nationally Determined Contributions [NDCs] proposed by the 53 African parties who participate in the Paris Agreement suggest that the hazards of highest concern for the region are the following:

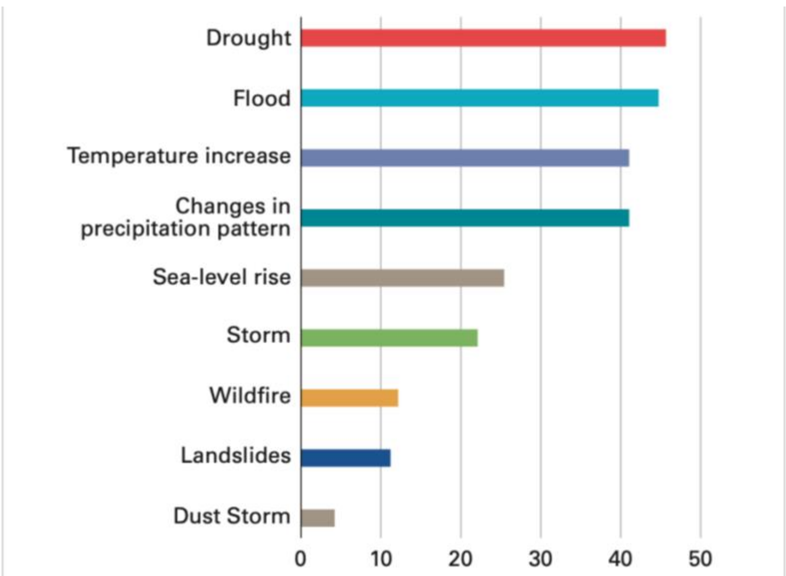

Figure 7: Hazards of highest concern for African nations according to their NDCs. (WMO 2021).

3.3.1 Acute Hazards

Physical acute climate hazards refer to discrete and intense climate events that can occur over a short time. However, these severe events can sustain for extended periods depending on their severity and may have effects that can persist for a long time. According to NGFS, acute physical climate risks refer to extreme weather events such as floods, drought, heat waves, wildfires, and cyclones, and are influenced by climate change (Network for Greening the Financial System [NGFS] 2022). These acute climate hazards can pose significant risks to humans and ecosystem systems, including displacement, infrastructure damage, loss of life, and serious disruption of food and water supplies. The most critical acute risks African countries face today and will be challenged by in the future are floods, drought, and tropical cyclones (WMO 2021).

3.3.1.1 Drought

Drought is a slow-onset disaster event defined as a prolonged dry period due to a lack of precipitation leading to water scarcity. Drought extensively impacts food security, health, displacement, and migration, and can undermine livelihoods, reverse development progress, and increase poverty for the millions who depend directly on the affected lands (World Health Organisation [WHO] 2023a). According to the WMO, drought has been estimated to be the world's most costly natural disaster at US$ 6-8 billion per year and to affect more people than any other natural disaster. It is also regarded by African governments as the hazard of highest concern according to the NDCs submitted to the Paris Agreement (WMO 2021), and the area affected by drought has doubled since the 1970s. Over the past century, drought has caused deaths to more than 11 million people and affected 2 billion others (WMO 2022a). The actual number of deaths attributable to drought indirectly through malnutrition, disease and displacements is likely much higher (United Nations Office for Disaster Risk Reduction [UNDRR] 2020). In many regions of Africa, and especially the southern half of the continent, farmers rely heavily on rainfed agriculture. With an increase in drought and altered precipitation patterns, these countries are more at risk due to rain variability’s impacts on agriculture (Alemaw, Simalenga 2015). Following studies and models on crop yield loss, it is shown that the increase in drought frequency and intensity will have a significant negative impact on crop production (Li, Ye, Wang & Yan 2009).

Unlike other extreme weather events, it can be more challenging to determine a clear beginning and end of a drought. The indirect impact of drought can also be harder to assess because of the cross-sectoral and cascading nature of drought characteristics with limited immediate visibility of impacts, as well as spatiotemporal variation, as droughts can last from a few months up to decades. It is, nevertheless, recognised that the impacts disproportionately affect poor and rural households. The longer a drought lasts, the greater the harmful effects on people, animals, and nature (National Geographic, 2023). The worsened water conditions in a drought will also affect natural systems, and animal food supplies and habitat can be permanently shrunk and degraded (UNDRR 2021).

The shortage of food and water that drought often brings can have additional induced impacts on human health. The sudden shortage of food and supply shocks has a significant effect on malnutrition (Cooper, Brown, Hochrainer-Stigler & Zvoleff 2019). Malnutrition can also affect immune responses and increase risks of infectious diseases such as pneumonia and cholera, which compounds with the lack of sanitation implied by displacement and water scarcity. The disruption of local health systems will also leave people without access to healthcare (WHO 2023a). The IPCC also warns that increasing populations, together with already severe water shortages and droughts, will put pressure on both food and additional water supplies (United Nations [UN] 2023b). Shocks in climatic conditions and disasters can often have a strong impact on poverty and act as a catalyst to trigger cascading migration trends. However, studies have thus far not found a strong attribution of mass migration directly to drought effects. However, displacement and migration will in general, leave populations more vulnerable to the effects of drought, often leaving them dependent on humanitarian aid (UNDRR 2021). In East Africa alone, 5,8 million people were displaced across borders by mid-2021, representing a particularly vulnerable group (United Nations Convention to Combat Desertification [UNCCD] 2022).

In IPCC's AR6 report, it is declared that the drought hazard is likely to increase in large parts of the African continent. There is a significantly higher risk of drought in the 2°C mean temperature rise scenario than at 1.5°C, and the increase in risk is expected to be most evident in central and west Africa (Trisos et al. 2022). However, assessments of drought trends are complicated because of decadal trends of natural variability, with major uncertainties on the extent of natural oscillation effects such as the El Niño Southern Oscillation [ENSO]. Additionally, the drivers of the shifts in intensity and frequency of droughts vary. Increased evapotranspiration and reduced precipitation are the main drivers of meteorological droughts, but hydrological droughts can occur due to drier dry seasons or shorter and more intense rainfall events (UNDRR 2021). Figure 8 below shows the projected change in drought risk across the continent.

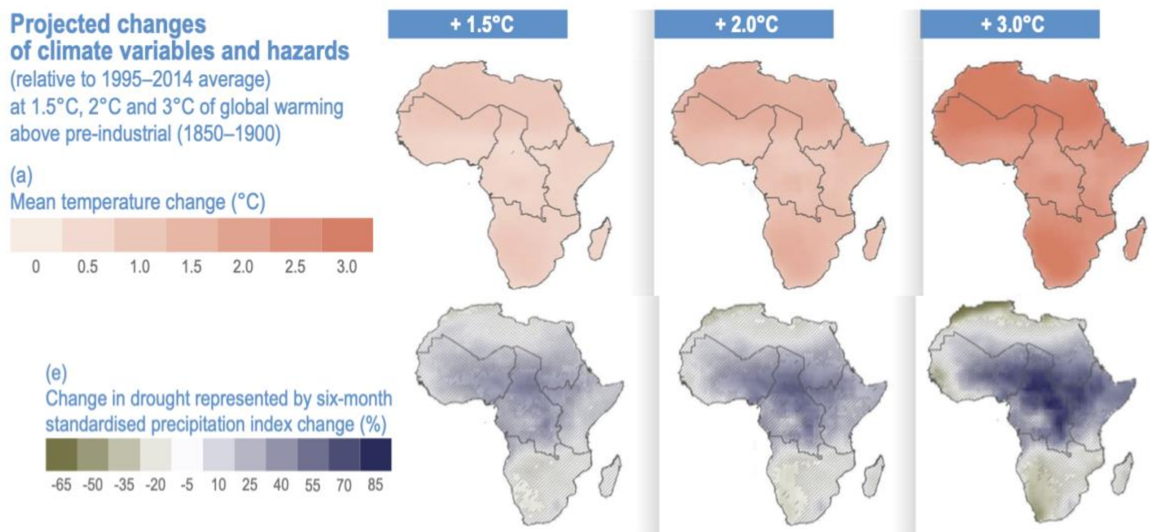

Figure 8: Projected changes of climate variables and hazards (Trisos et al. 2022).

3.3.1.2 Floods

Floods are the most common type of acute climate hazard and occur when a large amount of water at once oversaturates and submerges a piece of land. Floods lead to loss of life mainly through drowning but can imply knock-on effects that lead to further deaths through things such as electrocution, vector- and water-borne diseases and heart attacks. The damage to vital systems for food, water and infrastructure will both cause economic losses and lead to displacement and long-term disruptions to health, energy and transport systems. WHO stated that, between 1998-2017, more than 2 billion people worldwide were affected by floods (WHO 2023b). A study at Michigan University predicts severe impacts on food supply and population across the African continent due to increased flood exposure (Reed et al. 2022). Along with the direct effects, indirect and intangible losses such as lost income and education make the true impact harder to fairly assess (UNDRR 2023).

The WHO defines three general types of floods; *Coastal floods*, which affect coastal areas or cities and are driven by sea level rise and increases in coastal storm surges. *Riverine flooding* is a consequence of continuous rainfall or snowmelt causing a river to exceed its capacity and overflow, impacting nearby cropland and settlements. Finally, *flash floods* occur when torrential rainfall leads to rapid rises in water levels in bodies of water and on land, as the ground cannot absorb the rain masses quickly enough (WHO 2023b). As climate change entails intensified rainfall events, rising sea levels and increased occurrence of tropical storms, the frequency and severity of large-scale flooding are already increasing and are expected to continue to do so (WMO 2021).

Low and middle-income countries are disproportionately affected by floods, as they do not have adequate service capacities to preempt and cope with the consequences. It is also estimated that 89% of the people affected by floods live in these countries. The climate service capacities are also lacking in the region, with very basic or non-existing early warning systems (WMO 2021). The compounded effect of flood exposure and extreme poverty is evident in sub-Saharan Africa. In this region, 74.7 million people are exposed to floods and extreme poverty (WMO 2021). Poor living conditions, inadequate housing infrastructure and informal settlements are characteristics of poverty that exacerbate the consequences of floods (Internal Displacement Monitoring Centre [IDMC] 2019). The diagram below shows the proportion of the total population exposed to significant flood risks and living on an income of less than $5.20 daily. This implies that four out of ten people exposed to flood risks globally live in poverty (Rentschler, Salhab & Jafino 2022).

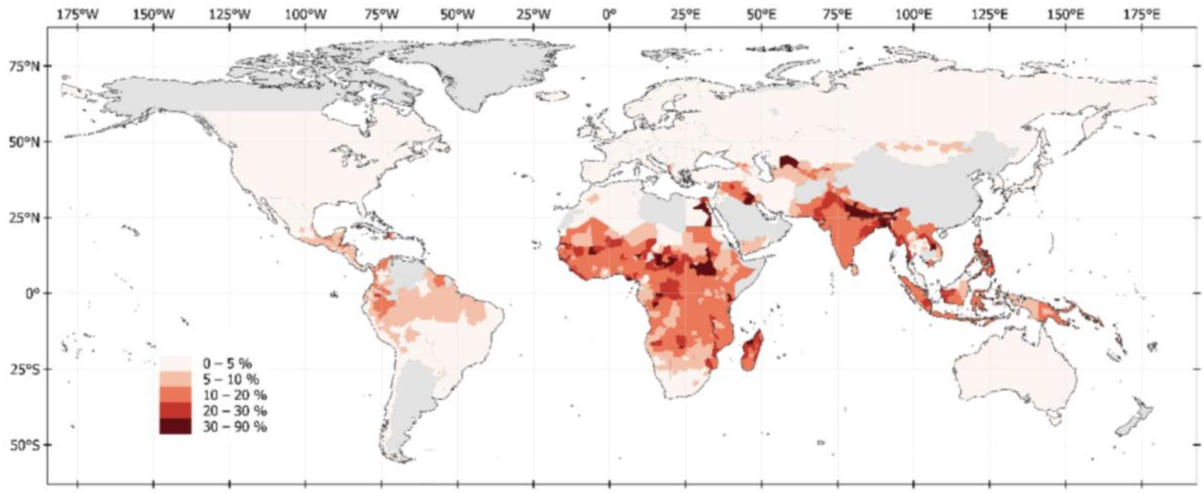

Figure 9: The share of the population exposed to flood risk and living under $5.50 per day (Rentschler, Salhab & Jafino 2022).

The impact on low-income communities is projected to worsen, partly due to rapid urbanisation in flood zones (Rentschler, Salhab & Jafino 2022). In a research report "*Changing global patterns of urban exposure to flood and drought hazards*" by Burak Güneralp, İnci Güneralp and Ying Liu, they predict that the extent of urban populations exposed to high-frequency flooding will increase by about 270 % in North Africa, 800 % in Southern Africa and 2600 % in mid-latitude Africa by 2030 compared to 2000 without considering climate change and only following GDP and population growth (Güneralp, Güneralp & Liu 2015). This urban growth will compound with the increased risks from climate change. The Assessment Report 6 from the IPCC states that severe floods in large African river basins with a current return period of 1 in 100 years are projected to occur with a more frequent 1 in 40 year return period under global warming scenarios of 1.5°C and 2°C, and 1 in 21 years with global warming of 4°C. Among the top 20 countries expected to suffer the greatest damage globally, African nations include Egypt, Nigeria, Sudan and the Democratic Republic of Congo (Trisos et al. 2022).

3.3.1.3 Tropical cyclones

Tropical cyclones can have a devastating impact on human life and infrastructure. A tropical cyclone occurs when the wind speed of a circular storm exceeds 119 km/h combined with heavy rain (WMO 2022b). In extreme cases, the wind speed can exceed 240 km/h. These severe storms originate over warm tropical oceans near the equator, where warm and humid air rises from the ocean surface, which creates a difference in air pressure that feeds the system of cloud and wind spins (Zehnder 2023).

According to the IPCC, several African regions experience tropical cyclones. Humans living in low-lying areas close to the coastal zones near the paths of the storms are the most exposed to the risk (Woodruff, Irish & Camargo 2013). The region with the highest risk is the southeast of Africa and includes Madagascar, Mozambique, Zimbabwe and Malawi which are all highly affected. Even though the number of tropical cyclones in this region is expected to decrease in climate models (Pillay & Fitchett 2012), the intensity of wind speeds and rainfall, as well as their duration, is projected to increase

(Malherbe, Engelbrecht & Landman 2012; Muthige et al. 2018). The recent cyclones “Idai” and “Kenneth" in 2019 destroyed thousands of kilometres of transmission and distribution lines for electricity, causing $133.5 million in damages and destroying over 230 000 homes. In the exposed city of Beira in Mozambique, 70% of houses were destroyed or damaged, and 60% of the city was put under water. Urban populations are projected to face increased exposure as storms intensify (Trisos et al. 2022). In February 2023, the tropical cyclone “Freddy” exposed several countries in southern Africa to high health risks and extensive destruction of health facilities, stretching the remaining healthcare capacity to its breaking point (WHO 2023c). The same cyclone has displaced over half a million people in Malawi alone (International Organisation for Migration [IOM] 2023).

According to the WHO, the most significant impacts from a tropical cyclone are not caused by the wind speed. The secondary events that result from cyclones, such as storm surges, flooding, landslides, and tornadoes, are the most harmful. Between 1998 and 2017, 233 000 people were killed due to these weather events, and about 726 million people were displaced, injured or homeless due to the disaster. Drowning and physical trauma are the most critical direct health consequences, but knock-on effects and indirect impacts are often found within the health and infrastructure sectors. The aftermath of a cyclone often impacts water security, leading to the increased spread of water-borne diseases such as cholera (Cambaza et al. 2019). The existing health systems are often disrupted and congested above their capacity, leaving communities without access to healthcare. Severe damage to essential infrastructure may leave communities without shelter, electricity, food and water (WHO 2023d). These physical damages to buildings and infrastructure have been shown to have severe long-term negative impacts on GDP growth in the region (Hsiang & Jina 2014).

The storms can also have a severe impact on natural systems and exhaust natural protective barriers in coastal systems such as mangrove covers. The Cyclone Eline in 2000 depleted 48% of the mangrove cover in Mozambique, with a 100% depletion of some mangrove species (Macamo, Massuanganhe, Nicolau, Bandeira & Adams 2016). Coastal forests and forest plantations can be severely affected by the strong winds during a cyclone. Still, the impact varies greatly based on topography and soil characteristics, where high elevation areas with high wind exposure are most vulnerable (Cortés-Ramos, Marfán & Herrera-Cervantes 2020).

3.3.2 Chronic Hazards

Chronic hazards are slow-onset processes and phenomena incrementally and exclusively driven by anthropogenic climate change. The processes lead to cumulative and potentially irreversible changes in the climate and impacted systems. The impact of chronic hazards is global, but the level of change varies across the globe because of regional factors (Schäfer et al. 2021). The cumulative nature of the chronic hazards leads to severe long-term loss and damage, but the less obvious short-term effects can result in a lack of urgency in addressing them compared to acute hazard events (Schäfer et al. 2021).

The chronic hazards are all heavily interlinked, and many are an exacerbation of an underlying increase in temperature in global warming. Chronic hazards can also influence and magnify acute hazard events, and overlapping or sequential hazards of both types can lead to substantial disruption (Schäfer et al. 2021). The chronic climatic hazards include *Temperature rise, Precipitation change, Sea level rise, Ocean acidification* and *Melting glaciers and permafrost* (UNFCCC 2008). The scope of this report focuses on the first three hazards and does not account for ocean acidification, melting glaciers nor permafrost.

3.3.2.1 Temperature Rise

Increases of GHG concentrations in the atmosphere caused by human activities have intensified the greenhouse effect, leading to an observed global warming of the atmosphere, ocean and land (IPCC 2021). From 1850 until 2011-2021, the global surface temperature has increased by 1.09°C, with a 1.59°C increase over land areas. IPCC concludes that it is likely that an estimated 1.07°C of this surface temperature increase was anthropogenic. The increase in temperature because of an increased GHG concentration was even higher, but is countered by cooling contributions from anthropogenic increases in aerosols (IPCC 2021). Projections for the 21st century indicate that the observed trend will continue and accelerate with the continuing GHG emissions.

The increase in temperature is observed to vary across the globe and is projected to continue to do so (IPCC 2021). The mean temperature rise in Africa is slightly above the global mean, and most of the continent has observed a rise of more than 1°C since 1901 (WMO 2019). The African mainland has experienced all three of the warmest years in average temperature on record after 2010 (WMO 2019). The increase in temperature has a plethora of implications, many of which are particularly worrying for the African continent.

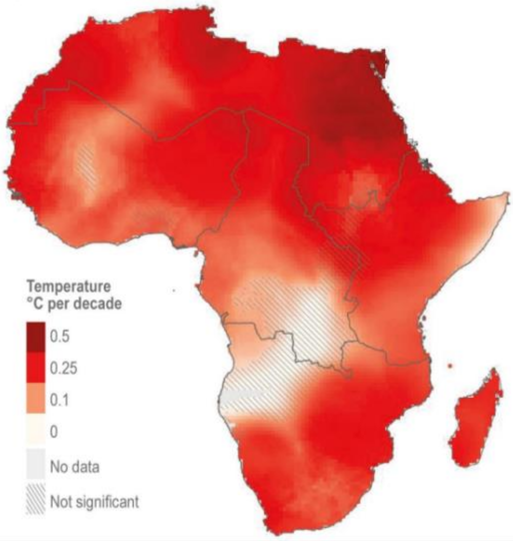

Figure 10: Observed temperature trends for 1980-2015 (Trisos et al. 2022).

Higher temperatures intensify the hydrologic cycle meaning that already arid regions are projected to become drier, with an observed intensification at twice the rate predicted by climate models (Durack, Wijffels & Matear 2012). With increased heat and a drier climate combined with changes in precipitation patterns, a key risk for the region is a reduction in agricultural productivity. As agriculture is the main driver of many African economies and livelihoods with 60% being employed in the sector, these risks will impact the food security and economic well-being of communities all across the continent (WMO 2019). This change is already being observed, as a study by Ortiz-Bobea et al. suggests that climate change has reduced African agricultural productivity growth by 34% since 1961 (Ortiz-Bobea et al. 2021). Crops will be affected differently, with projections suggesting that crops such as millet, maize and sorghum which have greater resilience to heat stress will be less affected than rice and wheat, with a potential 20-60% wheat yield decline in Southern and North Africa (WMO 2021). The higher temperatures will affect the soil composition of organic matter, moisture evaporation processes, and pest spread, all of which contribute to lower crop productivity in semi-arid and arid areas, further stressing food security. Decreased food security will increase the intensity of urbanisation and displacement, which means additional vulnerability to several other climate hazards (Trisos et al. 2022).

As ocean temperatures rise and salinisation becomes more frequent, fisheries will also face a reduction in productivity and a change in the distribution of catch (Trisos et al. 2022). As the fishing industry provides 19.3% of all protein intake in the region (Chan et al. 2018) and is the main source of livelihood for 12.3 million people (Garibaldi & de Graaf 2014), the impact poses a significant threat.

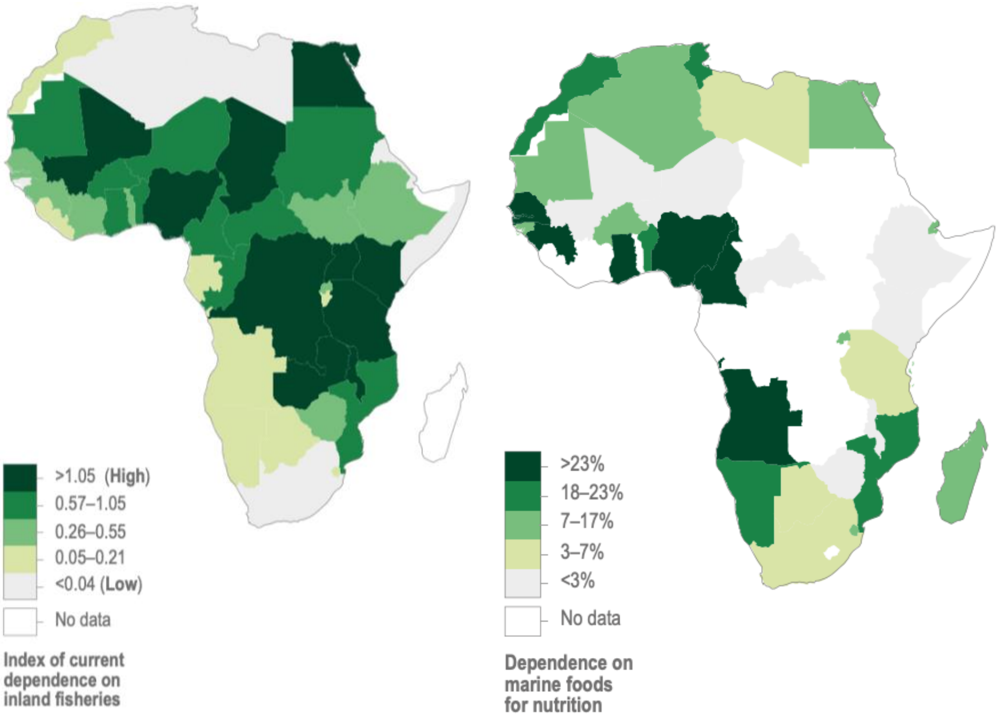

Figure 11: Dependence on inland fisheries and marine nutrition for African countries (Trisos et al. 2022).

Higher temperatures and changing habitats and precipitation result in a change in the regions of potential transmission of vector-borne diseases such as malaria and dengue fever, with a change in the distribution of disease vectors putting more people at risk (Patz, Campbell-Lendrum, Holloway & Foley 2005). As a whole, the population living in regions of potential transmission of vector-borne diseases will increase, and the window for the transmission season will be prolonged (Fankhauser et al. 2001). Even though projecting disease incidence remains a challenge, current models suggest that changes in temperature are causing an increase in malaria transmission and prevalence across southern and east Africa, while a decrease is expected in west Africa because of the climate turning less suitable for the vector and parasites in the region (Trisos et al. 2022). The usefulness of projections is limited by the difficulty of including driving factors such as population and vector movement, disease control and land use change. Trends in socioeconomic development have outweighed the negative effect of climate change (Tusting et al. 2013) and have contributed to malaria incidence falling by 33% in Africa between 2000 and 2010 (Caminade et al. 2013).

Africa is already known for their high-rising temperatures, and further increases lead to potentially fatal levels of heat stress. Sub-Saharan Africa is estimated to have a twice as high excess death rate from non-optimal temperatures than the global average with a particular excess in northern Africa (Zhao et al. 2021), and estimates suggest that 43.8% of heat-related mortality in South Africa was attributable to anthropogenic climate change (Vicedo-Cabrera, Scovronick & Sera 2021). The exposure to heat stress is amplified in urban areas because of an urban heat island effect (Chapman, Purse, Roy & Bullock 2017), and the number of high-heat-stress nights is 10 times larger in urban areas (Fischer, Oleson & Lawrence 2012). Heat stress will affect not only mortality rates but also the productivity of workers and possible working hours in Sub-Saharan Africa, especially for outdoor workers (Kjellstrom et al. 2016). The temperature-related mortality risk is projected to be heavily influenced by the GHG mitigation efforts, with heat-related deaths increasing sharply above 1.5°C warming (Krisos et al. 2022). An estimation made of the accumulated costs caused by heat stress sums up to above 51.3 billion USD, which is partly an indicator of the increased demand for cooling systems (Parry et al. 2019).

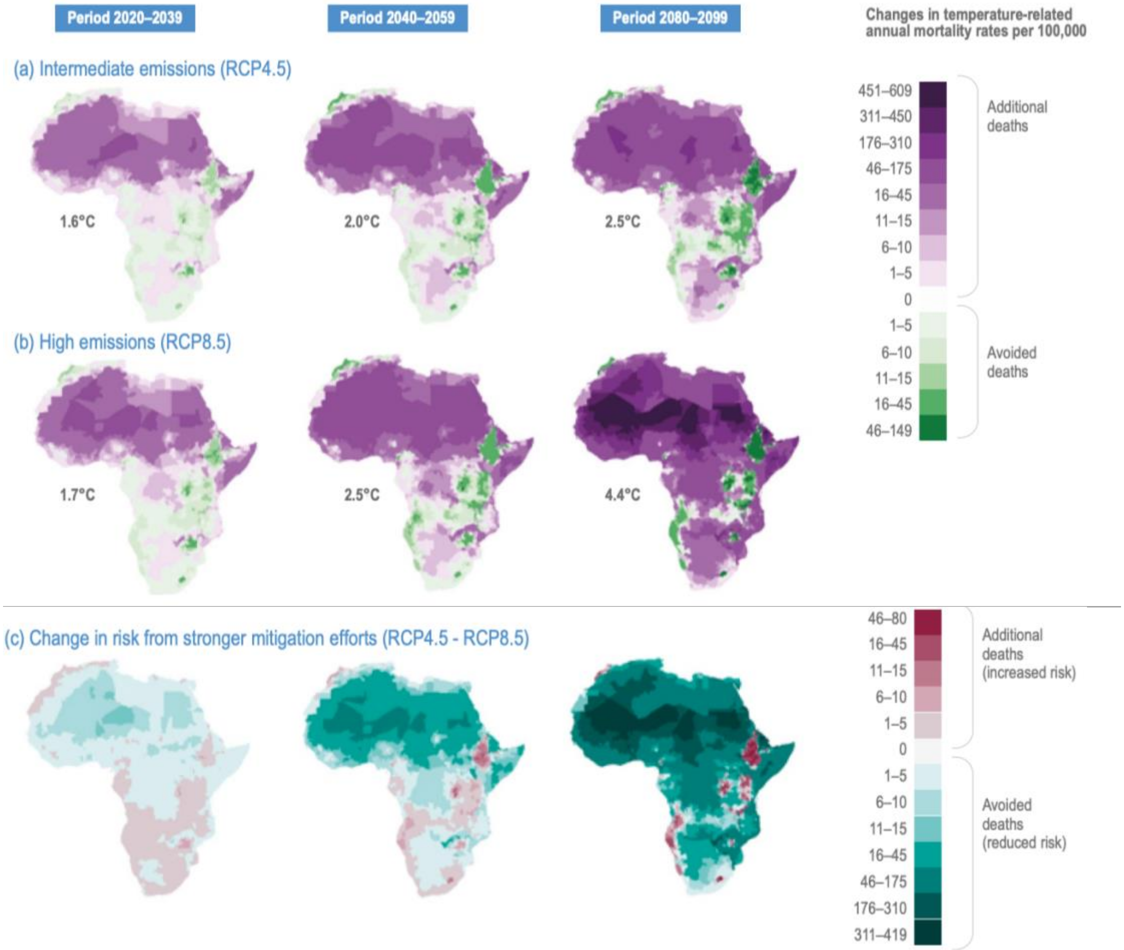

Figure 12: Temperature-related mortality risk in Africa with increased global warming (Trisos et al. 2022).

Climate change also impacts African biodiversity and ecosystems. The IPCC AR5 report highlighted the risk for desertification of semi-arid areas and vegetation loss (IPCC 2014b), but more recent studies observe that Africa is experiencing an expansion of grass and woody plant cover in areas in central and West Africa with increasing precipitation and CO_2 levels. This woody plant encroachment can improve the foraging possibilities for browsing species, to the detriment of wild and domestic grazers (Venter, Cramer & Hawkins 2018). However, in areas where hot and dry weather is intensifying, foraging turns less efficient, and species distributions are changing with decreases in both abundance and range. As species approach their physiological limits, climate hazards can tip them over the edge and lead to mass mortality events (du Plessis, Martin, Hockey, Cunningham & Ridley 2012). In the IPCC AR4 report, it was estimated that 20-30% of species are at an increased risk of extinction if the temperature rise exceeds 2-3°C (IPCC 2007). One vulnerable group is African birds, who, through ecosystem disruptions, are being forced to higher elevations (Neate-Clegg, Stuart, Mtui, Şekercioğlu & Newmark 2021) as higher temperatures shift plant abundance. Increasing temperatures may also have an effect on reproduction efficiency (Lee & Barnard 2015). Ecosystem impact can also be observed as add-on effects from other temperature-driven impacts, such as when agricultural yield losses contribute to forests being cleared to make room for additional cropland to cover the losses (Brandt et al. 2017).

Increasing temperatures and decreases in rainfall have implications for freshwater and marine ecosystems. As temperatures rise in surface water, nutrient mixing can be inhibited, leading to lower water quality and changing chemical compositions. These changes can have a significant impact on biological productivity and species distribution and in turn, affect fishery productivity both inland (Ndebele-Murisa 2014) and offshore (Roxy et al. 2015).

3.3.2.2 Precipitation

The impact of climate change on precipitation is much less generalisable, with significant regional variations. Regions will experience substantial changes in both directions, while others might not see any change. However, one observable trend is increased contrast in precipitation between arid and wet regions as temperatures increase. Currently, arid regions are expected to receive less precipitation, and moist regions are expected to receive bigger volumes and more intense precipitation events (Collins et al. 2013). Another pattern is high latitude areas experiencing higher precipitation due to a more humid and warm troposphere (Collins et al. 2013). The regional variations hold true also for the African region. The observed trends for 1980-2015 show an erratic variation and highlight the lack of sufficient data in many regions (Gutiérrez et al., 2021).

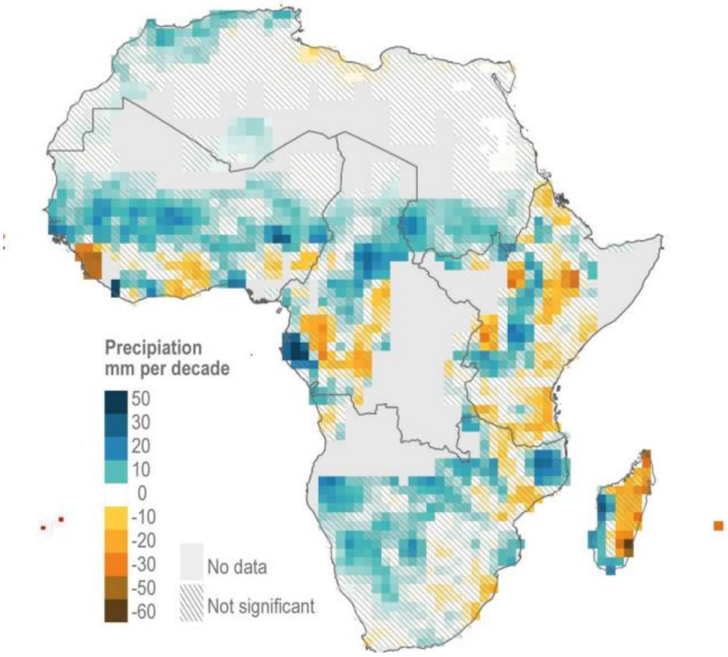

Figure 13: Precipitation trend in Africa per decade (Trisos et al. 2022).

As warming continues, precipitation reduction is expected over the northern and southwestern parts of Africa, where the climate is generally arider. No regions are confidently expected to experience an increase in mean precipitation, but the other regions are projected to experience more heavy precipitation events (Trisos et al. 2022). The precipitation patterns and intense rainfall events also follow the directions of the El Niño-Southern Oscillation ENSO, which further increases the uncertainty of the attributable effect of climate change (Park, Kang, Yoo, Im & Lee 2020) In the regions with reduced precipitation accompanied by higher temperatures, runoff is likely to decrease along with soil moisture leading to changes in river flows, declining agricultural yields and vegetation loss. In regions where runoff increases, flood risks can also lower agricultural productivity (Trisos et al. 2022). Africa is disproportionately exposed to the effects of precipitation variations, as 95% of cropland is rainfed with no other irrigation (Abrams 2018), with crop performance being highly sensitive to precipitation levels (WMO 2019). One study suggests that without the decreases in precipitation between 1960-2000, the gap in GDP between African countries and the rest of the developing world would be 15-40% smaller, mainly because countries are heavily dependent on agriculture and hydropower (Barrios, Bertinelli & Strobl 2010). Subsistence farming under water stress in semi-arid areas is currently sitting on the margin of climate suitability, and decreases in precipitation could tip the balance from a meagre livelihood to no livelihood at all (Fankhauser et al. 2001).

The strong urbanisation movement in many parts of Africa can be partly attributed to decreased precipitation in rural areas, as people seek the cities for non-agricultural livelihoods (Trisos et al. 2022). Excessive increases in precipitation can also lead to decreased agricultural productivity through waterlogging and soil erosion. When the soil becomes oversaturated with water, it becomes more prone to erosion and runoff increases, which depletes nutrients and lowers soil fertility (Nuruzzaman et al. 2019). Particular sensitivity to precipitation and runoff changes is expected for countries that are heavily reliant on hydropower, with decreased production, especially in the east and south parts of the region leading to sensitive electricity prices (Brooks 2019) and prolonged load shedding, which is reflected in the economic growth (Conway, Dalin, Landman & Osborn 2017). This risk is coupled with the significant planned increase in hydropower across the continent, with a planned sixfold expansion of total electricity production and a huge untapped potential in hydropower as only 7% of potential capacity is developed (Brooks 2019). In central Africa, hydropower production is projected to increase with the higher river flows (Climate Service Center [CSC] 2013).

The patterns of rainfall affect the way diseases are allowed to spread. A decrease in precipitation and limited access to clean water can mean having to turn to unsafe sources of drinking water and skipping procedures for hygiene and food safety, which allows for the spread of food- and water-borne diseases such as cholera (Trisos et al. 2022). Observations in West Africa suggest an increase in cholera outbreaks with increases in heavy rainfall (Constantin de Magny, Guégan, Petit & Cazelles 2007), and similar studies in East Africa suggest a positive correlation between rainfall and cholera cases (Fernández et al. 2008). Rainfall patterns also affect vector-borne diseases, as decreases in vector survival are correlated with lower rainfall levels (Fankhauser et al. 2001). Increases in rainfall and higher humidity instead increase survival and have been positively linked with malaria incidence (Adu-Prah & Tetteh 2014). Malaria outbreaks are sensitive to heavy rainfall and flooding events, according to studies in East Africa (Amadi et al. 2018).

3.3.2.3 Sea Level Rise

As temperatures rise, changes in sea levels are observed as glaciers and ice sheets melt along with a thermal expansion of water in warming oceans. Sea level rise is measured in *global* and *relative* rise, as local factors such as land elevation result in regional variation that make the relative rise at a given location differ from the global mean. *Relative sea level rise* is defined as the rise with respect to a specified reference point relative to the land, while *Global sea level rise* refers to a worldwide average (UNFCCC 2012). As sea levels rise, loss and damage occur (UNFCCC 2012):

- Damage to coastal infrastructure.
- Impairment of coastal drinking water aquifers.
- Salinisation of coastal soils and basins.
- Inundation of coastal ecosystems.
- Fish habitat and fishery production loss.

Coastal systems are vital clusters for human activity because of land fertility, fishing opportunities, and transport, meaning future sea level rise poses a substantial risk for society (Darwin & Tol 2001). The loss and damage are both attributed to the higher water levels and an increase in the frequency and severity of coastal flooding (IPCC 2021). Rising sea levels are a major threat to the well-being of coastal communities, as they can contaminate their groundwater sources. These aquifers are an important source of drinking water and crop irrigation. Coastal aquifers are particularly vulnerable to saltwater intrusion, which can occur even with minor sea level rises. This is of particular concern in North African coastal areas where groundwater is already overexploited to support population growth and agriculture (African Center for Strategic Studies 2022).

Even though significant regional variability exists, the SLR around Africa exceeds 5mm per year in several areas compared to the global average of 3.4mm (UNFCCC 2020). Africa and its low-elevation coastal zones are experiencing the strongest population growth of any region in the world and urbanisation, which amplifies the exposure to future sea level rise (Neumann, Vafeidies, Zimmermann & Nicholls 2015), and coastal urban populations already account for 25-29% of populations in west, north and southern Africa (OECD/SWAC, 2020). The 54 million people in Africa exposed to SLR in 2000 will have doubled by 2030 and is projected to reach 190-245 million by 2060 (Trisos et al. 2022), with the greatest exposure in Western Africa because of an abundance of low-lying highly populated deltas (UNEP 2016).

	Year 2000	Year 2030 (+10 cm sea level rise)				Year 2060 (+21 cm sea level rise)			
	Baseline	A	B	C	D	A	B	C	D
Africa	54.2	117.6	108.5	116.8	108.9	229.3	190.0	245.2	185.6
Western Africa	17.1	47.1	45.3	47.2	43.6	111.7	95.0	122.3	88.9
Northern Africa	30.3	52.3	46.6	52.3	48.6	72.4	56.3	74.8	61.4
Eastern Africa	5.2	15.1	13.8	14.1	13.8	39.9	34.8	42.5	31.1
Central Africa	1.1	2.2	2.0	2.2	2.0	3.8	3.0	4.1	3.0
Southern Africa	0.5	0.9	0.8	1.0	0.9	1.5	0.9	1.7	1.1

	Populations within LECZ				Populations within 100-year floodplains			
	Baseline 2000	Year 2030	Year 2060	Growth 2000–2060	Baseline 2000	Year 2030	Year 2060	Growth 2000–2060
Egypt	25.5	45.0	63.5	0.25	7.4	13.8	20.7	0.28
Nigeria	7.4	19.8	57.7	0.79	0.1	0.3	0.9	0.84
Senegal	2.9	8.5	19.2	0.66	0.4	1.1	2.7	0.76
Benin	1.4	5.4	15.0	1.06	0.1	0.6	1.6	1.12
Tanzania	0.6	2.8	14.0	2.2	0.2	0.9	4.3	2.3
Somalia	0.6	2.2	9.8	1.68	0.2	0.6	2.7	1.7
Cote d'Ivoire	1.2	3.0	7.6	0.64	0.1	0.3	0.7	0.65
Mozambique	2.3	4.4	7.5	0.33	0.7	1.4	2.5	0.36

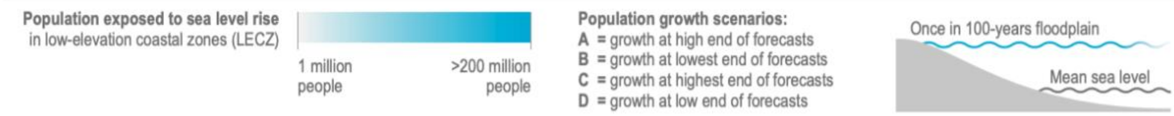

Figure 14:Current and future population exposed to sea level rise in low-elevation coastal zones in Africa (Trisos et al. 2022).

SLR in Africa will lead to significant economic damages and is projected to exceed 2-4% of sub-Saharan Africa's GDP by 2050 (Parrado et al. 2020). Studies that look at the aggregate damages due to SLR in major cities project expected average damage in 2050 of between USD 65-137 billion, and upwards of USD 187- 397 billion when considering low-probability high-damage events. The expected damage highly depends on coastal city characteristics (Abadie, Jackson, de Murieta, Jevrejeva & Galarraga 2020). Sea level rise is also projected to be a major driver of migration and displacement (IPCC 2019), increasing the vulnerable population of informal settlements (Satterthwaite et al. 2020) and thus amplifying existing stresses related to poverty, social and economic exclusion, and governance (Trisos et al. 2022).

The impacts of SLR also extend to natural ecosystems, through, for instance, erosion and degradation of coastal regions. Current observations suggest that 56% of coastlines in several West African countries are eroding at an average rate of 1.8m every year (West Africa Coastal Areas Management Program [WACA] 2018). The degradation extends to critical coastal ecosystems such as marine habitats and mangroves, and future costs are expected to increase considerably through aggregations with other factors (WMO 2019). These ecosystems can provide vital shoreline protection and trap sediment, and the risks of sea level rise could compound if they are compromised (Ghermandi, Obura, Knudsen & Nunes 2018).

3.4 Systemic Vulnerability

Along with the direct physical exposure and sensitivity to a specific climate hazard, the vulnerability of a nation will depend on some intrinsic characteristics. The climate hazards will stress systems that may already be heavily burdened, and natural and anthropogenic circumstances will limit or enable the adaptive capacity for preventing and tackling loss and damage. The above-mentioned aspects and sectors impacted by climate hazards might be more or less prominent in different nations and have a different role in the overall climate vulnerability. It is therefore relevant to include contextual indicators that can account for this *systemic vulnerability* for each country. Systemic vulnerability is in this paper divided into three categories; *Humanitarian, Economic,* and *Governance*.

3.4.1 Humanitarian Vulnerability

The social context and circumstances in which people are born, grow, live, work, and age plays a significant role in determining health outcomes (WHO 2008). In Africa, climate change interacts with underlying inequalities, exacerbating pressure on health and well-being (Trisos et al. 2022), and the existing health support systems and humanitarian circumstances will be a deciding prerequisite in assessing climate change impact and the extent of adaptation opportunities. The lack and migration of experienced healthcare personnel is causing a big problem in many developing countries, and the access to healthcare is further stressed by AIDS and other communicable diseases occupying large amounts of hospital beds (Boutayeb 2010). This leads to lower access to proper healthcare and generally lower public health outcomes. These health impacts resulting will be unevenly distributed across societies as well as genders (Nyahunda, Makhubele, Mabvurira & Matlakala 2020) and socioeconomic groups (St.Louis & Hess 2008). Negative health outcomes from climate hazards will particularly affect vulnerable groups in society with limited access to healthcare and already face health disparities (Falchetta, Hammad & Shayegh 2020).

Climate change's impact on food security will have a greater impact on nations that already struggle to deliver basic nutritional needs to these vulnerable groups (Chen et al. 2015). For example, shocks in food prices during the 2008-2009 financial crisis are estimated to have contributed to the deaths of an additional 30 000-50 000 malnourished children in Sub-Saharan Africa (Friedman & Schady 2012). A study by Lloyd, Kovats and Chalabi studied future child malnutrition with and without climate change and found a 31-55% increase in the relative percent of severely stunted children with the presence of climate change impacts (Lloyd, Kovats & Chalabi 2011). Globally, climate-related events will result in varying degrees of food shocks for different nations, driven by import-related price fluctuations. (Hallegatte & Rozenberg 2017). Nations that have a higher rate of food imported will be more exposed to shocks in the international market, whose volatility may be accentuated by climate change (Nelson et al. 2010).

The health outcomes of climate change can be mitigated by the presence of resilient health systems (WHO 2015) but can also be exacerbated by inadequate health systems and water and sanitation infrastructure (Armitage et al. 2014). In regions with vector control programmes or where functional vaccination, detection and treatment of infectious diseases are present, the burdens of climate-sensitive conditions could be curtailed (Trisos et al. 2022).

The demographic characteristics of a nation will be telling in the vulnerability to climate change. The youngest and oldest of the population will be more vulnerable to climate hazards and will be disproportionately affected by climate change (Trisos et al. 2022). Gender inequality will also play a role, as both vulnerability to climate change impacts (Adzawla, Azumah, Anani & Donkoh 2019) and adaptive capacity (Jaka & Shava 2018) may differ between men and women. Women in Africa shoulder considerable responsibility for subsistence agriculture (Viatte, De Graaf, Demeke, Takahatake & Rey de Arce 2009) and may be particularly vulnerable in employment (AfDB 2014). Women are also over-represented in the agricultural sector, as 70% of women are employed in the sector in low-income food-deficit countries (WMO, 2019).Vulnerability attributed to demography extends to social inequality, and living in slum-like conditions increases sensitivity because of the pre-existing lack of water security and sanitation (St.Louis & Hess 2008). This also makes slum populations more exposed to climate-induced increases in water-borne diseases (Chen et al. 2015).

The severe health impacts climate change may have on vulnerable communities and climate emergency effects from extreme weather events will likely force migration and increase the number of internally displaced people and climate refugees (McMahon et al. 2021).

3.4.2 Economic Vulnerability

Even though some specific climate hazards can be attributed to causing economic loss and damage in certain sectors, the total impact on macroeconomic systems will be compounded by several different hazards and trends (Carleton & Hsiang 2016). The *economic vulnerability* thus aims to explain the general systemic sensitivity of African economies, which consists of both the current economic well-being of a nation, the projected economic trends and developments, as well as the economic effect of climate change impacts. An already struggling economy with a downward trend might have less room for further climate-induced downturn and expect more severe consequences of additional marginal impacts.

The negative climate change impact on economic output and growth is larger in Africa than in other regions (Odusola & Abidoye 2015). Economic productivity, i.e. the efficiency of turning resources into new goods and services, is found to peak at an average temperature of 13°C and decline strongly at higher temperatures, which highlights the risks of an already hot Africa getting hotter (Burke, Hsiang & Miguel 2015). This has slowed the progress in lowering global economic inequality over the past half century, as cooler wealthier countries are profiting from the increase in temperatures while growth is stifled in warm countries. Estimates suggest that GDP per capita in Africa is, on average, 13.6% lower than it should be because of the observed effects of anthropogenic climate change and has been reduced by 17-31% for the nations in the four poorest deciles of a GDP per capita distribution (Diffenbaugh & Burke 2019). Additionally, economic inequality between African countries is also projected to widen (Baarsch et al. 2019).

The observed effect of climate change on African economies has already been significant and is projected to drastically worsen if mitigation efforts are not put in place. The observed GDP decrease has been the worst in the Saharan region, but a severe impact is expected on the entire continent. Limiting global warming to 1.5°C rather than 2°C would have a substantial economic upside for almost all African countries (Burke, Davis & Diffenbaugh 2018), and business-as-usual climate emissions could result in up to 90% decreases in GDP compared to scenarios without global warming (Burke, Hsiang & Miguel 2015).

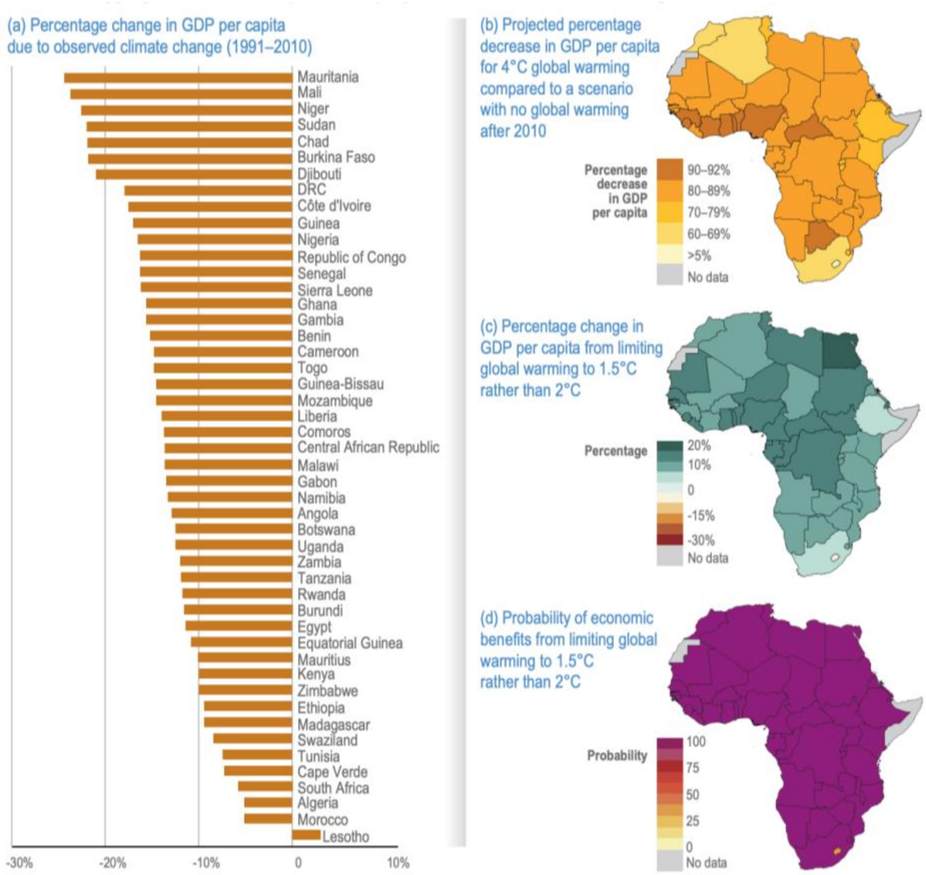

Figure 15: Observed aggregate economic impacts and projected risks from climate change in Africa (Trisos et al. 2022).

The economic impact of climate change in Africa cannot fully be represented by GDP-based projections however, as economic activity in informal sectors, which account for 85.8% of all employment in Africa, is not captured in the metric (Trisos et al. 2022). Informal sector employment is 21.4% higher in Africa than global levels and also varies greatly within the region, with levels ranging from 30% in South Africa to 94.6% in Burkina Faso (International Labour Organisation [ILO] 2018). Informal sector activity is just as sensitive to climate impacts and disruptions, and endures added adversities in recovering assets due to lack of insurance (Trisos et al. 2022). The level of informal activity and the support networks in existence to aid these sectors will thus have considerable implications for economic adaptive capacity.

The economic adaptive capacity will depend on a multitude of factors, but a lack of infrastructure, education and capital indicates a structural limit to protecting economic ecosystems (Fankhauser et al. 2001). Education opportunities are critical for socio-economic development and help unlock vital skills and labour that will be necessary for an efficient adaptation to climate change. Investments in education can thus prove just as important as physical adaptation projects such as seawalls and irrigation systems, and provides a foundation of knowledge to build additional adaptive capacity upon (Lutz, Muttarak & Striessnig 2014). Current strides are being made in improving education access, but these are undermined by climate change effects such as displacement, livelihood losses and more. Studies suggest that current and future climate change reduces educational attainment and participation, especially in poor and vulnerable families (Trisos et al. 2022). This might be attributed to climate conditions reducing household incomes (Marchetta, Sahn & Tiberti 2019) or climate-induced undernutrition affecting cognitive development and schooling potential (Bartlett 2008).

One economic aspect that will indicate economic well-being and enable coping capacity with climate hazards is the systemic infrastructure, such as networks for transport, electricity and ICT. These systems are the bedrock upon which modern social and economic activity depends. They will be a precondition for rural and vulnerable groups to take part in adaptation measures and facilitate their climate-induced disruption responses (Chen et al. 2015). The African Development Bank stated that over 640 million people were without access to basic electricity in Africa, corresponding to an electricity access rate of slightly above 40 % in the region (AfDB 2018). According to the IEA, a few countries faced extremely low rates with the Central African Republic at 4,4%, South Sudan at 7% and Chad at 7,8% (International Energy Agency [IEA] 2022), leaving the Sub-Saharan region with the lowest rates in the world. These low rates have negative effects on health, education and poverty reduction (United Nations Conference on Trade and Development [UNCTAD] 2023), leaving the region particularly vulnerable to additional systemic shocks, such as the impacts of climate change. In addition, IMF highlights the macroeconomic effects of climate change and how simulations have shown pressure on real interest and inflation rates. These economic uncertainties are also likely to amplify the effects of climate change (Thakoor & Kara 2022).

3.4.3 Governance

Governance is for the Worldwide Governance Indicators [WGI] defined as "the traditions and institutions by which authority in a country is exercised" (Kaufmann, Kraay & Mastruzzi 2010). Governing bodies play a key role in enabling adaptation to loss and damage on international, national, regional and personal levels. Strong local governance can put in place frameworks that protect the population and the economy from adverse climate impacts and build long-term climate resilience (Shukla et al. 2019). IPCC concludes that climate resilient development will require long-term planning, transboundary cooperation and all-of-government approaches to increase adaptation. Without this, governmental responses in one sector can cause risks in other sectors and cause maladaptation (Trisos et al. 2022). Responses to and planning for the above-mentioned systemic vulnerabilities will depend on governmental effectiveness and the quality of public services (Trisos et al. 2022), and overcoming barriers in governance will be vital to ensure successful climate adaptation (Pasquini 2019). These barriers include, among others, slow policy implementation, lack of coordination and governance mandates (Shackleton, Ziervogel, Sallu, Gill & Tschakert 2015), and inadequate systems to handle climate finance (Granoff, Hogarth & Miller 2016). Nevertheless, many African institutions are struggling to implement and finance activities that support adaptation measures (Trisos et al. 2022).

The institutional capabilities of a nation will be influenced by political stability, and it is listed as one of the six dimensions of governance by the WGI Project (Kaufmann & Kraay 2010). Models have highlighted a strong historical linkage between the likelihood of conflict and warmer temperatures, with future projections of temperature suggesting a 54% increase in armed conflict incidence by 2030 (Burke, Miguel, Satyanath, Dykema & Lobell 2009). Even though the temperature is only one of many driving factors, examples of violent conflict timed with temperature spikes have been observed in Sudan, South Sudan, Kenya and across sub-Saharan Africa. Conflicts lead to displacement and further impacts on already vulnerable populations such as agriculturally dependent and politically excluded groups (Trisos et al. 2022), and lack of political freedom limits the capacity for citizen participation and individual climate interventions in Africa (Antwi-Agyei, Dougill & Stringer 2014). A country experiencing political instability will carry limited coping capacity to the impact of climate hazards and be further sensitive to acute climate shocks, as well as receive less financial aid (Chen et al. 2015).

The climate impact responses can be further compromised if fraudulent activities and corruption are commonplace, as resources are incorrectly distributed and managed, which discourages external financing for climate adaptation efforts (Ashurst 2022). As many of the poorest countries and those most vulnerable to climate change impact also experience high corruption, this undermining is exacerbated (Transparency International 2022). Corruption and security can be driving factors to the perceptive rule *of law,* which indicates the confidence society has in the rules of society and enforcement of the law (Kaufmann & Kraay 2010). The trust in governance and public services will depend on the allowed level of citizen participation in selecting and influencing government, as well as freedom of expression, association and free media (Kaufmann & Kraay 2010).

In assessing the views and experiences of national individuals and actors in sectors that are impacted by governance, there exists the WGI. These summarise surveyed views on the quality of governance on a national level and provide composite indicators that cover six different dimensions of governance; *Voice & Accountability, Political Stability and Absence of Violence, Government effectiveness, Regulatory Quality, Rule of Law* and *Control of Corruption* (Kaufmann & Kraay 2010). In addition, in order to address disaster risk reduction, the Sendai Framework is a global action plan which was established in parallel with the Paris Agreement and aimed to prevent new and reduce the current disaster risks and impacts (UNDRR 2015).

3.5 Designing a Composite Index

A country-specific composite index aims to provide a comparison between a group of countries by deriving an ordinal or cardinal scoring based on standardised criteria in order to support analysis and decision-making. Ordinal scoring creates a ranking with no inference on the magnitude of disparities between scores, while cardinal scoring does (Danielson & Ekenberg 2016). Cardinal scoring also allows for greater transparency in the process of reaching the concluding score. A composite index can assess the characteristics of a country by using indicators, which are based on underlying comparable data that accurately reflects the characteristic. They are increasingly being recognised as useful tools in conveying comprehensible summations of complex and elusive underlying problems in order to facilitate public communication and policy analysis. By simplifying and benchmarking comparisons, the public interest may be enhanced and the threshold is lowered for actors to partake in the discussion. However, since the composite indices are by default simplifications, they should be used in combination with the information in the sub-indicators when drawing sophisticated policy conclusions (Organisation for Economic Co-Operation and Development [OECD] 2008). The choice of indicators can be made by surveying literature and consulting experts to find causation between data and the causative characteristic. Generally, the process of converting data into an index follows the following structure (Chen et al. 2015; OECD 2008; Marin-Ferrer, Vernaccini & Poljansek 2017):

Figure 16: Flowchart of the index design process.

1. **Theoretical framework -** A theoretically based framework is needed to guide selections and combinations of indicators in a way that fits the underlying purpose of the index.
2. **Data selection -** Decide upon what characteristics the index should assess, and select and collect raw data that can function as indicators based on some criteria.
3. **Data transformation -** Potential data errors are identified and corrected, and appropriate units and eventual data transformations are chosen to correctly represent the differences in skewed data values and make datasets more comparable.
4. **Missing data -** Missing data for specific countries and indicators are handled through interpolation, labelling of the data points or by complementing with additional indicators.
5. **Scaling -** Choose baseline minimum and maximum levels for the raw datasets in order to counter outliers who may skew the scaling of the data, as well as reference points that represent a maximum value implying zero vulnerability. Indicators are rescaled to have an identical range by normalising using the reference point and range baselines.
6. **Aggregation -** Indicators are aggregated in order to achieve the index scoring. The aggregation is performed using methods such as *arithmetic mean* or *geometric mean* and can use weights when justified to control the contribution of each indicator to the overall composite.
7. **Sensitivity Analysis -** The robustness of the index is analysed by evaluating the inclusion of indicators, the normalisation schemes, the missing data imputations and applied methods for

weighting and aggregation. The correlation and linkages between indicators and dimensions should also be highlighted and assessed.

When creating a composite index, there will always be a valid criticism of objectivity in determining the measure. Designing the composition and choosing the indicators therein will ultimately come down to the decision of the evaluator, and transparent compromises are always needed (OECD 2008). Attributing weights to the components can be helpful in correcting the contributions, but adds another element of subjectivity and increases the involvement of the evaluator and their arbitrary decisions. To maintain objectivity and usefulness, the index needs to be properly based on the theoretical framework and convincingly argued (A.Nika, personal communication, March 2023). Additionally, the design of an index must account for the intended user and therefore be designed in a way that can constitute trust among them. Redundant indicators may be valuable if the data they represent or the organisations they stem from are familiar and trusted by the intended users (A.Nika, personal communication, March 2023).

The number of included indicators will be a key factor for the usability and credibility of an index, and several theories can be adhered to. *Deductive* indices employ a low number of indicators and are based on prior knowledge or theoretical frameworks that support a conviction that the indicators fully capture the objective. If this is not the case, adding more indicators may be required. *Inductive* indices involve a bottom-up approach where a large set of indicators are identified based on the data available and then analysed and culled using statistical methods. The goal is to identify the indicators with the strongest correlation to the underlying objective, and can be done by using Principal Component Analysis. A middle-ground option is a *hierarchical* structure, where one identifies overarching dimension constructs based on the theoretical framework and then divides them into subcomponents that can be indicated using data. The multi-level structure allows for a more nuanced understanding and combines prior knowledge and correlation analysis (S. Marzi, personal communication, April 2023). An index should be created with a clear goal and provide clear information on the state and progress, and the choice of method should mirror the original goal. Fully data-driven indices that use a pool of indicators without prioritizations and sub-indicators might make it harder to discern what drives the performance of a country and dilute the index's initial purpose (Klasen 2018).

The level of aggregation as well as the choice of aggregation method will play a key role in the indicator representation. Those in favour of composite indices argue that the accessibility of an aggregated index is worthwhile. Meanwhile, others argue one should stop the aggregation at a sub-indicator level as additional aggregation hides the inference from the data collection work behind a single arbitrary number that is too reliant on the weighting process by which the variables are combined (OECD 2008). Aggregation methods range from using arithmetic or geometric means, choosing the maximum or minimum value, with each method being suitable for different data characteristics (A.Nika, personal communication, March 2023). Using an arithmetic mean, which is simply the average of the included values, implies that the designer of the index considers the included indicators equal and substitutable through compensation. If one score is high and one is low, the high-scoring indicator will in an arithmetic mean compensate for the lack in the low-scoring one. If a compensation principle cannot be backed, it is advised to avoid the method (S.Marzi, personal communication, April 2023). Using a geometric mean can in these cases be a more advisable choice. A country that does well in one indicator and horribly in another will receive a lower score than a more balanced counterpart, a desirable composition trait. However, the geometric mean is not as transparent and intuitive, and more complex non-linear aggregations like this can make tradeoffs harder to assess and drivers harder to communicate (Sen 1998). Additionally, it requires the aggregated values to be strictly positive and on an identical measurement scale through a consequential normalisation method (OECD 2008).

The quality of a composite index will largely end up depending on the quality of the underlying data, and a lack of reliable data can severely hamper the credibility of an indicator. Internationally comparable data is often scarce, and the reason for data being unavailable can both be random and indicative. OECD mentions in their composite indicator handbook that missing values can depend on the values themselves, and a missing value can signal both high or low true values depending on the nature of the data collection. *Imputation* using substitutions, regressions and algorithms can fill some of the gaps left by missing data, but can introduce further bias and mislead users into thinking data coverage is better than it is (OECD 2008).

A sensitivity and uncertainty analysis is essential for identifying deficiencies in robustness among indicators and assessing to what extent the composite indicator depends upon the input information. It allows an assessment of how underlying uncertainties can propagate throughout the composition and contribute to the final scoring. One such deficiency is an excessive correlation between parameters. If the correlation between two indicators is beyond a given threshold, the inclusion of both indicators can mean counting an aspect twice. However, the causality may not be apparent and two highly correlated indicators can still measure highly different aspects of a problem, meaning statistical comparisons cannot solely be relied upon. Along with correlating indicators, uncertainties may arise from the methodology in weighting, aggregation, normalisation and scaling, and ideally, all potential sources of uncertainties should be evaluated (OECD 2008).

To provide insights into creating an index for climate risk, we examine two existing climate risk indices; The *European Commission Disaster Risk Management Knowledge Centre´s INFORM Risk Index* and the *Notre Dame Global Adaptation Index*.

3.5.1 ND-GAIN

The *Notre Dame Global Adaptation Index,* also known as ND-GAIN, is an open-source global index by the University of Notre Dame which aims to show the vulnerability of a country to climate disruptions, as well as their readiness to initiate adaptive measures. The index covers 192 countries and provides two scores, one *vulnerability score* and a *readiness score* which should be interpreted through the following ND-GAIN Matrix (Chen et al. 2015):

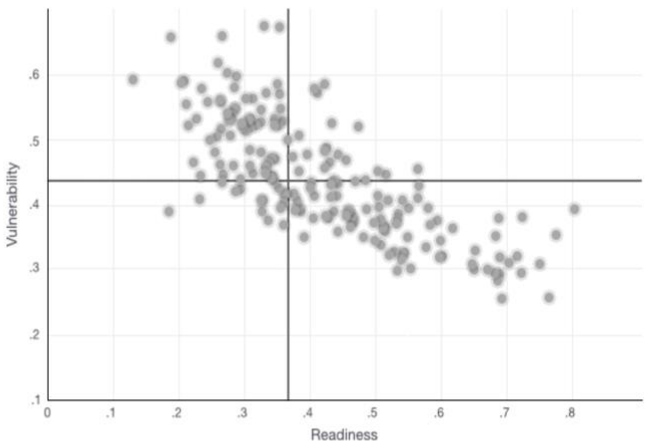

Figure 17: The ND-Gain Index matrix (Chen et al. 2015).

The matrix highlights that the exposure to climate risk and the sensitivity to these disruptions is coupled with the ability to leverage investment for adaptive action. The framework breaks down each aspect into three levels. Vulnerability is broken down into *exposure, sensitivity* and *adaptive capacity*, while readiness consists of *economic, governance*, and *social components*. The vulnerability parameter also breaks down vulnerability into sector-specific vulnerability for six sectors; *Health, Food, Ecosystems, Habitat, Water* and *Infrastructure*. For each sector, two indicators are identified for each component of vulnerability. Since they have three components and six sectors, the vulnerability score is composed of 36 indicators. The economic readiness components have one indicator, and the other components have four each, resulting in nine readiness indicators (Chen et al. 2015).

The ND-GAIN uses a total of 74 data sources to shape their 45 indicators. Their process generally follows the above-mentioned procedure but differs from the INFORM Risk Index in choosing to use reference points that are not always the baseline minimum. A theoretically perfect value for an indicator might be impossible in reality, making a reference point above or below the minimum useful in data scaling. The index scales indicators between 0 and 1 and uses an arithmetic mean without weights to aggregate the two scores, meaning all indicators are equally regarded. The two scores are also compounded into an overall ND-GAIN score (Chen et al. 2015):

$$ND - Gain\ score\ =\ (Readiness\ score - Vulnerability\ score\ + 1) \cdot 50. \quad (1)$$

For each indicator, ND-GAIN provides a description, a rationale for including it, a description of how it is calculated and how many nations it covers, as well as data sources. The choices are based on peer-reviewed material, IPCC Review processes and practitioner feedback, and the indicators are chosen to fit the following criteria (Chen et al. 2015):

- The indicator should focus on sectors and components that have impacts on *human well-being* and *biophysical systems* which affect a country's society, as well as socioeconomic factors that affect said impacts.
- All indicators except those regarding exposure should be *actionable*, meaning it should be possible to act upon and see concrete results.
- The indicators *should be able to scale down* from national to sub-national levels.
- They *avoid using measures related to GDP*, as global inequalities mean it would penalise developing countries.
- The underlying data should be *transparent, available and accessible*, with time series allowing tracking of trends.

The indicators used in the ND-GAIN Index are listed in

Appendix D – ND-GAIN Indicators (Chen et al. 2015).

3.5.2 DRMKC INFORM Risk Index

The INFORM Risk Index provided by the INFORM forum through the Disaster Risk Management Knowledge Centre at the European Commission aims to develop a comprehensive, flexible and evidence-based multi-hazard risk index with global coverage. The composite indicator is designed to support decisions about hazard prevention, preparedness and response by identifying countries at risk from humanitarian emergencies and disasters that could overwhelm current response capacity, and would therefore need international assistance. These disaster risks are not solely focused on hazards driven or induced by climate change. It aims to provide insight into what countries are at risk, what factors are driving the risk, and how these risks change with time (Marin-Ferrer, Vernaccini & Poljansek 2017). INFORM highlights the *pressure and release* relationship of vulnerability, which defines outcomes as occurring at the tangent between the two forces of physical exposure to climate hazards and the pressures and processes that generate vulnerability (Aziz 2018). The index score is an equally weighted aggregation of three dimensions of risk; *Hazards & Exposure, Vulnerability,* and *Lack of Coping Capacity*. The first dimension focuses on the probabilities of acute climate hazards and conflicts, and how many people would be affected. The second dimension addresses socioeconomic fragility that makes the nations more susceptible to the adverse effects of these hazards, and the final dimension addresses the governmental capacity to cope and increase resilience (Marin-Ferrer, Vernaccini & Poljansek 2017). The aggregation is thus as follows:

$$Risk = Hazard \,\&\, Exposure^{1/3} \cdot Vulnerability^{1/3} \cdot Lack\ of\ coping\ capacity^{1/3} \qquad (2)$$

The index uses a total of 54 indicators with reliable data from international sources and academic institutes. The indicators are direct data measures, proxies that can represent the indicator indirectly, or composite indicators of several underlying aspects. The indicators are chosen based on the following criteria (Marin-Ferrer, Vernaccini & Poljansek 2017):

- The underlying data should be open source to increase transparency.
- The underlying data should provide sufficient and consistent global coverage.
- The data should be both temporally and geographically scalable, from a yearly to monthly level and national to a local level respectively.

The INFORM Risk Index is unique in that each score on both category, dimension and total level is discretized into one of five risk classes in order to evaluate risks in a consistent way that is easier to manage (Marin-Ferrer, Vernaccini & Poljansek 2017). It also stands out as they combine the natural hazards with conflict intensity. The chosen hazards are earthquakes, tsunamis, floods, tropical cyclones and droughts, and the natural hazard score is an equally weighted geometric average of the five hazards. Each hazard is thus recognised as equally severe. The final exposure score is then a geometrically weighted average of the total for natural hazards with conflict intensity, meaning these two aspects are recognised as equal. However, where the theoretical framework justifies it, the index does use weights to control the contribution of aggregated indicators (De Groeve, Poljansek & Vernaccini 2014). The index also provides a cluster analysis to identify similarities between countries.

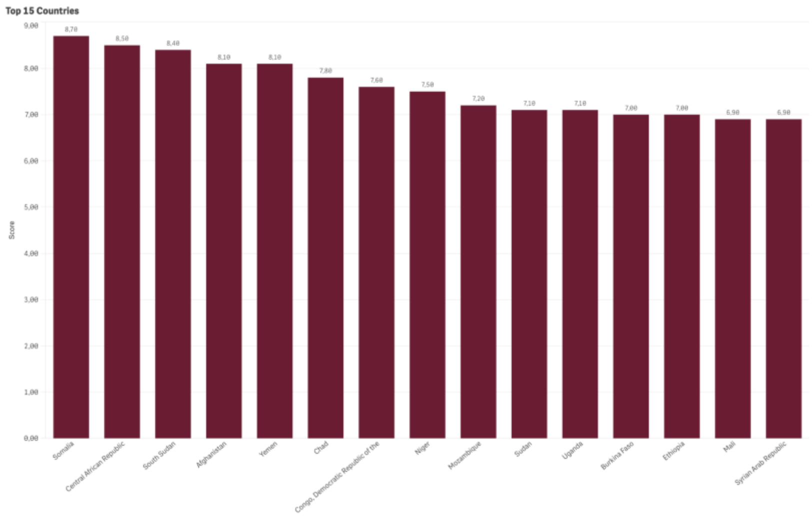

Figure 18: Top 15 countries globally in the DRMKC INFORM Risk Index ((De Groeve, Poljansek & Vernaccini 2014).

When transformations of the data are justified because of skewed data, the Risk Index uses a log transformation. Outliers are identified by evaluating anomalies in skewness and kurtosis, along with box plots. Based on the results of a workshop held by the JRC on composite indicators and scoreboards (Joint Research Centre [JRC] 2015), they set criteria for the maximum skewness and kurtosis allowed. The values were 2 and 3.5 respectively, and were used in an iterative process where minimum and maximum values were labelled as outliers until the remaining values showed skewness and kurtosis below these limits (Marin-Ferrer, Vernaccini & Poljansek 2017).

The creators of the index admit that there are limitations to representativeness because of the use of composite indicators and proxy measures, but state that these are needed for phenomena that cannot be measured by standard data. They also refrain from considering interactions between dimensions, as the methodology is limited to doing so in a quantitative manner. The indicators used in the INFORM Risk Index can be found in

Appendix E - INFORM Risk Index Indicators (Marin-Ferrer, Vernaccini & Poljansek 2017).

3.5.3 SDG Indicators

The 2030 Agenda for Sustainable Development is a project from the United Nations that provides a set of transformative goals and targets for development that aim to eradicate poverty and hunger, and create conditions for sustainable and sustained growth and prosperity. It is based on the existing declarations for human rights and the right of development, and continues to build upon the framework for development that was laid out in the Millennium Development Goals [MDG] by complementing the deficiencies in MDG for reaching the most vulnerable. The agenda presents 17 Sustainable Development Goals [SDG] with 169 targets, combined with indicators brought forth by the Inter Agency and Expert Group on SDG Indicators that aim to assist in evaluating progress. The establishment of these indicators was coupled with an intensified effort to strengthen statistical capabilities and data collection for vulnerable countries, particularly those in Africa. The indicators are set up on a global level, with the intention for member states to develop indicators on a regional and national level to complement them (United Nations Department of Economic and Social Affairs [DESA] 2015) and could be included in assessing countries based on various criterias.

4. Methodology

Although the methodology of building an index follows a standardised structure, the process is littered with trade-offs and simplifications, and will always carry a level of subjectivity. This chapter aims to highlight these tradeoffs and simplifications in order to make the subjective elements as transparent as possible. The overall creation process of the ACHA Index and the decisions therein are based on three main elements:

1. The *Handbook on Constructing Composite Indicators* by the OECD and the JRC of the European Commission.
2. The methodologies and technical documents provided by the similar indices *ND-GAIN* and *INFORM Risk Index*.
3. Input and feedback from interviews conducted with experts on climate change impact as well as composite indices.

The process by which the index was created is illustrated below, with a more detailed process being presented within each step.

Figure 19: Illustration of the methodology process.

4.1 Research Methodology

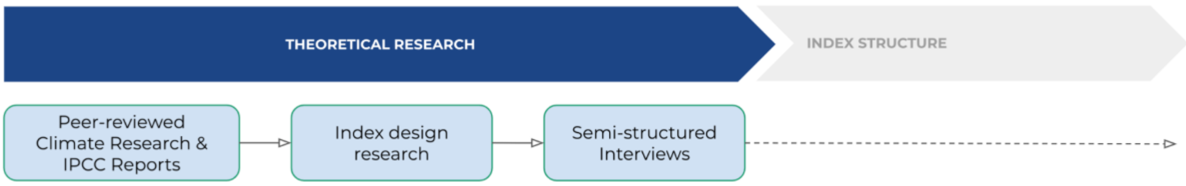

Figure 20: Breakdown of the method for theoretical research.

The decisions and tradeoffs made in creating the ACHA Index are based on the presented theory in the earlier chapter. The research into this theory has been conducted by studying relevant peer-reviewed literature from established and international institutions. It has been rooted in the findings of the IPCC AR6 report and its contributors. The international and collaborative nature of climate change research allows access to transparent and reliable data. Still, as the field is rapidly expanding and evolving, the turnover of knowledge must be accounted for by using updated sources. For example, in the AR5 the risks of desertification were a key point of concern, while the following observations showed a rather opposite trend of expansion of green vegetation in the findings of AR6 (IPCC 2014a). The report has thus prioritised using newer research sources wherever possible.

Constructing an index is, by default, a subjective process of choosing indicators one believes accurately represents a parameter. In order to support these decisions and complement the available peer-reviewed material and IPCC reports, semi-structured interviews have been held with experts in relevant fields. Semi-structured interviews consist of predetermined structured questions but allow for exploratory discussion and open responses in order to encourage elaborations and to pivot based on the received answers (Barclay 2018). The interviewees have mainly been consulted to provide insight into adaptation measures, which help the discussion of how the index results can and should be interpreted. Decisions regarding index design and data handling have been consulted with authors from the ND-GAIN and INFORM Risk Indices. The interviews held are credited below in Table 2:

Table 2: Interviewees used in the creation of the ACHA Index.

Name	Position	Organisation	Interview Date
Dr Olufunso Somorin	Regional Principal Officer	African Development Bank	27/03/2023
Lindelwe Lesley Ndlovu	CEO, African Risk Capacity [ARC]	The African Union	28/03/2023
Angeliki Nika	INFORM Index Co-Author	ACAPS	31/03/2023
Sepehr Marzi	INFORM Index Author	Joint Research Centre [JRC]	03/04/2023
Jessica J. Hellmann	ND-GAIN Index Co-Author	University of Minnesota	05/04/2023
Nfamara Dampha	Research Scientist, Natural Capital & Ecosystem Services (US)	University of Minnesota	25/04/2023
Felix Kanungwe Kalaba	IPCC Lead Author	Copperbelt University	30/05/2023

4.2 Index Structure

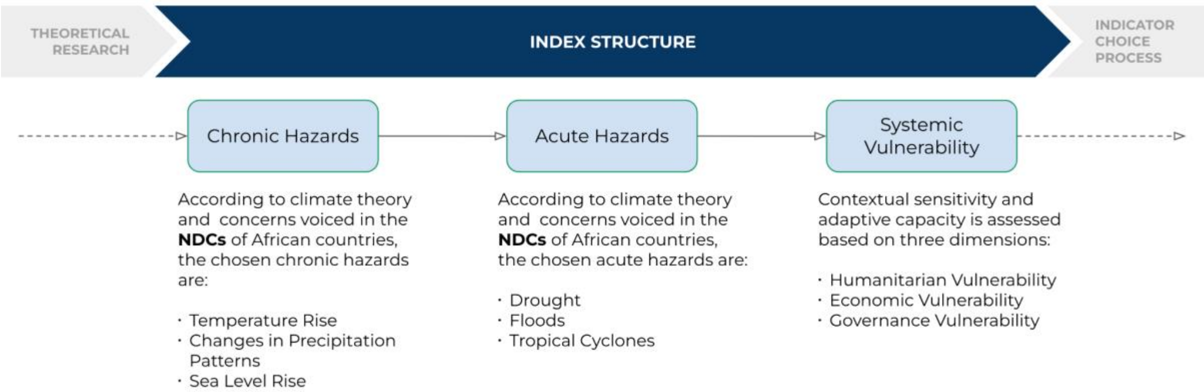

Figure 21: Breakdown of the method for designing the index structure.

The ACHA Index structure is designed in order to fulfil the established objectives and provide insight into climate risks for individual climate hazards. It defines vulnerability to climate hazards by using a *pressure and release* model. The index weighs the exposure to specific climate hazards with the processes that drive sensitivity to each hazard. The exposure and sensitivity to a hazard are assessed in order to create a sub-dimension score that represents the national vulnerability for each hazard. Separating the individual acute and chronic hazards allows more transparent communication of the exact characteristics and drivers of each climate hazard risk. This will in turn be a relevant input into decisions for adaptation measures and financing of these, as widely different financing structures are needed based on the risk (International Group of Seven [G7] & Vulnerable 20 [V20] 2022). While there is an interplay between the occurrence of acute and chronic climate hazards, they are kept separate to highlight this difference in the required adaptation approach. The ACHA Index consults the existing theory in climate risk impact and the concerns voiced by African parties in their NDCs in order to choose three hazards each for acute and chronic hazard risk, which can be regarded as being the most stressing for the African continent. The included acute hazards are *floods, droughts* and *tropical cyclones*, while the chronic hazards included are *temperature rise, precipitation changes* and *sea level rise*.

The structure of the ACHA Index will follow a *hierarchical* structure, with the different hazards as the overarching structure and the exposure and sensitivity aspects as the subcomponent breakdown with relevant indicators. Basing the index structure on keeping different hazard risks separate may cloud the fact that climate hazards are heavily interlinked. Temperature rise is a driving factor for many different climate change processes that lead to other climate hazards, and the occurrence of one hazard may limit or compound effects from others. One such interesting example is the changes in precipitation patterns. A decrease in precipitation may cause droughts, while an increase in heavy precipitation can lead to floods. Sea level rise will also affect the impact of coastal flooding. By identifying separate exposure indicators with climate projections that take these interplaying effects into consideration, the index aims to account for the correlation while also allowing the sensitivity indicators to separately reflect the drivers of impact from each hazard. The correlations and potential effects of an increase in another hazard are not included in any other way than the projections in order to keep the index structure simple and easily understood. If the sensitivity drivers are the same for several hazards, the index is allowed to use the same indicators for these.

Systemic vulnerability accounts for the contextual sensitivity of each nation and provides a separate sub-dimension from the climate hazards. The systemic vulnerability is represented by sensitivity factors that cannot be derived back to a specific hazard, but play a key role in the severity of climate change impacts and African nations' adaptive capacity. This systemic vulnerability highlights the already existing strains on human and natural systems and can indicate proximity to potential breaking points, where additional setbacks are more severe. Climate risk impact research has been consulted in order to choose three relevant sub-dimensions of systemic vulnerability, each of which is aggregated separately. The chosen subdimensions are *humanitarian vulnerability, economic vulnerability* and *governance*. An overall index score is computed using the systemic vulnerabilities together with the six chosen hazards to allow for comparisons between countries. Still, the importance of understanding the underlying sub-indicators and their contribution is particularly stressed.

4.3 Indicator Choice Process

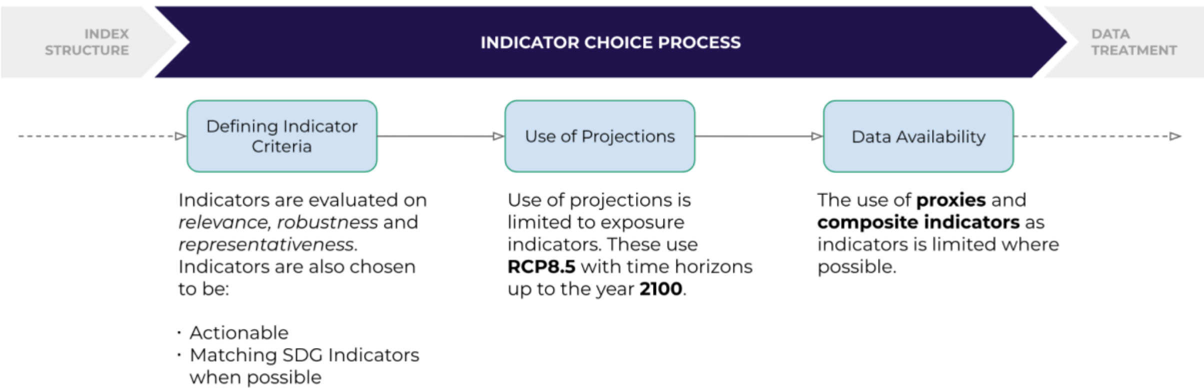

Figure 22: Breakdown of the method for the indicator choice process.

The indicators have been chosen in order to accurately and exhaustively describe their respective sub-dimension. Each indicator has been evaluated on relevance, robustness and representativeness in order to minimise subjectivity in the design process. The collective exhaustiveness of the indicators implies a tradeoff with the usability of the index, as the inference from the aggregated score becomes increasingly obscure the more indicators are included. Including too many indicators may counteract the original goal of starting a dialogue, as the general applicability and interpretability that helps in doing so can suffer (J. Hellmann, personal communication, April 2023). This evaluation is done on a case-by-case basis, as the number of necessary indicators to represent a hazard will vary greatly. Some aspects of climate change impact are also highly complex and may affect concentrated areas greatly while not others, such as the melting of glaciers around Kilimanjaro. In order to not shift focus from more severe and integrated risk aspects, indicators for these types of diffuse impacts have been excluded.

Outside of hazard exposure, which is driven by global climate change trends, the indicators were chosen based on criteria of actionability. Decision-makers should be able to potentially take action on the issues the indicator highlights and be able to influence the outcomes over time, given that the resources are available. This makes the output of the ACHA Index clear and is in line with the foundational goal of helping policy-maker decision processes. As the index keeps humanitarian aspects central throughout, the goals and targets set out in the Agenda 2030 for Sustainable Development are highly relevant and share the same vision. The indicators used to track the progress in the SDGs have therefore been prioritised where relevant in the indicator choice progress, as these datasets are considered approved by the highly credible project and therefore suitable for this index (DESA 2015).

4.3.1 Projections

Projections have been used as indicators to evaluate the future levels of hazard risks when available. These projections are based on the RCP and SSP scenarios for GHG emissions and socioeconomic conditions, and are reliably provided by the IPCC together with the climate modelling community (IPCC 2021). Scenario projections for all of the hazards are not fully available under the CMIP5 models and will be made available and improved in the upcoming CMIP6 model assessments (S. Marzi, personal communication, April 2023). Using projections for the expected physical changes in climate enables the index to assess future vulnerability and can allow for more proactive decision-making. Projections for hazard sensitivity and systemic vulnerability factors are not guaranteed to carry the same robust scientific foundation as the climate modelling projections and can be heavily dependent on unknown outcomes of future socioeconomic trends and adaptation efforts. The inclusion of such projections has thus been evaluated on a case-by-case basis. In order to derive the true climate-induced exposures to each hazard, the projections have used the RCP 8.5 scenario with time horizons ranging from 2040 to 2100. This more pessimistic scenario allows the index score to more clearly highlight the differences between the countries in hazard exposure.

4.3.2 Data Availability

The choice of indicators to address an aspect of sensitivity can, in some cases, be a tradeoff between data availability and relevance. Thorough research into climate change impact is often done on spatial or continental levels, and breakdowns of impact on national levels are rare and incomplete for African nations in some research areas. While the need for relevance of an indicator to the aspect it is describing is rather obvious, the data availability must also be considered. Methods to handle missing data such as those mentioned in the theory exist, but will make the final result less reliable. If specific nations for various reasons are underrepresented in available data for several indicators, their final scoring will end up arbitrary. Some aspects of vulnerability, such as the economic damages attributed to sea level rise, are heavily understudied and can therefore not be accounted for in the creation of the index. Even though tampering with data relevance was avoided to the highest possible extent, some indicators have been modified to fit the national scale of comparison to improve data availability.

Some drivers of sensitivity are difficult to represent and compare accurately using only pure data. Additionally, some aspects of vulnerability may even be misleading to measure with their direct data because of low data availability or irregular characteristics. In these cases, the index has been allowed to deploy the use of *proxies*. Proxies are indicators that use data that is not directly derived from the aspect it means to indicate but rather from indirect but heavily correlated aspects that can be used as an estimation for comparisons and trends. It should have the same features as the direct indicator it substitutes and provide sufficient information to allow the same assessment as intended for the unavailable original indicator (European Commission 2016). However, as they introduce additional variability and subjectivity to the assessment, the use of proxies is strictly limited to sensitivity aspects for which there is no available or appropriate data and where the substitute can be robustly warranted.

Some sensitivity factors are complex and have many different aspects that drive the vulnerability with no common meaningful unit, making it difficult to perform assessments on a national level. In these cases, the index is restricted to using other *composite indicators*. Composite indicators are aggregations of several sub-indicators that may have no obvious common unit, which can provide a simplified conclusion to multi-dimensional issues. For example, using some existing index as an indicator for an aspect would mean using a composite indicator, the design of which may involve subjective decisions or simplistic comparisons that fail to highlight severe failings in some parts of systems (Saisana 2004). However, many composite indicators are constructed from reliable sources and are backed by credible and substantial resources that the creators of this index do not possess. For this reason, composite indicators are allowed but limited to when data availability and data characteristics restrain other options.

4.4 Data Treatment

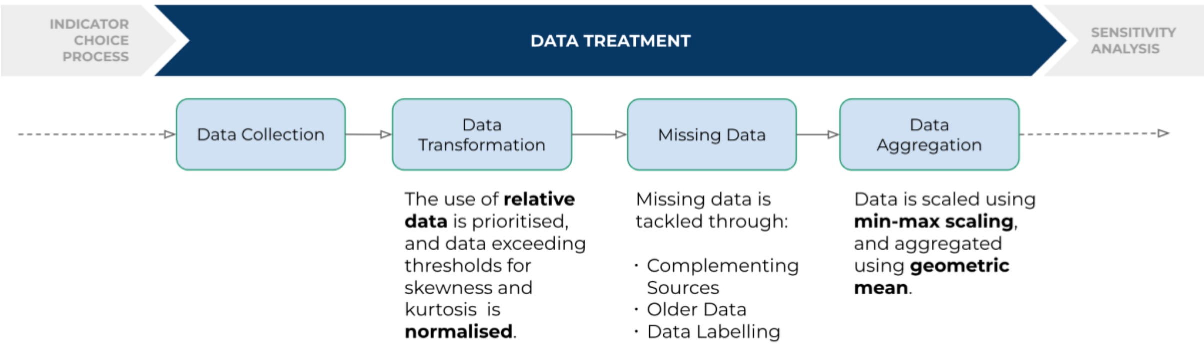

Figure 23: Breakdown of the method for the data treatment process.

4.4.1 Data Collection

Once the relevant indicator has been identified, the data collection has been focused on finding reliable sources with sufficient data coverage. Organisations such as the World Bank, The Food and Agriculture Organisation [FAO] of the UN, and the World Health Organisation [WHO] are recurring sources, and similarly trusted international organisations have been prioritised. Datasets that rely on self-reporting from participating have been avoided whenever possible in order to avoid bias in the data reporting. All of the data has been checked to identify potential data errors.

4.4.2 Data Transformation

Relative data have been prioritised or retrieved from absolute data when available by including percentage values instead of total values. This is done in order to scale the values with the national context and so as not to penalise smaller countries. When the ACHA Index uses absolute or generally unevenly distributed data, the normality of the data has been evaluated and corrected when considered necessary. This evaluation was performed by creating a histogram of the data, as well as calculating the skewness and kurtosis. The data has been deemed far from Normal distribution if the histogram shows highly skewed data and if the skewness exceeds an absolute value of 2 and the kurtosis exceeds an absolute value of 3.5. These thresholds are taken as advised by the INFORM Risk Index methodology, as mentioned in the theory. On the occasions where the data is deemed not Normal enough according to these criteria, the histogram has been used to evaluate the best course of action. If the skewness is caused by one or several obvious outliers, these have been iteratively omitted until the criteria were met. These outliers, if examined correctly, were then given the maximum or minimum value based on which tail of the distribution they reside in. If the data assumes a histogram similar to a logarithmic distribution, which was often the case for absolute data, the dataset has been normalised by using a base ten logarithm. This makes the indicator pay higher regard to the differences between similar lower values in the more densely populated section of the distribution. In the case of a logarithm being used, a minimum reference value has been set in order to avoid excessively small or infinitely small minimum values for the logarithm of very low numbers and zeros respectively. In these cases, all values below the reference point are given the reference value. Because of the min-max scaling, these countries will receive the minimum/maximum score for that indicator.

4.4.3 Missing data

In the cases of missing data for individual countries, the first hand choice is to find complementing sources for the same data with similar reliability for these countries. If this is not possible, older data from the original dataset is used as an estimation if regarded as still applicable. Suppose the data in an indicator is more scarce and missing for a considerable number of countries. In that case, the indicator when possible includes additional complementing datasets that do not measure the same data but are still deemed suitable for driving the indicator. As the main objective of the index is to highlight individual differences between African countries, interpolation with similar countries has not been performed. Suppose none of the above-mentioned methods for missing data is applicable. In that case, the country data is labelled as missing and the indicator is omitted from the sub-dimension aggregation for that country.

4.4.4 Data aggregation

When the missing data has been handled and the distribution is satisfactory, the data is scaled down to a comparable scale using *min-max scaling*. By rescaling the data in the range between the maximum and minimum value, the resulting score on a scale from 0 to 1 will be in regard to the common limitations and potentials of the region. The nation with the best score is not necessarily perfect in the evaluated aspect but is performing the best in the region. This scaling method helps the goal of highlighting the regional differences, as it widens comparisons of indicators that range within a small interval (OECD 2008). The formula for calculating the scaled value is given in Equation 3 below:

$$X_{scaled} = (X_0 - MIN)/(MAX - MIN) \qquad (3)$$

If an indicator uses more than one dataset, the overall score for the indicator is calculated as a geometric mean of the scaled values of each dataset. In the cases where the performance of the included sets is considered substitutable, an arithmetic mean is applied instead. Since the geometric mean functions as a way to pay higher regard to poor scores, the scaling needs to be directed accordingly. By letting 0 indicate the worst possible score and 1 being the best, the low scores will be regarded correctly by the geometric mean. Since min-max scaling is used, the dataset will contain at least one nation with a score of 0. The geometric aggregation approaches zero when one of the underlying values approaches zero, so a method of balancing this influence over the mean needs to be found. This is done similarly to the method for avoiding the same problem for the transformation, where a reference value is identified and assigned to all scores below it. An iterative method of trial and error is used to balance this influence, and the final reference value is assigned as 0,01. Scaled values below 0,01 are rounded up to 0,01 in the calculation of the geometric mean, and missing values are not included. When the geometric mean is computed, the aggregated score will not necessarily be scaled between 0 and 1 anymore, and is thus rescaled in order to be comparable to other scores. The geometric mean is also used with the same reference value for aggregating the different indicators into the sub-dimensions of hazards and systemic vulnerabilities, and is finally inverted so as to provide a higher score for a higher risk. The formula for the geometric mean X of n included scores is given in Equation 4 below:

$$X = \left(\prod_{i=1}^{n} x_i\right)^{1/n} = \sqrt[n]{x_1 x_2 x_3 \dots x_n} \qquad (4)$$

When aggregating the different indicators, there are arguments to be made for weighting the included indicators differently. However, this would imply that the index explicitly states that one indicator is more important than another, which introduces additional subjectivity to the index. If weighting is done based on data coverage or quality, it may introduce bias against more complex information that is harder to measure but still plays a vital role (OECD 2008). Weighting is therefore avoided between different sensitivity indicators, as well as for the systemic indicators. However, since sensitivity does not matter if there is no exposure, weighting is implemented for the exposure indicator for each hazard. As there is no evidence to explicitly state whether exposure or sensitivity is more detrimental, the two aspects of vulnerability are weighted equally. This means that the index first aggregates the sensitivity indicators and exposure indicators into separate scores using the geometric mean, and these are then combined with another geometric mean into a final hazard score.

4.5 Sensitivity Analysis

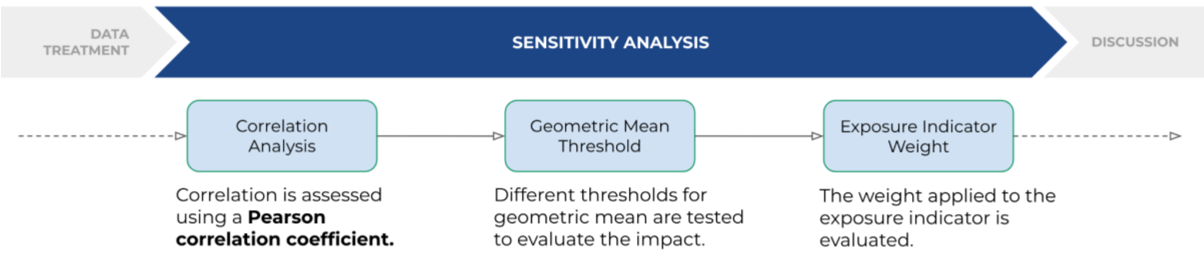

Figure 24: Breakdown of the method for the sensitivity analysis.

The importance of a thorough sensitivity analysis when assessing the credibility and useability of an index must be stressed. However, the scope and resources of this paper are not sufficient to perform a fully comprehensible high-end statistical analysis of the contribution of all aspects which introduces some level of uncertainty. Therefore, the most common drivers of uncertainty mentioned in the theory have been identified and evaluated using established methods of analysis, and the identified results of this analysis are complemented with a discussion of potential improvements in the latter chapters.

4.5.1 Correlation Analysis

In order to ensure that the level of collinearity between equally weighted indicators is limited, an analysis of statistical correlation has been performed using the *Pearson correlation coefficient*. Suppose the correlation between two indicators is above a certain threshold. In that case, they are considered as double counting and one is removed in order to minimise the number of indicators and reinstate equal weighting. The Pearson correlation coefficient, also known as the *Pearson product-moment correlation coefficient* calculates the correlation between the random variables X and Y as the following (OECD 2008):

$$R_{xy} = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{(n-1)s_x s_y} \qquad (5)$$

Here $\bar{x}$ and $\bar{y}$ denote the means of the values of the two different indicators being compared, and s_x and s_y denote the standard deviations of each set of indicator values. The coefficient takes on a value between -1 and +1, where a positive value indicates a positive correlation. As the correlation analysis requires values for all data points, missing data for this assessment has been substituted with the average value from all countries for the specific indicator where data is missing. The identified level of correlation uses thresholds values established by Evans (Evans 2021):

Correlation Value	**Strength of Correlation**
1 (+/-)	Perfect Correlation
0.6 -1 (+/-)	Strong Correlation
0.4 - 0.6 (+/-)	Moderate Correlation
0 - 0.4 (+/-)	Weak Correlation
0	No correlation

A similar correlation analysis is also conducted in order to compare the ACHA Index scores with ND-GAIN and INFORM's Risk and Climate Change indices. To enable comparability of the data, it will be normalised on a scale ranging from 0-1, with 1 representing the most vulnerable nation. The purpose of the analysis is to assess similarities and differences between the indices.

4.5.2 Geometric Mean Threshold

Since the geometric mean is the most widely used aggregation method throughout the index combined with the min-max scaling, the problem of aggregating zeros arose. In order to counter this and limit the exponential influence on the mean of a country scoring the lowest, a threshold was set for which all values below were set. The choice of threshold is a subjective assessment and does not have a strong foundation in the theoretical framework. Therefore, the choice of threshold has been studied in this uncertainty analysis. Three different thresholds were compared for the geometric aggregations on the indicator level as well as the aggregation of the total score, and the main differences and impacted countries were highlighted.

4.5.3 Exposure Indicator Weight

The only weight included in the index is applied in the physical hazard aggregations. Based on the theory of three dimensions of vulnerability, the exposure to risk is combined with the sensitivity to said risk. The theoretical framework does not give any evidence as to whether or not any of these aspects play a more important role in contributing to the overall vulnerability, and the goal of the aggregation is therefore to avoid inferring such by weighting them equally. Since the physical hazards mainly use only a single exposure indicator and several sensitivity indicators, the weight for the exposure is implemented. In order to assess to what extent this weighting affects the outcome of the index, a sensitivity analysis is performed where the weighting is at first removed, implying sensitivity plays a bigger role, and then enhanced, which implies the opposite

5. Results

This chapter lays out a comprehensive presentation of the final index. The first section of the chapter contains an introduction to each ACHA indicator, together with a description of the dataset used, the underlying reasoning for inclusion and a link to the original source. The subsequent section presents the ACHA Index scores, followed by the results of the sensitivity analysis.

5.1 ACHA Index Indicators

The following tables list all the indicators used in the ACHA Index. Below the tables, each indicator is presented with a description, a motivation for inclusion and eventual notes on cautions and data shortages, as well as the source.

5.1.1 Acute Hazards

Table 3: Overview of the composed indictors reflecting the acute hazards.

Acute Hazards			
Hazard Name	**Drought**	**Floods**	**Tropical Cyclone**
Exposure	Drought Exposure: Current Baseline and future projection	Flood Exposure: Current Baseline and future projection	Tropical Cyclones Exposure: Current Baseline and future projection
Sensitivity	Crop Yield Loss	Urban Growth	Level of Infrastructure
	Rural Population	Food Insecurity	Slum Population
	Rainfed Agriculture	Slum Population	Healthcare Access
	Food Insecurity	Level of Infrastructure	Healthcare Expenditure
	Water Insecurity	Water- and Vector-Borne Disease Spread	Water-Borne Disease Spread
	Population Growth		

5.1.1.1 Droughts

Drought Exposure: Current Baseline & Future projection

Description: The current baseline for drought exposure uses the exposure provided in the INFORM Risk Index. The data uses the estimated number of people exposed to severe and extreme drought based on a 12-month period standardised precipitation evapotranspiration index (SPEI) Dataset for historical periods (1976 to 2005) combined with future projections up to 2080 (RCP4.5 and RCP8.5). The Climate Knowledge Portal is used to provide the projected exposure of droughts simulated with the Annual

SPEI Drought Index for 2080-2099 using the SSP5 and RCP8.5 scenarios. The projections are collected for each province, summarised and aggregated to a common score for the overall country.
Rationale: Current baseline of drought exposure for each country indicates the current exposure to the natural hazard. Future projected exposure to droughts for each country indicates its likelihood of being exposed to severe droughts as a consequence of climate change later this century.
Notes:
Source: INFORM Risk Index (DRMKC European Commission), Climate Knowledge Portal (World Bank)

Crop Yield Loss

Description: The projected reduction in crop yield attributable to climate change by mid-century for three crops: rice, wheat and maize.
Rationale: Crop yield reduction can serve as a critical indicator of a country's sensitivity towards droughts. Drought can cause soil moisture levels to decrease, resulting in crop wilting and death. This in turn can lead to reduced crop yields, lower farmer incomes, and food shortages. By monitoring crop losses, policymakers can pinpoint regions that are highly susceptible to drought and allocate resources to address the impact of climate change on agriculture.
Notes:
Source: ND Gain Indicator

Rural Population

Description: Rural population as a percentage of the total population up until 2020 combined with the rural population growth in 2021.
Rationale: Rural communities often depend on agriculture, have limited access to key information and resources, and lack essential infrastructure, all of which are negatively impacted by droughts. The greater the proportion of rural people living in rural areas, the more vulnerable a country is to drought.
Notes:
Source: World Bank (1), (2)

Rainfed Agriculture

Description: The indicator shows the ratio of arable land not equipped for irrigation as a percentage of total arable land as a 3-year average from 2017-2019. Arable land refers to the area used for temporary agricultural crops, temporary meadows, market and kitchen gardens, and temporary fallow land. It does not include abandoned land from shifting cultivation and does not indicate the total potentially cultivable land.
Rationale: The theory highlights that 95% of African cropland is solely rainfed, implying reductions in precipitation will negatively impact agricultural yields. The higher the percentage of agriculture which is solely rainfed, the bigger the sensitivity during a drought.
Notes: Data for *South Sudan* is missing from the original FAO source, and complemented from an internal South Sudanese Agriculture sector policy framework for the period 2012-2017.
Source: Food and Agriculture Data FAOSTAT, FAOLEX Database

Food Insecurity

Description: Prevalence of moderate or severe food insecurity as a percentage of the total population in 2020.
Rationale: As food production is limited during droughts, which causes greater food stress during the drought. A population already facing food scarcity is therefore particularly sensitive towards droughts, as compounding food stress has more severe impacts. The indicators reflect the SDGs 2.1-2.2, aiming to combat hunger and malnutrition, especially in vulnerable communities.
Notes: Data has been complemented with the Global Hunger Index (2015) for the following countries: *Burundi, Chad, Gabon, Mali, Niger, Rwanda* and *Seychelles.* In addition, *Eritrea* and *Equatorial Guinea* have data points from The Borgen Project (2020).

Source: World Bank, Global Hunger Index, Borgen Project

Water Insecurity

Description: The indicator combines three datasets: (1) Percentage of the population using at least basic drinking water services, (2) Mortality rate attributed to unsafe water, unsafe sanitation and lack of hygiene and (3) Water stress, indicated by the freshwater withdrawal as a proportion of available freshwater resources. The data is collected from 2016-2020.
Rationale: A country's vulnerability to drought depends on its water supply, which is not always linked to the amount of water available. Regions that depend mainly on rainfall for their water supply are more likely to suffer from drought than regions that have access to other sources, such as rivers or groundwater. When a drought occurs, water shortages can lead to poor sanitation and hygiene, increasing the spread of infectious diseases. If these issues were already stressed before the drought, it indicates an already strained system that may be further exacerbated by the drought. The indicator and its components are in line with SDG 3.9 which aims to reduce the number of deaths and illnesses due to unsafe water, and SDGs 6.1-6.4 which aim to ensure the availability of fresh and safe water as well as sustainable sanitation to all.
Notes: Water stress data is missing for *Seychelles* and is therefore not included in the aggregation for the total indicator.
Source: World Bank(1), (2), (3)

Population Growth

Description: Annual percentage population growth. Data was taken from the latest update from 2021.
Rationale: Experts predict that in the next few decades, population growth will have a greater impact than climate change on the number of people facing water scarcity. Around 40% of the increase in exposure to water stress can be attributed to population growth alone, while the remaining percentage is influenced by both population growth and anthropogenic climate change. High population growth therefore indicates a bigger susceptibility to water stress.
Notes:
Source: World Bank

5.1.1.2 Floods

Flood Exposure: Current Baseline & Future projection

Description: Percentage of the population exposed to high flood risk. Jun R. et al. merge three types of baseline flood exposure: coastal, pluvial, and fluvial floods. The projected exposure of floods, riverine and coastal is simulated with the INFORM Climate tool using the SSP5 and RCP8.5 scenario for the time horizon up to 2080.
Rationale: The flood exposure baseline for each country indicates the historical occurrence of floods and their current impact on people. The projected exposure to floods for each country indicates its likelihood of being exposed to the hazard and its impacts as a consequence of climate change later this century.
Notes:
Source: Rentschler, J., Salhab, M., Jafino, B.A. (2022)., INFORM Climate Change Tool (DRMKC European Commission)

Urban Growth

Description: Annual percentage urban population growth from 2021.
Rationale: As cities grow, they often expand into previously undeveloped areas such as forests, grasslands and wetlands. These natural areas play an essential role in regulating water flow by absorbing

rainfall, filtering out pollutants and slowly releasing water into streams and rivers. In a country with high urbanisation growth, these natural areas are often paved or built up, which can increase the risk of flooding.
Notes:
Source: World Bank

Food Insecurity

Description: Prevalence of moderate or severe food insecurity as a share of the total population in 2020.
Rationale: Floods can have a significant impact on food production and availability. Floods can destroy crops, contaminate water sources and disrupt transport networks, leading to food shortages and increased prices. Countries and regions with already high levels of food insecurity are therefore particularly vulnerable to these impacts. The indicators reflect the SDGs 2.1-2.2 which aim to end hunger and malnutrition, especially in vulnerable communities.
Notes: Data has been complemented with the Global Hunger Index (2015) for the following countries: *Burundi, Chad, Gabon, Mali, Niger, Rwanda* and *Seychelles*. In addition, *Eritrea* and *Equatorial Guinea* have data points from The Borgen Project (2020).
Source: World Bank, Global Hunger Index, Borgen Project

Slum Population

Description: The percentage of urban populations living in slums in 2020. The definition used for a 'slum household' is a household which lacks one of the following; *Water service access, sanitation facility access, sufficient living area,* and *housing durability*.
Rationale: Slums often lack adequate housing infrastructure and are often built in low-lying areas prone to flooding. In addition, slums often lack proper sanitation and waste disposal, systems which are stressed during floods. This can increase the risk of clogging waterways and drainage systems, which further increases the severity of flooding.The urban slum dataset is included as an indicator for SDG 11; *Make cities and human settlements inclusive, safe, resilient and sustainable.*
Notes: The urban slum dataset lacks data for 2020 for some countries. For *Comoros, Gabon, Namibia* and *Niger,* data from 2018 is used instead. For the *Central African Republic* and *South Sudan*, data from 2016 is used. A separate UN Habitat source with data from 2018 is used for *Somalia, Equatorial Guinea* and *Djibouti*. Data is missing for *Cabo Verde, Eritrea, Libya, Algeria, Mauritius* and *Seychelles*.
Source: World Development Indicators [WDI], World Cities Report 2020, UN Habitat

Level of Infrastructure

Description: The AfDB has produced the Africa Infrastructure Development Index [AIDI] in order to monitor and evaluate infrastructure development progress in Africa.The AIDI comprises four composite indices: (1) Transport composite Index, (2) Electricity composite Index, (3) ICT composite Index and (4) WSS composite Index.
Rationale: Underdeveloped transportation systems are more likely to be damaged by flooding, making it more difficult to repair and making roads or railways unpassable. Flooding in areas with poor ICT and electricity infrastructure can cause more severe impacts on critical services such as healthcare facilities and communication systems and lead to extended power outages. Electricity access is also crucial for adaption measures. Lack of well-functioning ICT connectivity can hinder the implementation of early warning systems and emergency response. In addition, as floods contaminate water sources and damage WSS facilities, a low level of WSS infrastructure could make the country even more vulnerable to waterborne diseases and reduce access to safe drinking water and sanitation. This indicator is related to SDG 11.5 aiming to drastically reduce the number of deaths and people affected as well as economic losses due to natural disasters and increase the protection of poor and vulnerable populations.
Notes:
Source: African Development Bank [AfDB]

Water- and Vector-Borne Disease Spread

Description: The indicator combines the prevalence of malaria, cholera and typhoid fever. The indicator for malaria combines the national incidence and morbidity of malaria. The incidence measures the number of new cases of malaria per 1000 populations at risk per year, where the population at risk is defined as communities living in areas where malaria transmission occurs. National malaria control programs reported the deaths resulting from locally transmitted malaria to WHO, and species-specific case fatality rates were applied after estimating the number of malaria cases per Plasmodium species to determine the number of deaths. Meanwhile, the water-borne diseases only use the estimated number of cases from 2022 and 2017 respectively. The water-borne diseases group countries into five different groups based on their level of incidence, on a scale from 0 to 5.

Rationale: Many studies have shown the link between floods and malaria outbreaks and also a significant increase in disease susceptibility after flood exposure. The impact of floods on water and sanitation infrastructure will also increase the risk of water pollution and increased competition for water resources, which is associated with the spread of waterborne diseases such as cholera and typhoid. An already high prevalence of these types of diseases may indicate a higher disease burden and weak coping systems and is thus used as a sensitivity indicator. The indicator is linked to Sustainable Development Goal 3.3 which targets epidemics of malaria as well as tropical, waterborne and other communicable diseases.

Notes:

Source: World Health Organisation [WHO], European Centre for Disease Prevention and Control [ECDC], The Lancet

5.1.1.3 Tropical Cyclones

Tropical Cyclones Exposure: Current Baseline & Future Projection

Description: The INFORM Climate Change Tool is used to indicate the current baseline exposure for tropical cyclones as of the year 2022 as well as the projected exposure to tropical cyclones, simulated with the tool using the SSP5 and RCP8.5 scenario for the time horizon up to 2080.

Rationale: The baseline shows how affected the country is today and provides insights into its vulnerability to continued and increasing exposure to the hazard. The future projected exposure of tropical cyclones for each country indicates its likelihood of being exposed to the hazard and its impacts as a consequence of climate change later this century.

Notes:

Source: INFORM Climate Change Tool (DRMKC European Commission)

Slum Population

Description: The percentage of urban populations living in slums in 2020. The definition used for a 'slum household' is a household which lacks one of the following; *Water service access, sanitation facility access, sufficient living area,* and *housing durability*.

Rationale: People living in slums are often more vulnerable to the effects of extreme weather events such as tropical cyclones. Slums are usually characterised by poor housing conditions, insufficient infrastructure and limited access to basic services such as healthcare and clean water. Therefore, people living in slums are often more exposed and vulnerable to the effects of extreme weather events such as tropical cyclones, including flooding, landslides and wind damage. Countries with high slum populations are likely to be more vulnerable to these events and may need more support and resources to build resilience and adapt to the effects of climate change. The urban slum dataset is included as an indicator for SDG 11; *Make cities and human settlements inclusive, safe, resilient and sustainable.*

Notes: The urban slum dataset lacks data for 2020 for some countries. For *Comoros, Gabon, Namibia* and *Niger,* data from 2018 is used instead. For the *Central African Republic* and *South Sudan*, data from

2016 is used. A separate UN Habitat source with data from 2018 is used for *Somalia, Equatorial Guinea* and *Djibouti*. Data is missing for *Cabo Verde, Eritrea, Libya, Algeria, Mauritius* and *Seychelles*.
Source: World Development Indicators [WDI], World Cities Report 2020, UN Habitat

Healthcare Access

Description: The number of nurses and midwives per 1000 people, who include both professional, auxiliary and enrolled nurses and midwives as well as other associated personnel. The data is collected between 2014-2020.
Rationale: The proportion of the population with access to health care can be an important indicator of a country's vulnerability to tropical cyclones. Examining the level of access to health care can provide insight into a country's vulnerability to the health impacts of tropical cyclones. Adequate health services can help meet the health needs of the affected population and prevent the spread of diseases in the aftermath of the disaster. The indicator reflects SDG 3c which focuses on substantially developing the healthcare systems and looks into the health worker density and distribution.
Notes:
Source: World Development Indicators [WDI]

Healthcare Expenditure

Description: The indicator shows the 2019 expenditure per capita in current US dollars, including healthcare goods and consumed services.
Rationale: Governmental expenditure on healthcare, including medical facilities, trained healthcare workers, and essential medicines, can help to prevent and treat health issues caused by tropical cyclones. By examining the level of government expenditure on healthcare, you can gain insights into a country's level of preparedness and capacity to respond to the health impacts of tropical cyclones. The indicator is connected to SDG 1a which focuses on government expenditure on essential services.
Notes: Data is missing for *Somalia* and *Libya.*
Source: World Development Indicators [WDI]

Level of Infrastructure

Description: The African Development Bank has produced the Africa Infrastructure Development Index (AIDI) to monitor and evaluate infrastructure development progress in Africa.The AIDI comprises four composite indices: (1) Transport composite Index, (2) Electricity composite Index, (3) ICT composite Index and (4) WSS composite Index.
Rationale: Underdeveloped transportation systems are more likely to be damaged by flooding, making it more difficult to repair and making roads or railways unpassable. Flooding in areas with poor ICT and electricity infrastructure can cause more severe impacts on critical services such as healthcare facilities and communication systems and lead to extended power outages. Electricity access is also crucial for adaption measures. Lack of well-functioning ICT connectivity can hinder the implementation of early warning systems and emergency response. In addition, as floods contaminate water sources and damage WSS facilities, a low level of WSS infrastructure could make the country even more vulnerable to waterborne diseases and reduce access to safe drinking water and sanitation. This indicator is related to SDG 11.5 aiming to drastically reduce the number of deaths and people affected as well as economic losses due to natural disasters and increase the protection of poor and vulnerable populations.
Notes:
Source: African Development Bank [AfDB]

Water-Borne Disease Spread

Description: The indicator combines the prevalence of the water-borne diseases cholera and typhoid fever. Cholera is represented by the number of cases reported in 2022 to the European Centre for Disease Prevention and Control. The incidence rate for typhoid and paratyphoid fever in 2017 is provided by the Lancet. The water-borne diseases group countries into five different groups based on their level of incidence, on a scale from 0 to 5.

Rationale: Tropical cyclones can cause contamination of water sources, which leads to increased spread of waterborne diseases. In addition, the destruction of sanitary infrastructure and displacement of people can exacerbate the spread of these diseases. The level of the current spread can provide information on how vulnerable countries are to these seasons that are expected to increase and can be useful in identifying areas that need more support and resources to build resilience and adapt to the impacts of climate change. The indicator is linked to Sustainable Development Goal 3.3 which targets ending epidemics of malaria as well as tropical, waterborne and other communicable diseases.

Notes:

Source: European Centre for Disease Prevention and Control [ECDC], The Lancet

5.1.2 Chronic Hazards

Table 4: Overview of the composed indictors reflecting the chronic hazards.

Chronic Hazards			
Hazard Name	**Temperature Rise**	**Precipitation Change**	**Sea Level Rise**
Exposure	Projected Temperature Anomaly	Projected Precipitation Decrease	Percentage of Land below 5m
Sensitivity	Heat Stress Risk	Dependence on Rainfed Agriculture	Percentage of Population Occupying Vulnerable Land
	Agriculture, Forestry & Fishing Employment	Hydropower Dependency	Low-Elevation Coastal Zone Population Projection
	Share of Value Added from Agriculture, Forestry & Fishing	Water Stress	Level of WSS Infrastructure
	Malaria Prevalence		
	Biodiversity Loss		

5.1.2.1 Temperature Rise

Projected Temperature Anomaly

Description: Projected annual mean temperature anomaly for the CMIP6 model with a SSP5-8.5 scenario for the time period 2040-2060 compared to a reference period of 1995-2014. As the CMIP6 model provides a projection for each region in a country, the national average is calculated as an arithmetic mean of the regional anomalies.

Rationale: The anomaly highlights the projected increase in temperature for each country as a consequence of global warming. An equally weighted arithmetic mean for the regional values is used as more populated regions tend to be smaller, countering the size difference.

Notes:

Source: World Bank, Climate Change Knowledge Portal

Heat Stress Risk

Description: The indicator combines a heat stress risk during physical activity estimation for 2021 with the percentage of urban populations living in slums in 2020. The heat stress risk during physical activity indicates how many hours per day during which physical activity would entail a risk for heat stress, based on ambient temperature and relative humidity. The definition used for a 'slum household' is a household which lacks one of the following; *Water service access, sanitation facility access, sufficient living area,* and *housing durability*.

Rationale: An increase in the number of hours which pose a heat stress risk has been observed, and can lead to limited economic productivity from labour and working capacity, and in some cases increased heat–related mortality (Lancet Countdown 2022). Because of the urban heat island effect mentioned in the theory combined with poor quality housing, urban slums will be especially vulnerable to heat stress. The urban slum dataset is included as an indicator for SDG goal 11; *Make cities and human settlements inclusive, safe, resilient and sustainable.*

Notes: Lancet highlights that the heat stress risk may not be uniform for the entire population, and differences can be expected for vulnerable demographics and pregnant women. The urban slum dataset lacks data for 2020 for some countries. For *Comoros, Gabon, Namibia* and *Niger,* data from 2018 is used instead. For the *Central African Republic* and *South Sudan*, data from 2016 is used. A separate UN Habitat source with data from 2018 is used for *Somalia, Equatorial Guinea* and *Djibouti*. Data is missing for *Cabo Verde, Eritrea, Libya, Algeria, Mauritius* and *Seychelles*.

Source: Lancet Countdown, World Development Indicators [WDI], World Bank, World Cities Report, UN Habitat

Agriculture, Forestry & Fishing Employment

Description: The share of total national employment is based in the sectors of agriculture, forestry or fishing. The figures are based on modelled estimates from the International Labour Organisation for the year 2021.

Rationale: The theory concludes that temperature increases will have a negative impact on agricultural productivity and fishery yields. A bigger employment share in these sectors implies more people will face economic hardship because of the productivity loss in their field of labour, meaning a bigger sensitivity.

Notes: The data from 2021 for *Seychelles* is not available, and thus uses 2020 data instead.

Source: Food and Agriculture data, FAOSTAT

Share of Value Added from Agriculture, Forestry & Fishing

Description: The share of total value added from the sectors of agriculture, forestry or fishing as a percentage of the GDP for the year 2020 in dollars.

Rationale: A bigger production value in these sectors implies a strong economic reliance, resulting in a higher sensitivity to shocks in agricultural yields and international food prices.

Notes:
Source: Food and Agriculture data, FAOSTAT

Malaria Prevalence

Description: The indicator combines the national incidence and morbidity of malaria. The incidence measures the number of new cases of malaria per 1000 populations at risk per year, where the population at risk is defined as communities living in areas where malaria transmission occurs. National malaria control programs reported the deaths resulting from locally transmitted malaria to WHO, and species-specific case fatality rates were applied after estimating the number of malaria cases per Plasmodium species to determine the number of deaths.
Rationale: Vector-borne diseases such as malaria are affected by the temperature rise and the following habitat changes. The current malaria incidence and morbidity will hint at the current state of malaria transmission and vector control and may indicate the expected trends for a future potential temperature-induced malaria increase. Malaria incidence is also an indicator of SDG 3; *Ensure healthy lives and promote well-being for all at all ages.*
Notes:
Source: World Health Organisation [WHO]

Biodiversity Loss

Description: Biodiversity loss is estimated using the *Red List Index*, which measures the national changes in extinction risk of species over time based on the Red List of Threatened Species by the International Union for Conservation of Nature IUCN. A value of 1 in the index signals no risk of extinction, while a value of 0 equates to all species having gone extinct.
Rationale: The change in extinction risk over time provides a national assessment of the biodiversity risk under the ongoing climate changes. Climate change and temperature rise are key drivers for biodiversity loss, and the species who are already being diminished are being so because they are sensitive to the changes that will be a consequence of climate change (J. Hellmann, personal communication, April 2023). The Red List Index was used as a measurement for the SGD 15.5, aiming to take urgent actions to reduce the biodiversity loss and protect ecosystems.
Notes: *Mauritius* is an outlier with a relatively low value of 0,4. In the scaling, it is given a minimum value of 0,6 which lowers the skewness and kurtosis below the threshold, so as not to skew the rest of the distribution but still receive the lowest possible score.
Source: International Union for Conservation of Nature and Natural Resources [IUCN] Red List

5.1.2.2 Precipitation Change

Projected Precipitation Decrease

Description: Projected annual mean precipitation decrease for the CMIP6 model with a SSP5-8.5 scenario for the time period 2090-2099 compared to a reference period of 1995-2014. As the CMIP6 model provides a projection for each region in a country, the national average is calculated as an arithmetic mean of the regional anomalies. Regions that expect an increase in precipitation are denoted as a 0 on the average, as the increase is not deemed to compensate for decreases in other regions.
Rationale: Deviations from a historical precipitation level imply a disruption for the ecosystem and communities that were shaped by said level. The negative consequences of a gradual decrease in precipitation are more apparent than those of a gradual increase, and a gradual increase can sometimes be positive. The negative aspects of increased precipitation are mainly related to intense rainfall, and are covered by the flood dimension. In order to provide relevant sensitivity indicators, this hazard only accounts for slow onset decreases in precipitation. In order to see the true climate-induced effect on precipitation, a pessimistic emission scenario and a long time horizon are used.
Notes:
Source: World Bank, Climate Change Knowledge Portal

Dependence on Rainfed Agriculture

Description: The indicator shows the ratio of arable land which is not equipped for irrigation as a percentage of total arable land as a 3-year average from 2017-2019. Arable land refers to the area used for temporary agricultural crops, temporary meadows, market and kitchen gardens, and temporary fallow land. It does not include abandoned land from shifting cultivation and does not indicate the total potentially cultivable land.

Rationale: The theory highlights that 95% of African cropland is solely rainfed, implying variations in precipitation will negatively impact agricultural yields. The higher the percentage of agriculture solely rainfed, the bigger the sensitivity to a reduction in precipitation.

Notes: Data for *South Sudan* is missing from the original FAO source, and complemented from an internal South Sudanese Agriculture sector policy framework for the period 2012-2017.

Source: Food and Agriculture data, FAOSTAT, FAOLEX

Hydropower Dependency

Description: The indicator is a combination of the percentage of total national electricity supply in GWh from the year 2020 which is from hydropower provided by the International Energy Association IEA, as well as the total national hydropower capacity in MW that was existing, planned or committed to in 2022 according to the International Renewable Energy Agency IRENA.

Rationale: As the theory suggests, the demand for electricity grows exponentially in Africa and hydropower plays a critical role in the plans of African governments. During water stress, hydropower generations may have to compete with other water uses, and lowering electricity output can lead to load shedding and sensitive electricity prices. Including future projects allows the index to account for how the sensitivity to climate impact on hydropower will change.

Notes: Data is missing for several countries. For the missing countries with a hydropower production below 200 GWh, a value of 0 has been assigned. For the missing countries of *Malawi, Mali, Sierra Leone,* and *Guinea* which have a production of over 200 GWh, separate IRENA sources were used. For the missing data for *Burkina Faso*, a separate research paper by Moner-Girona et al. was used.

Source: International Energy Agency [IEA], International Renewable Energy Agency [IRENA], Moner-Girona et al. (2016), IRENA Malawi Energy Profile, IRENA Mali Energy Profile, IRENA Sierra Leone Energy Profile , IRENA Guinea Energy Profile

Water Stress

Description: The indicator combines the level of annual freshwater withdrawal for 2019 from the World Bank with a projection for water stress in 2040 made by the World Resources Institute [WRI] Aqueduct project. Annual freshwater withdrawals represent the total amount of water taken from freshwater sources for agriculture, industry or domestic uses, excluding losses from evaporation. In areas with substantial non-renewable aquifer extraction, desalination plants, or water reuse, withdrawals may surpass 100% of the renewable resources. The WRI Aqueduct Water Stress Ranking projects changes in water supply and demand for withdrawals under a business-as-usual 2040 scenario using SSP2 and RCP8.5, where a higher value indicates more competition for water between users.

Rationale: The extraction of freshwater is vital in order to ensure water security and availability for agricultural and industrial uses. A higher level of freshwater withdrawals means more available resources are used and necessary, which implies a higher sensitivity to changes in the level of available freshwater sources. Stress on water availability because of precipitation anomalies from climate change will be more severe for nations with more withdrawal. The withdrawal dataset is used as an indicator for SDG goal 6; *Ensure availability and sustainable management of water and sanitation for all*.

Notes: *Egypt, Libya* and *Mauritania* are heavy outliers for their freshwater withdrawals and are therefore removed and given the maximum final score of 1 for that dataset. Countries with withdrawals below 1% were assigned the minimum value in the logarithmic transformation. For the missing countries in water stress projections, the indicator only accounts for the withdrawal dataset.

Source: World Bank, World Resources Institute [WRI] Aqueduct

5.1.2.3 Sea Level Rise

Percentage of Land below 5 metres

Description: Measures the percentage of total land with an elevation of 5 metres or less above sea level.

Rationale: The indicator shows how much low-elevation land in countries is and could be exposed to rising sea levels, which would have an effect on agriculture, water resources and coastal ecosystems.

Notes: Countries with less than 0,1% of land under 5 metres are assigned the minimum value in the logarithmic transformation.

Source: World Bank

Percentage of Population Occupying Vulnerable Land

Description: The percentage of the current population that is living on land which is vulnerable to sea level rise according to the CoastalDEM elevation model, using the 50th percentile for permanent and one-year return levels, with the *k14* sea level projection for ice sheet dynamics which is closely aligned with the findings of the IPCC, as well as RCP8.5 emissions until the year 2100. Permanent exposure implies the projected elevation below a future high tide line.

Rationale: The indicator shows how much of the current population is living in areas that sea level projections suggest are vulnerable to sea level rise. The percentage shows the relative exposure of the population to sea level rise and coastal inundation. The indicator does not account for future population growth. The use of the CoastalDEM model is chosen above SRTM as it is stated in the research to "strongly and consistently outperform SRTM" in the validation. SRTM is also error-prone based on factors such as land slope, dense vegetation and high population density, which has a natural spatial autocorrelation.

Notes: The report mentions that caution should be applied when interpreting CoastalDEM errors for national scale assessments, especially for SIDS countries. Land-locked countries are given the minimum score. For the logarithm transformation, all nations with less than 0,1% of the population occupying vulnerable land were also assigned the minimum value.

Source: Kulp & Strauss (2019)

Low-Elevation Coastal Zone Population Projection

Description: Population projections for low elevation coastal zones, with separate projections having been made for urban and non-urban areas. The projection uses 'Scenario A', which indicates a high global economic growth and exclusive socioeconomic governance, resulting in a higher-end growth in developing world populations. The projections refer to the baseline Low-Elevation Coastal Zone [LECZ] from the year 2000 and do not include zones that due to sea level rise will be low-elevation in the future. The indicator uses both a logarithm of the total number of projected LECZ inhabitants in 2060 as well as the percentage of the total population for both 2030 and 2060.

Rationale: The indicator provides projections for population growth for urban and non-urban LECZ, where higher population growth will imply a bigger future exposure to the sea level rise that is expected in these areas. The inclusion of both an absolute and percentage measurement of the LECZ population gives insight into both the magnitude of the problem and the relative impact on the country. Small countries are penalised in the absolute measure, while nations with huge projected populations are penalised by the percentage even though the absolute problem is significant.

Notes: The data for *Morocco* include the disputed region of West Sahara. Data is missing for S*outh Sudan.*

Source: Neumann, B., Vafeides, A.T., Zimmermann, J., Nicholls, R.J. (2015), Data

Level of WSS Infrastructure

Description: The indicator uses the index score for Water Supply and Sanitation [WSS] from the African Infrastructure Development Index [AIDI] by the African Development Bank. The index is used to measure the level of development for different aspects of infrastructure based on the development

level in key sectors. The Water Supply and Sanitation dimension of AIDI includes access, quality and reliability of safe drinking water services and basic sanitation facilities.
Rationale: Improving water supply and sanitation infrastructure is crucial for promoting public health and economic development in Africa. Inadequate water and sanitation infrastructure can lead to the spread of waterborne diseases, such as cholera and dysentery, and can impede economic growth by reducing productivity and increasing healthcare costs. These infrastructures and the progress being made in improving them may be impeded and diverted because of the impacts of sea level rise through the inundation and intrusion of ocean water.
Notes: As landlocked countries will not be affected by sea level rise, these are given a score of zero regardless of the original AIDI score.
Source: Africa Infrastructure Development Index [AIDI]

5.1.3 Systemic Vulnerability

Table 5: Overview of the composed indictors reflecting the systemic vulnerability.

Systemic Vulnerability		
Humanitarian	**Economic**	**Governance**
Slum Population	Poverty Level	Control of Corruption
Vulnerable Demographics	Inequality Level	Political Stability & Absence of Violence
Population Growth	GDP per Capita	Government Effectiveness
Refugee Population	Debt-to-GDP Ratio	Regulatory Quality
Internally Displaced People	Informal Employment	Rule of Law
Food Import Dependency	Education Level	Voice & Accountability
Undernutrition	Education Investment	Disaster Risk Reduction
Water Mortality	Unemployment Rate	
Healthcare Access	Infrastructure	
Healthcare Expenditure		
HIV/AIDS Prevalence		
Gender Inequality		

5.1.3.1 Humanitarian Vulnerability

Slum Population

Description: The percentage of urban populations living in slums in 2020. The definition used for a 'slum household' is a household which lacks one of the following; *Water service access, sanitation facility access, sufficient living area,* and *housing durability*.

Rationale: The theory explains that living in slum-like conditions increases vulnerability to water security and climate-induced increases in water-borne diseases. The urban slum dataset is included as an indicator for SDG 11; *Make cities and human settlements inclusive, safe, resilient and sustainable.*

Notes: The urban slum dataset lacks data for 2020 for some countries. For *Comoros, Gabon, Namibia* and *Niger,* data from 2018 is used instead. For the *Central African Republic* and *South Sudan*, data from 2016 is used. A separate UN Habitat source with data from 2018 is used for *Somalia, Equatorial Guinea* and *Djibouti*. Data is missing for *Cabo Verde, Eritrea, Libya, Algeria, Mauritius* and *Seychelles*.

Source: World Development Indicators [WDI], World Cities Report 2020, UN Habitat

Vulnerable Demographics

Description: The indicator combined the 2021 and projected 2050 vulnerable demographics, which are defined as the percentages of the population that are below the age of 14 or above the age of 65.

Rationale: The theory highlights that the youngest and oldest of the population are disproportionately affected by climate change, as their health levels are more sensitive to the impacts of climate change. The indicator reflects SDG 1.3, aiming to implement national social protection and especially for the poor and vulnerable, such as people with disabilities, children and the elderly.

Notes: The elders and the youth are weighted as equally vulnerable, and the projections for 2050 are weighted equally with current 2021 numbers.

Source: World Development Indicators [WDI]

Population Growth

Description: The annual percentage of population growth during 2021.

Rationale: A higher population growth means that current resources will in the future have to suffice for more people and can exacerbate the problems that arise in food security and rapid urbanisation. The SDG Indicators use the population growth compared to land consumption to highlight this resource balance in goal 11; *Make cities and human settlements inclusive, safe, resilient and sustainable*.

Notes:

Source: World Development Indicators [WDI]

Refugee Population

Description: The indicator shows the total number of refugees by country of origin. Refugees are individuals acknowledged as such under the 1951 Convention or its 1967 Protocol, the 1969 African Convention, those recognized under the UNHCR statute, those granted refugee-like humanitarian status, and those provided temporary protection. Asylum seekers, who have applied for asylum or refugee status but have not received a decision or are still registered as seekers, are not included. A claimant's country of origin usually pertains to their nationality or citizenship.

Rationale: A lot of existing refugees from a country will highlight unfriendly conditions of conflict or disaster that the remaining population is enduring, making them more vulnerable to additional deficits. The dataset is used as an SDG indicator for goal 10; *Reduce inequality within and among countries.*

Notes: All nations with less than 1000 refugees are assigned a minimum score in the logarithmic transformation.

Source: World Development Indicators [WDI]

Internally Displaced People

Description: The indicator uses two datasets retrieved from the World Bank with updates from 2008-2020: (1) Internally displaced people [IDP], annual new displacements associated with disasters. (2) Internally displaced people, annual new displacements associated with conflicts and violence.

Rationale: The number of IDPs can be an indicator of a country's vulnerability to climate change and extreme weather events that force people to leave their communities. Displaced people are more vulnerable to the effects of climate change and support in terms of adaptation measures, disaster risk reduction and humanitarian assistance. Furthermore, a large number of IDPs can have social, economic and political consequences for a country and its population.
Notes: The score is based on the geometric mean of IDPs caused by disasters and conflicts. Data for conflicts are missing for several countries, and for these the score is only based on disaster IDPs. *Equatorial Guinea* is missing data for both, and is therefore not covered.
Source: World Bank (1), (2)

Food Import Dependency

Description: The relative level of cereal consumption which is obtained from imports. Cereal is, according to FAO, referred to as "crops harvested for dry grain only" and includes wheat, rice, maize and millets among others. The consumption is calculated as the production combined with the net import/export. The consumption uses a three-year average for the years 2017-2019.
Rationale: Countries highly dependent on food imports are susceptible to shocks in food prices in the international market. Climate change and its impacts on the African agriculture sector may accentuate regional price volatility, making these susceptible nations more vulnerable.
Notes: Because of missing data for the three-year average of 2017-2019, the following nations use older data; *Comoros* uses 2016-2018, *Central African Republic* uses 2015-2017, *Mauritius* and *Sao Tome & Principe* use 2014-2016 and *Guinea-Bissau* uses 2012-2014. Data is missing altogether for the countries *Eritrea, Somalia, South Sudan* and *Equatorial Guinea.*
Source: Food and Agriculture data FAOSTAT

Undernutrition

Description: The indicator combines the three different prevalences of undernourishment, wasting and stunting. Prevalence of undernourishment shows the percentage of the population in 2020 who do not have access to dietary resources that they require to maintain a healthy life according to the World Bank. The prevalence of stunting is the 2020 percentage of children below 5 years of age whose height for age are more than two standard deviations below the expected median for an international reference. The prevalence of wasting is the percentage of children below 5 years in the time period 2017-2021 whose weight for height is more than two standard deviations below the expected median for an international reference (United Nations Children's Fund [UNICEF] 2022).
Rationale: The three prevalences show different materialisations of undernutrition, and are all used as both indicators and targets for SDG 2; *End hunger, achieve food security and improved nutrition and promote sustainable agriculture.*
Notes: For the nations where the World Bank does not present data on wasting, the dataset is complemented with the most recent UNICEF Joint Child Malnutrition estimate, which for these nations uses older data than the World Bank. The year from which the wasting data is collected is mentioned in the dataset.
Source: World Development Indicators [WDI], United Nations Children's Fund [UNICEF]

Water Mortality

Description: The relative amount of deaths attributable to unsafe water, unsafe sanitation, and lack of hygiene in 2016. The indicator attributes these deaths by including diarrhoeal diseases, intestinal nematode infections and protein-energy malnutrition.
Rationale: A high water mortality rate indicates severe discrepancies in water and sanitation quality, which will hamper the average health of the population and make them less healthy and thus more vulnerable to additional deficiencies caused by climate change. Water mortality is used as an SDG Indicator for goal 3; *Ensure healthy lives and promote well-being for all at all ages.*
Notes:
Source: World Development Indicators [WDI]

Healthcare Access

Description: The number of nurses and midwives per 1000 people, who include both professional, auxiliary and enrolled nurses and midwives as well as other associated personnel. The data is collected between 2014-2020.

Rationale: The lack and migration of quality healthcare personnel is a big problem in many developing countries, and a lack means lower access to proper healthcare and generally lower public health outcomes. The SDG indicators use similar data for health worker density to highlight health access in goal 3; *Ensure healthy lives and promote well-being for all at all ages.*

Notes:

Source: World Development Indicators [WDI]

Healthcare Expenditure

Description: The indicator shows the 2019 expenditure per capita in current US dollars, including healthcare goods and consumed services.

Rationale: Higher healthcare expenditure shows the ability and willingness to invest in improved health, and the lack thereof signals a weaker influence over personal health which makes populations more vulnerable. The indicator is connected to SDG 1a which looks into the proportion of total government expenditure on essential services.

Notes: Data is missing for *Somalia* and *Libya.*

Source: World Development Indicators [WDI]

HIV/AIDS Prevalence

Description: The percentage of the population aged 15-49 who 2020 lived with HIV or AIDS.

Rationale: Life expectancy in countries heavily impacted by HIV/AIDS dropped by 12.1 years from 1995 to 2000 and is projected to decline by 29.4 years between 2010 and 2015. In sub-Saharan Africa, HIV/AIDS and related illnesses occupy over 50% of hospital beds and in some regions up to 50% of hospital admissions. A significant portion of the healthcare workforce in many African countries has been lost due to AIDS and other communicable diseases (Boutayeb 2010). The greater the proportion of hospital capacity used to treat patients with serious diseases such as AIDS, the less capacity the country has left to treat climate-related diseases and injuries associated with extreme weather events. The indicator is linked to Sustainable Development Goal 3.3 which targets ending epidemics of AIDS, malaria and neglected tropical, waterborne and other communicable diseases.

Notes: Prevalences below 1% have been assigned as the minimum value in the logarithmic transformation.

Source: UNAIDS

Gender Inequality Index

Description: The Gender Inequality Index is a composite index which evaluates inequality between women and men based on reproductive health, empowerment and labour market opportunities. A score of 0 indicates equal opportunities, and a score of 1 indicates that one gender fares as poorly as possible.

Rationale: The theory suggests that climate vulnerability may vary between men and women, and a stronger gender inequality will imply the discriminated gender is worse off. The composite index uses several SDG indicators, such as indicators for Maternal mortality ratio, Adolescent birth rate, Share of seats in parliament and more.

Notes: Data is missing for the following countries: *Comoros, Djibouti, Equatorial Guinea, Eritrea, Seychelles* and *Somalia*.

Source: Gender Inequality Index, United Nations Development Programme [UNDP]

5.1.3.2 Economic Vulnerability

Poverty Level

Description: The indicator reflects the poverty headcount ratio in the population for 2015-2020, where poverty is measured as living below $2.15 a day.

Rationale: Climate change is anticipated to cause decreased crop yields, the loss of livestock, and infrastructure damage, all of which have adverse economic implications for poor populations. Moreover, people living in poverty frequently encounter challenges in accessing vital resources such as insurance, savings, and credit to assist them in responding to and recovering from climate change impacts. Additionally, their limited access to healthcare, education, and other crucial services may affect their ability to adapt. The indicator reflects on the SDG 1.1-2 aiming to reduce the population living below both international and national poverty lines.

Notes: Missing data from Madagascar. Data updates are more than 10 years old from the following countries: *Algeria, Central African Republic, Equatorial Guinea, Madagascar, Congo Republic, and Congo Democratic Republic.*

Source: World Bank

Inequality level

Description: The indicator uses the Gini coefficient which is the most commonly used measure of income distribution, showing the gap between the incomes of a country's richest and poorest people.

Rationale: Climate change may exacerbate existing inequalities and lead to increased poverty and reduce the opportunities for vulnerable groups. High levels of inequality can lead to social unrest, making it more difficult for a country to respond effectively to climate change. Finally, inequality can reduce a country's overall resilience, making it harder to adapt to the changing climate. The indicator is supported by SDG 10 which aims to reduce inequality among countries.

Notes: Data is missing for *Eritrea* and *Equatorial Guinea.*

Source: World Population Review

GDP per Capita

Description: The Gross National Product [GDP] per capita from 2021.

Rationale: GDP per capita provides a snapshot of a country's economic well-being and capacity to respond and recover from the impacts of climate change. Countries with lower GDP per capita are likely to have limited resources to invest in adaptation and mitigation measures, which puts them at a higher risk of suffering from the economic impacts of climate change. It can also reflect the ability of a country to cope with and recover from climate-related shocks and stresses.

Notes: Old data from *Eritrea* and *South Sudan*.

Source: World Bank

Informal Employment

Description: The percentage of the population who are employed informally. Informal employment is defined as "all remunerative work that is not registered, regulated or protected by existing legal or regulatory frameworks, as well as non-remunerative work undertaken in an income-producing enterprise. Informal workers do not have secure employment contracts, workers' benefits, social protection or workers' representation" (ILO 2003).

Rationale: The effects of climate change may have a particularly devastating impact on sectors that rely on informal workers, such as agriculture, fisheries, and construction. This can result in reduced income and increased job insecurity. Moreover, informal workers are often excluded from social protection programs, which can leave them without support in times of crisis. Consequently, the prevalence of informal employment is an important indicator for identifying an African country's economic vulnerability to climate change. The indicator reflects SDG 8.3 which aims to encourage the formalisation and growth of micro-, small- and medium-sized enterprises, including through access to financial services.

Notes: For the nations not covered by ILO, the dataset is complemented by data from World Economics. Data is missing without a complementary source for the following countries: *Egypt, Eritrea, Sao Tome and Principe, Seychelles, Somalia,* and *South Sudan.*

Source: International Labour Organisation [ILO] Statistics, World Economics

Education Investment

Description: Percentage of government expenditure which is allocated to education during the period 2015-2021.

Rationale: Education plays a vital role in building resilience and enabling communities to adapt to the effects of climate change. The governmental investments spent on education can indicate the efforts a country is making to build long-term resilience and stable communities. Moreover, education can provide the skills and knowledge required for the development and implementation of climate change policies and strategies. The indicator is related to SDG 1a which aims to ensure that countries are using their resources to reduce poverty and enhance development.

Notes: Old data from *Equatorial Guinea* (2006) due to lack of recent updates. Data missing for the following countries: *Egypt* and *Libya.*

Source: World Bank

Education Level

Description: The indicator combines three indicators for education level: (1) Expected years of schooling, (2) Mean years of schooling and (3) Literacy rate as a percentage of youth aged 15-24. All data were collected during 2018-2021.

Rationale: Higher education enrollment rates and literacy rates can lead to a better understanding of climate change and its impacts, as well as the development of skills and knowledge required for adaptation and mitigation strategies. The indicator is supported by SDG 4.1, which aims to ensure that all children complete free, equitable and quality education.

Notes: For the nations where the UNDP does not present any data, the dataset is complemented with data from the World Bank. Due to a lack of data, data more than 10 years old is used for *Libya* and *Equatorial Guinea.*

Source: United Nations Development Programme [UNDP], World Bank

Debt-to-GDP

Description: Ratio of country debt compared to GDP by country in 2023.

Rationale: A country's level of debt relative to the country's GDP is an important factor determining how well a country can financially respond to climate change and shocks. High levels of debt can limit a country's ability to invest in long-term climate adaptation and mitigation measures, such as renewable energy, sustainable agriculture and disaster risk reduction. This can make a country more vulnerable to the long-term effects of climate change. The indicator reflects SDG 17.4, which aims to increase debt sustainability for developing countries and reduce debt distress.

Notes: For *Somalia, Mali,* and *South Sudan* where the Trading Economics does not present updates, they are complemented with data from Economy and Statista.

Source: Trading Economics, Economy, Statista

Unemployment rate

Description: Unemployment as a percentage of the total labour force in 2021.

Rationale: The unemployment rate is a key indicator to identify a country's economic vulnerability to climate change, as unemployment can worsen the impacts. People without jobs have limited financial means and are less able to adapt to changing climate conditions. High levels of unemployment can

cause social instability and distress, which can undermine a country's capacity to respond to the effects of climate change. The indicator reflects SDG 8.5, which aims to reach productive employment and decent work for all.
Notes:
Source: World Bank

Infrastructure

Description: The African Development Bank has produced the Africa Infrastructure Development Index (AIDI) in order to monitor and evaluate infrastructure development progress in Africa.The AIDI comprises four composite indices: (1) Transport composite Index, (2) Electricity composite Index, (3) ICT composite Index and (4) WSS composite Index.
Rationale: Poor infrastructure in a country can exacerbate the impacts of climate change by limiting the ability of individuals and communities to adapt and respond to extreme weather events. For example, inadequate transportation systems can impede evacuation efforts during a disaster. Insufficient water and sanitation infrastructure can contribute to the spread of disease following floods or droughts. Poorly constructed buildings and homes can be more susceptible to high winds or flooding damage. And finally, weak electrical grids and communication networks can hinder emergency response and recovery efforts. Electricity access is also crucial for adaption measures.The indicator is supported by SDG 11.5, which aims to reduce the number of deaths and people affected by disasters due to poor infrastructure.
Notes:
Source: African Development Bank [AfDB]

5.1.3.3 Governance

The governance indicators used are mainly the Worldwide Governance Indicators developed by Kaufmann, Kraay and Mastruzzi from the World Bank in 2010. They identify three aspects of governance, and construct two indicators for every aspect for a total of six dimensions (Kaufmann, Kraay & Mastruzzi 2010). All six dimensions are included in the governance dimension of this index.

Control of Corruption

Description: The indicator reflects the degree to which public officials are perceived to use their power for personal gain, encompassing both minor and major forms of corruption. The index value is from 2021.
Rationale: The theory states that climate change impact responses may be impeded if corruption is commonplace and the distribution of much-needed resources can be incorrectly managed. This results in hampered adaptation efforts, especially as many of the poorest countries and those most vulnerable to climate change impact also experience high corruption. The indicator reflects SGD 16.5, targeting a substantial reduction of corruption and bribery in all forms.
Notes:
Source: World Governance Indicators [WGI]

Political Stability and Absence of Violence

Description: The indicator reflects the degree to which the likelihood of political instability is perceived, as well as politically motivated violence and terrorism.
Rationale: Political instability and conflict will hamper the possibility for governments to act on climate-related issues and adaptation, and multilateral and bilateral funding may be discouraged for unstable countries. The indicator refers to SDG 16, aiming to promote peaceful and inclusive societies with accountable institutions and reduce violence in all forms.
Notes:
Source: World Governance Indicators [WGI]

Government Effectiveness

Description: This indicator reflects the perceived quality of public and civil services and their independence from political agendas and lobbying, as well the general quality of policy formulation and implementation and the reliability of the government's commitment to such policies.
Rationale: Better government effectiveness will mean better and quicker responses to climate disasters, and allows more efficient and thorough plans for adaptation. The indicator reflects specifically the SDG sub-goal 16.6, focusing on developing effective, reliable and transparent institutions at all levels.
Notes:
Source: World Governance Indicators [WGI]

Regulatory Quality

Description: This indicator reflects the perceived ability of the government to implement and enforce sound policies and regulations that promote and support developments in the private sector.
Rationale: The ability to implement policies that support the private sector can unlock potential capital and innovation for coping and adaptation and help accelerate progress in tackling climate change impacts.
Notes:
Source: World Governance Indicators [WGI]

Rule of Law

Description: This indicator reflects the perceived extent to which laws and rules of society are abided by and enforced, the general level of quality of police and courts, and the likelihood of crime and violence.
Rationale: A functioning legal system and a safe society are key for unlocking progress and efficient governance, which will be needed in adaptation and coping efforts against climate change impacts. The indicator refers to SDG 16.3 which promotes "the rule of law at both national and international levels and ensures equal access to justice for all".
Notes:
Source: World Governance Indicators [WGI]

Voice & Accountability

Description: This indicator reflects the perceived freedom of expression, association and free media, as well as the people's influence over the selection of their own government.
Rationale: Community involvement and influence help unlock local resources and highlight the direct needs of the communities in regard to their climate adaptation needs. A stronger mutual connection between the people and the government will help voice the needs and concerns of the people regarding climate change sensitivity and adaptation efforts, as well as improve disaster response. This indicator is connected to SDG 10.6 which aims to build more effective, trustworthy, accountable and legitimate institutions in developing countries.
Notes:
Source: World Governance Indicators [WGI]

Disaster Risk Reduction

Description: To better understand a country's preparedness for reducing the impacts of climate disaster, two datasets from the Sendai Framework are being used with data from whatever most recent year available at the earliest from 2016. The first Sendai dataset used is retrieved from Target E, which highlights the goal to create more and better DRR strategies. The data for this target is collected through surveys conducted by the United Nations Office for Disaster Risk Reduction and other partners. The other dataset from the Sendai Framework is retrieved from Target G and tackles increasing the availability of multi-hazard early warning systems and risk information spread. This data is collected through a variety of sources, including national meteorological and hydrological services, disaster management agencies, and other organisations that provide early warning systems and disaster risk information. The score is assigned as the maximum score of these two targets. In order not to penalise them in the aggregation, a reference point for the minimum value is set at 0 instead of the lowest recorded score.

Rationale: The existence of early warning systems and the foundation and progress for disaster risk reduction will play an important role in tackling the aftermath of acute hazards. A country taking part in the framework is a sign that they are making strides to care for and improve their disaster risk reduction. The indicator connected to the SDG 1.5 intends to build resilience of the poor and people and vulnerable situations and reduce their exposure to climate-related extreme events and other disasters with disaster risk reduction strategies.

Notes: The data may be perceived as unreliable since the nature of self-reporting surveys may lead to inflated grades. Data is missing for a lot of countries that are not partaking in the action plans, and since similar national comparisons are scarce, the indicator is overlooked in these countries' final governance scores.

Source: Sendai Monitor

5.2 ACHA Index Scores

The ACHA Index scoring is presented below. Each country is showcased with their individual hazard scores, the total aggregated score as well as their hazard total, which is an aggregation of all six physical hazards excluding the systemic dimension. The aggregation of the underlying indicators into the hazard scores is provided in an open source repository, whose DOI link is provided in Appendix A - Hazard data sets.

Table 6: ACHA Index scoring for all African countries for the six different hazards and systemic vulnerabilities, which are combined into final scoring.

Country Name	Chronic			Acute			Systemic			Total	
	Temperature Rise	Precipitation Change	Sea Level Rise	Drought	Flood	Tropical Cyclone	Humanitarian	Economic	Governance	Total	Hazard Total
Somalia	0,44	0,15	0,45	0,97	0,86	0,95	0,98	0,99	1,00	**0,92**	0,80
South Sudan	0,78	0,17	0,00	0,72	1,00	0,00	1,00	1,00	0,99	**0,91**	0,72
Liberia	1,00	1,00	0,68	0,40	0,83	0,00	0,56	0,62	0,56	**0,82**	0,88
Madagascar	0,54	0,53	0,92	0,43	0,69	1,00	0,71	0,79	0,55	**0,79**	0,82
Niger	0,73	0,34	0,00	0,99	0,74	0,00	0,92	0,88	0,55	**0,77**	0,72
Democratic Republic of the Congo	0,62	0,97	0,43	0,53	0,77	0,00	0,89	0,65	0,82	**0,74**	0,70
Central African Republic	0,83	0,66	0,00	0,90	0,72	0,00	0,86	0,87	0,81	**0,74**	0,65

Egypt	0,68	0,62	0,94	0,93	0,96	0,00	0,16	0,12	0,53	**0,73**	0,84
Mozambique	0,64	0,65	0,70	0,61	0,80	0,78	0,63	0,69	0,58	**0,68**	0,70
Zimbabwe	0,62	0,53	0,00	1,00	0,31	0,33	0,38	0,71	0,71	**0,67**	0,69
Chad	0,62	0,26	0,00	0,85	0,77	0,00	0,90	0,74	0,77	**0,66**	0,54
Eritrea	0,49	0,25	0,57	0,52	0,54	0,00	0,59	0,86	0,94	**0,63**	0,42
Benin	0,81	0,36	0,93	0,44	0,73	0,00	0,65	0,44	0,46	**0,62**	0,67
Guinea-Bissau	0,49	0,81	0,88	0,46	0,68	0,00	0,48	0,52	0,66	**0,62**	0,65
Sierra Leone	0,72	0,78	0,70	0,58	0,81	0,00	0,57	0,47	0,50	**0,62**	0,66
Senegal	0,34	0,41	1,00	0,58	0,57	0,00	0,43	0,32	0,31	**0,62**	0,70
Djibouti	0,42	0,05	0,95	0,70	0,39	0,00	0,56	0,75	0,61	**0,61**	0,58
Nigeria	0,56	0,44	0,66	0,34	0,84	0,00	0,77	0,66	0,64	**0,60**	0,55
Burundi	0,75	0,23	0,00	0,68	0,64	0,00	0,81	0,72	0,77	**0,60**	0,47
Libya	0,66	0,68	0,34	0,72	0,18	0,00	0,36	0,50	0,90	**0,57**	0,50
Mali	0,84	0,30	0,00	0,63	0,61	0,00	0,67	0,57	0,70	**0,55**	0,50
Gambia	0,37	0,54	0,91	0,48	0,61	0,00	0,58	0,45	0,45	**0,55**	0,58
Sudan	0,55	0,41	0,28	0,46	0,61	0,00	0,59	0,81	0,76	**0,55**	0,42
Guinea	0,59	0,72	0,58	0,47	0,69	0,00	0,52	0,46	0,63	**0,55**	0,56
Malawi	0,56	0,44	0,00	0,68	0,67	0,76	0,54	0,58	0,36	**0,55**	0,57
Algeria	0,98	0,59	0,09	0,51	0,21	0,00	0,23	0,06	0,58	**0,55**	0,63
Tanzania	0,55	0,39	0,46	0,58	0,67	0,56	0,53	0,50	0,45	**0,53**	0,54
Republic of the Congo	0,33	0,35	0,25	0,54	0,80	0,00	0,63	0,55	0,73	**0,52**	0,44
Comoros	0,33	0,38	0,69	0,52	0,47	0,59	0,43	0,38	0,70	**0,52**	0,51
Ethiopia	0,53	0,71	0,00	0,54	0,59	0,00	0,67	0,47	0,63	**0,51**	0,46
Uganda	0,53	0,64	0,00	0,62	0,73	0,00	0,54	0,52	0,53	**0,50**	0,49
Burkina Faso	0,83	0,29	0,00	0,55	0,71	0,00	0,53	0,49	0,48	**0,50**	0,50
Angola	0,49	0,53	0,28	0,54	0,58	0,00	0,59	0,60	0,56	**0,49**	0,43

Mauritania	0,60	0,22	0,51	0,74	0,48	0,00	0,53	0,41	0,56	**0,49**	0,48
Botswana	0,95	0,50	0,00	0,55	0,22	0,00	0,44	0,33	0,08	**0,47**	0,54
Cote d'Ivoire	0,54	0,58	0,54	0,62	0,46	0,00	0,52	0,31	0,46	**0,47**	0,48
Namibia	0,62	0,65	0,22	0,83	0,34	0,00	0,34	0,44	0,18	**0,47**	0,53
Zambia	0,54	0,54	0,00	0,62	0,49	0,00	0,48	0,65	0,47	**0,46**	0,41
Cameroon	0,44	0,41	0,38	0,41	0,60	0,00	0,53	0,46	0,66	**0,46**	0,40
Seychelles	0,45	0,00	0,99	0,00	0,00	0,00	0,19	0,00	0,05	**0,45**	0,58
Mauritius	0,45	0,39	0,58	0,11	0,02	0,95	0,09	0,01	0,00	**0,44**	0,58
Togo	0,51	0,40	0,63	0,34	0,54	0,00	0,46	0,39	0,51	**0,44**	0,43
Equatorial Guinea	0,44	0,29	0,39	0,29	0,43	0,00	0,39	0,46	0,81	**0,43**	0,32
Morocco	0,55	0,74	0,30	0,81	0,20	0,00	0,08	0,14	0,37	**0,43**	0,52
South Africa	0,48	0,51	0,12	0,74	0,04	0,13	0,19	0,76	0,31	**0,43**	0,39
Lesotho	0,57	0,48	0,00	0,67	0,25	0,00	0,53	0,49	0,44	**0,42**	0,38
Tunisia	0,73	0,49	0,45	0,71	0,31	0,00	0,00	0,06	0,35	**0,41**	0,50
Ghana	0,63	0,60	0,36	0,23	0,57	0,00	0,29	0,28	0,27	**0,39**	0,44
Kenya	0,33	0,31	0,38	0,58	0,52	0,00	0,44	0,30	0,43	**0,38**	0,38
Gabon	0,31	0,30	0,45	0,21	0,51	0,00	0,42	0,38	0,54	**0,36**	0,32
Eswatini	0,32	0,26	0,00	0,43	0,21	0,24	0,48	0,54	0,53	**0,35**	0,25
Rwanda	0,43	0,37	0,00	0,53	0,36	0,00	0,39	0,54	0,30	**0,35**	0,31
Sao Tome and Principe	0,28	0,01	0,71	0,12	0,30	0,00	0,35	0,36	0,37	**0,32**	0,29
Cabo Verde	0,00	0,21	0,65	0,41	0,08	0,00	0,40	0,31	0,11	**0,28**	0,27

Below the ACHA Index have been illustrated on maps for the aggregated total score as well as for the individual sub-dimensions. The colouring of the map indicates the index score, with green signifying low vulnerability and red signifying high.

Figure 25: Legend for ACHA Index map colouring, with a red colour indicating a high ranking.

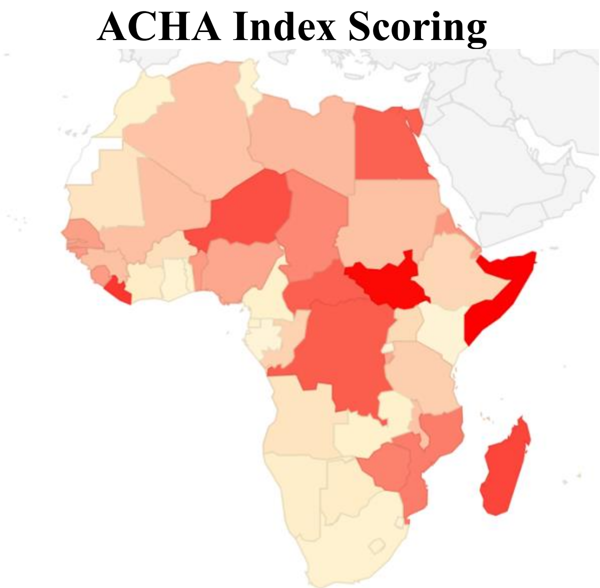

Figure 26: Map graph of Risk Index Scoring.

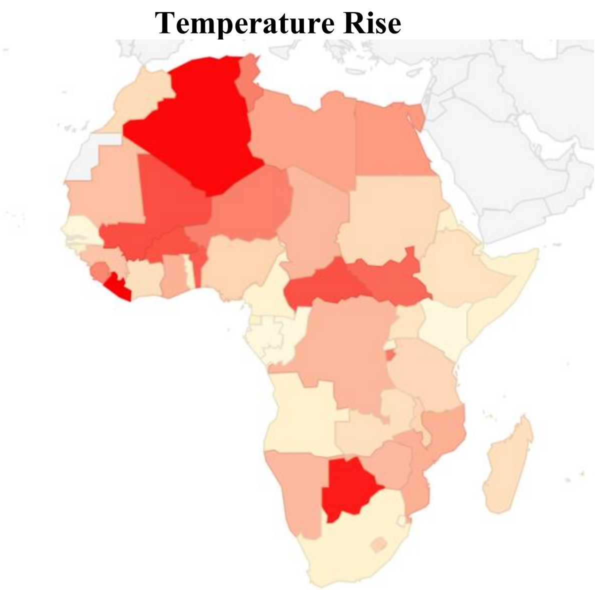

Figure 27: Map graph of Temperature Rise Scoring.

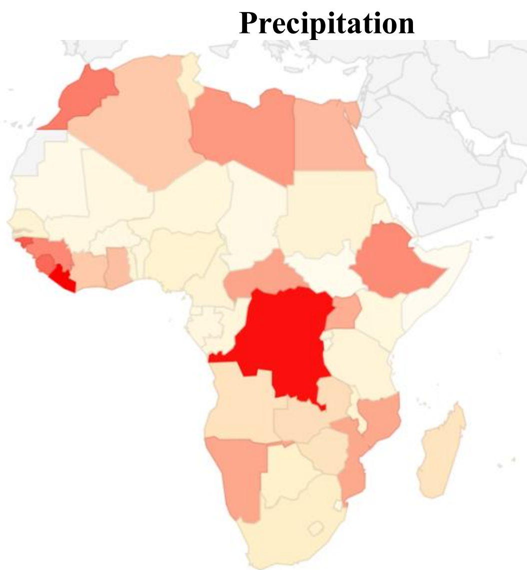

Figure 28: Map graph of Precipitation Change Scoring.

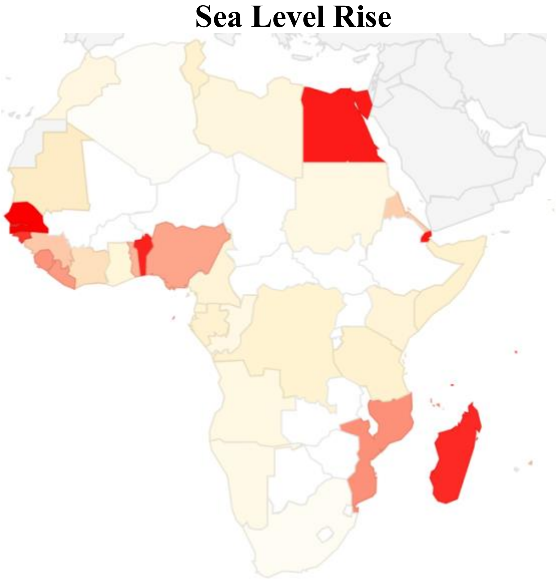

Figure 29: Map graph of Sea Level Rise Scoring.

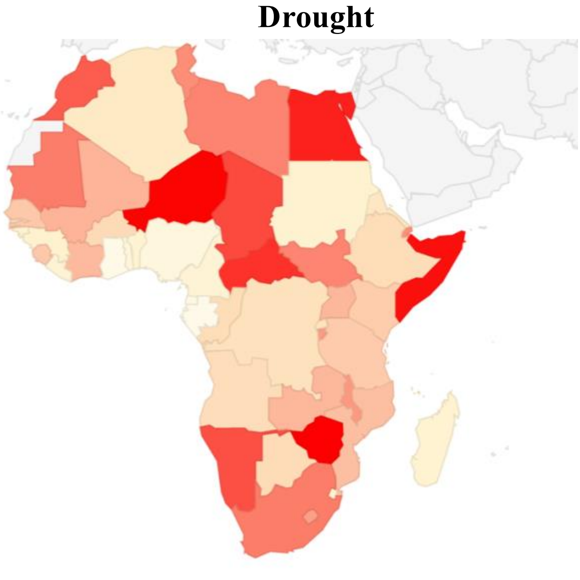

Figure 30: Map graph of Drought Risk Scoring.

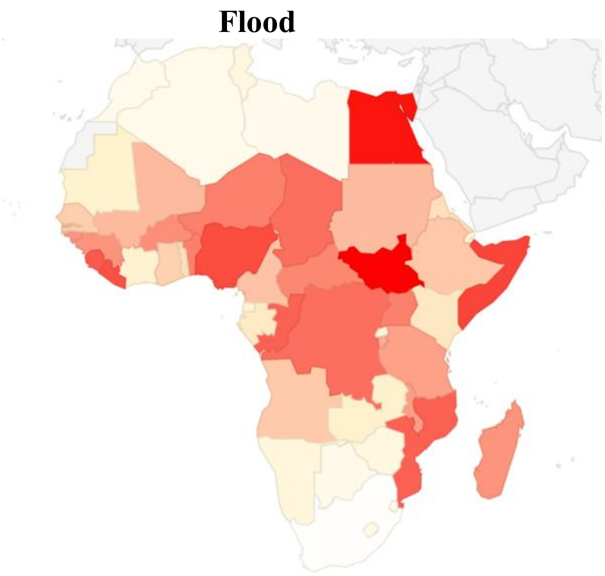

Figure 31: Map graph of Flood Risk Scoring.

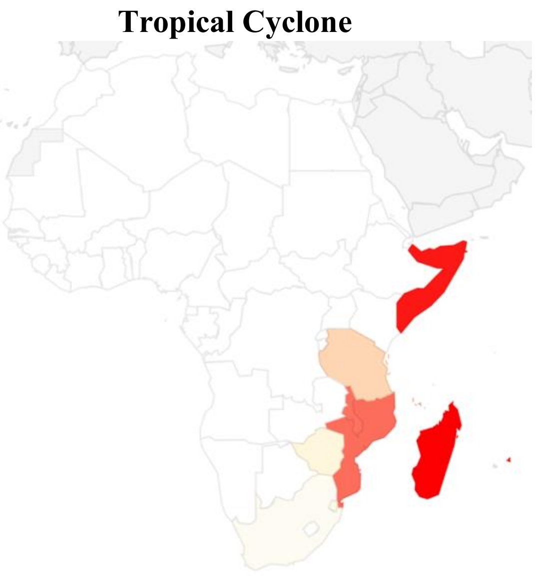

Figure 32: Map graph of Tropical Cyclones Risk Scoring.

Humanitarian

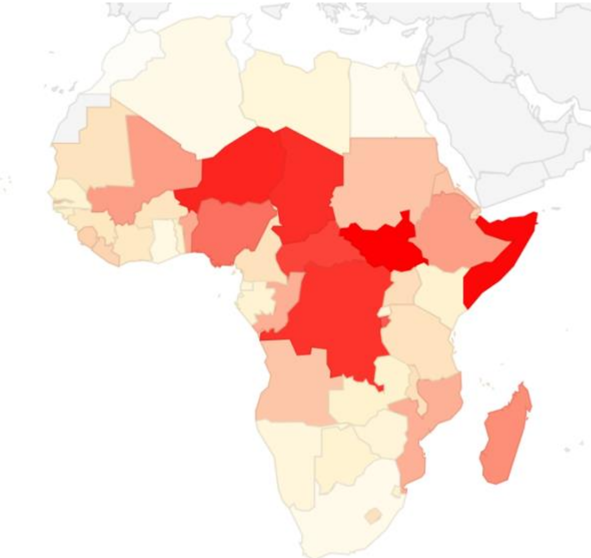

Figure 33: Map graph of Humanitarian Vulnerability Scoring.

Economic

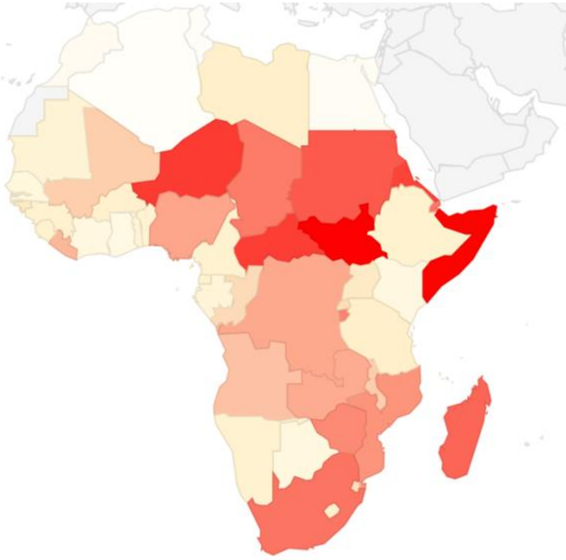

Figure 34: Map graph of Economic Vulnerability Scoring.

Governance

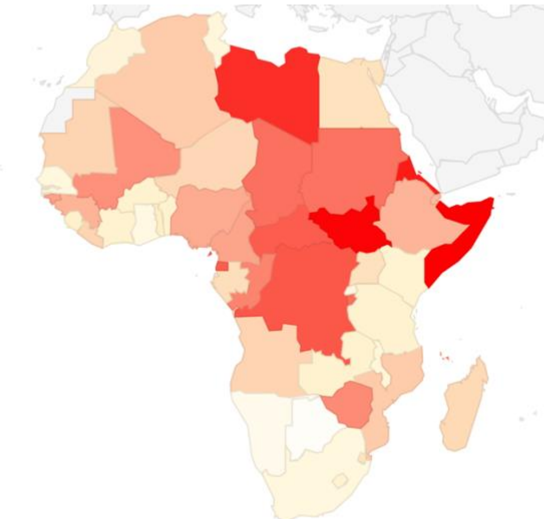

Figure 35: Map graph of Governance Vulnerability Scoring.

Below the ACHA Index sub-dimension scores have been illustrated for six nations that portray interesting risk patterns.

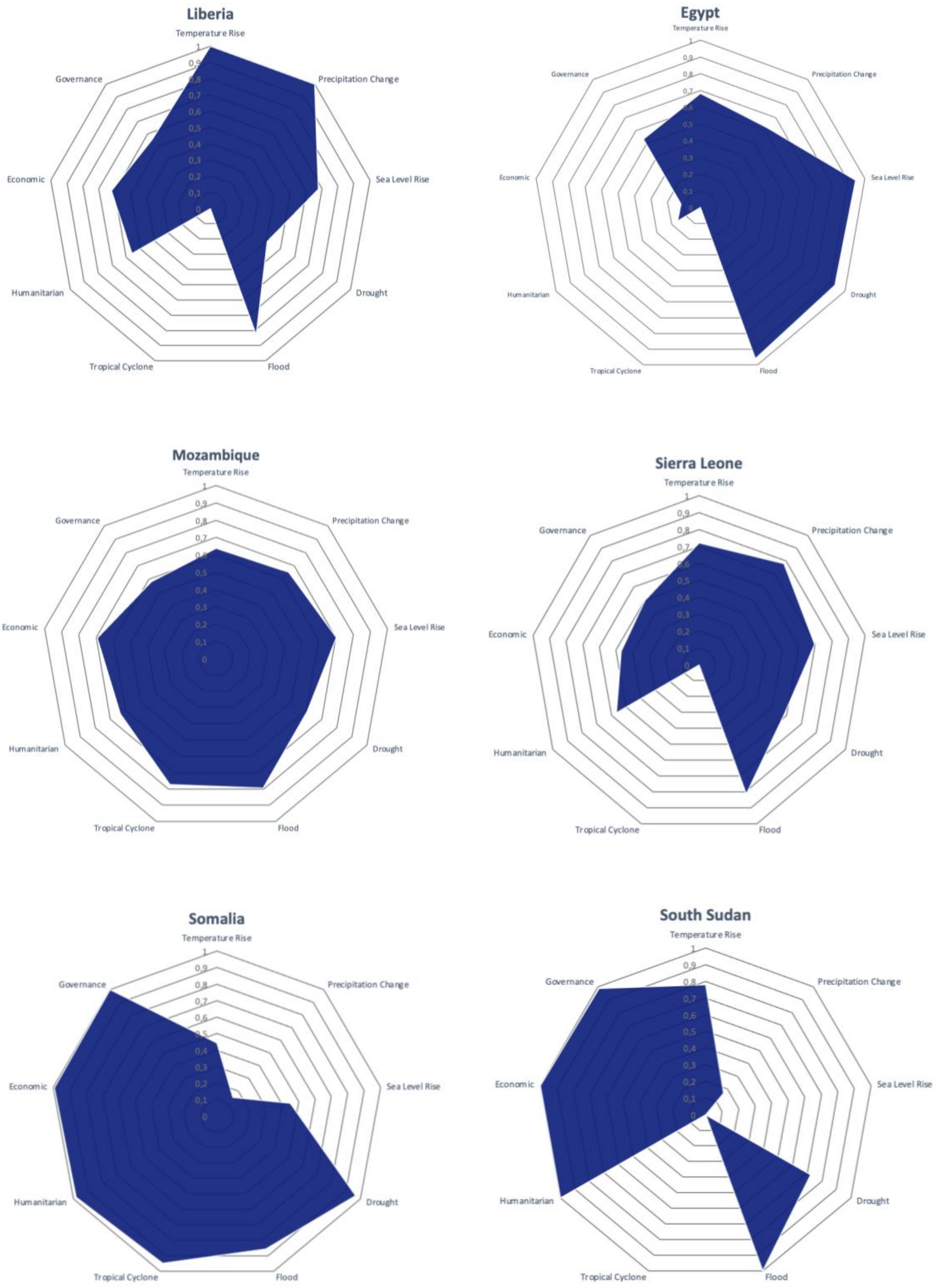

Figure 36: Graphs of the different sub-dimension scores for Liberia, Egypt, Mozambique, Sierra Leone, Somalia & South Sudan.

5.3 Sensitivity Analysis Result

The full ACHA Index scoring for the analysed scenarios can be found in Appendix B - Sensitivity Analysis. The key results of the analysis are summarised in the tables below.

5.3.1 Correlation analysis within the index

The table below shows the results from the correlation analysis. Moderate to strong correlations are marked with bold numbers. Table one includes the analysis of the total scores among the nine individual hazards together with the overall aggregated score. The full analysis between and within the various hazards can be found in Appendix B - Sensitivity Analysis.

Table 7: Correlation analysis table showing the Pearson's coefficient for each hazard and the total score.

Total Score										
	Temperature Rise	**Precipitation Change**	**Sea Level Rise**	**Drought**	**Flood**	**Tropical Cyclone**	**Humanitarian**	**Economic**	**Governance**	**Total**
Temperature Rise	1,000	0,383	-0,303	0,317	0,290	-0,135	0,170	0,110	0,175	**0,470**
Precipitation Change	0,383	1,000	-0,019	0,168	0,207	-0,072	-0,078	-0,068	0,034	0,208
Sea Level Rise	-0,303	-0,019	1,000	-0,397	0,068	0,129	-0,202	-0,294	-0,159	0,105
Drought	0,317	0,168	-0,397	1,000	0,256	0,020	0,286	**0,428**	0,356	**0,467**
Flood	0,290	0,207	0,068	0,256	1,000	0,034	**0,692**	**0,500**	**0,565**	**0,678**
Tropical Cyclone	-0,135	-0,072	0,129	0,020	0,034	1,000	0,061	0,142	-0,027	0,266
Humanitarian	0,170	-0,078	-0,202	0,286	**0,692**	0,061	1,000	**0,798**	**0,635**	**0,638**
Economic	0,110	-0,068	-0,294	**0,428**	**0,500**	0,142	**0,798**	1,000	**0,663**	**0,601**
Governance	0,175	0,034	-0,159	0,356	**0,565**	-0,027	**0,635**	**0,663**	1,000	**0,598**
Total	**0,470**	0,208	0,105	**0,467**	**0,678**	0,266	**0,638**	**0,601**	**0,598**	1,000

5.3.2 Correlation analysis with composite indices

The table below highlights the results from the correlation analysis of the ACHA index compared with the composite indices ND Gain, INFORM Risk and INFORM Climate Change. For the ACHA index, the total score as well as the stand-alone score for the physical climate hazards are included. Moderate to strong correlations are marked with bold numbers.

Table 8: Correlation analysis table showing the Pearson's coefficient between the ACHA index and composite indices.

Composite Indices					
	ACHA Index	**ACHA Hazard Index**	**ND GAIN**	**INFORM CC**	**INFORM RISK**
ACHA Index	1	**0,866**	**0,606**	**0,700**	**0,617**
ACHA Hazard Index	**0,866**	1	0,269	**0,415**	0,298
ND GAIN	**0,606**	0,269	1	0,715	**0,712**
INFORM CC	**0,700**	**0,415**	**0,715**	1	**0,945**
INFORM RISK	**0,617**	0,298	**0,712**	**0,945**	1

5.3.3 Geometric mean analysis

The three tables presented in this section present the sensitivity analysis made using different geometric mean thresholds.

Table 9: Sensitivity analysis of the 10 most vulnerable nations (for 0,01 threshold) and Sierra Leone in the original index for three different threshold values for geometric aggregations.

Country Name, Original	0,01 Threshold		0,05 Threshold		0,1 Threshold	
	Rank	**Score**	**Rank**	**Score**	**Rank**	**Score**
Somalia	1	*0,92*	1	*0,87*	2	*0,81*
South Sudan	2	*0,91*	2	*0,83*	6	*0,76*
Liberia	3	*0,82*	3	*0,79*	5	*0,76*
Madagascar	4	*0,79*	7	*0,76*	7	*0,76*
Niger	5	*0,77*	10	*0,73*	9	*0,73*
Democratic Republic of the Congo	6	*0,74*	5	*0,78*	3	*0,77*
Central African Republic	7	*0,74*	4	*0,78*	4	*0,77*
Egypt	8	*0,73*	13	*0,72*	16	*0,67*
Mozambique	9	*0,68*	6	*0,78*	1	*0,82*
Zimbabwe	10	*0,67*	18	*0,64*	24	*0,63*
Sierra Leone	16	*0,62*	8	*0,75*	8	*0,74*

Table 10: Sensitivity analysis of the 10 most vulnerable nations (for 0,01 threshold) and Sierra Leone to hazards only for three different threshold values for geometric aggregations.

Country Name, Hazards Only	0,01 Threshold		0,05 Threshold		0,1 Threshold	
	Rank	Score	Rank	Score	Rank	Score
Liberia	1	*0,88*	1	*0,84*	3	*0,80*
Egypt	2	*0,84*	4	*0,81*	5	*0,77*
Madagascar	3	*0,82*	6	*0,79*	4	*0,78*
Somalia	4	*0,80*	5	*0,79*	8	*0,73*
Niger	5	*0,72*	11	*0,69*	13	*0,68*
South Sudan	6	*0,72*	12	*0,68*	23	*0,62*
Mozambique	7	*0,70*	3	*0,81*	1	*0,85*
Senegal	8	*0,70*	18	*0,64*	24	*0,62*
Democratic Republic of the Congo	9	*0,70*	8	*0,76*	9	*0,73*
Zimbabwe	10	*0,69*	21	*0,64*	21	*0,62*
Sierra Leone	12	*0,66*	2	*0,81*	2	*0,80*

Table 11: Sensitivity analysis of the 10 most vulnerable nations to hazards only when shifting the weighting of the hazard exposure indicators.

Country Name, Hazards Only	Original Weight		No Weight		Enhanced Weight	
	Rank	Score	Rank	Score	Rank	Score
Liberia	1	*0,88*	2	*0,87*	2	*0,80*
Egypt	2	*0,84*	14	*0,70*	1	*0,84*
Madagascar	3	*0,82*	5	*0,83*	3	*0,79*
Somalia	4	*0,80*	6	*0,83*	4	*0,72*
Niger	5	*0,72*	4	*0,84*	5	*0,68*
South Sudan	6	*0,72*	1	*0,89*	16	*0,56*
Mozambique	7	*0,70*	11	*0,75*	10	*0,66*
Senegal	8	*0,70*	12	*0,72*	13	*0,59*

Democratic Republic of the Congo	9	*0,70*	2	*0,88*	19	*0,54*
Zimbabwe	10	*0,69*	35	*0,53*	6	*0,68*

6. Discussion

This chapter provides a walkthrough of the final index scores and analyses the outcome based on the theoretical framework. The first section reflects on the final scores and highlights distinctive nations among the countries being assessed. It continues by suggesting ways to interpret the different scores and the inputs behind them and discusses the outcomes of the sensitivity analysis. Lastly, the discussion highlights potential improvements and suggestions for further research.

6.1 Interpretation of Index Scores

When reviewing the index scores, available in Appendix A - Hazard data sets, the user can compare the countries by the overall total score or by each of the nine sub-dimension scores. Somalia, South Sudan, Liberia and Madagascar are the four countries most vulnerable to climate change according to the final aggregated score of the ACHA Index. The contributing hazards behind the aggregated scores are vastly different for the highest-ranking countries, and these differences must be accounted for when assessing each country's risk. While all climate hazards are driven by the same greenhouse effect and to some extent each other, coping measures will have to be tailored to the national and regional risk profile. On the other hand, the four least vulnerable countries to climate change according to the ACHA Index are Cabo Verde, Sao Tome and Principe, Rwanda and Eswatini. The low ranking of these countries highlights a lower exposure to physical climate risks in conjunction with a systemic resilience that allows them to respond to climate change and its impacts.

It is important to highlight the implied simplification of complex issues by the total risk aggregation, and it is crucial to analyse the underlying drivers and indicators in order to understand each country's vulnerability to climate risk. The interpretation should be done carefully and complemented with regional resources and knowledge, as the true risk will vary within the countries based on local differences. In addition, any interpretation should pay respect to the fact that the risk comparison is relative to other African nations, and risks are scaled between the minimum and maximum risks in the region. A country scoring low in an indicator does not necessarily mean there is no risk, but rather that they experience the lowest risk in the region.

Interpreting the visualisations
Visualised in Figures 26 to 36, a country's vulnerability depends on various drivers and differentiate among countries. These diagrams show that high-ranking countries such as Liberia and South Sudan are driven by a few severe hazards, while countries such as Mozambique have a more equal distribution of hazard impacts. Somalia and South Sudan experience the highest vulnerability largely due to their significantly high scores for systemic vulnerability, indicating an insufficient ability to respond to climate impacts and disasters. The lack of adaptive capacity in more systemically sensitive countries will provoke the overall vulnerability and lower the threshold for system failure in the case of climate hazards. The mapping of the individual hazards in Figures 26 to 36 highlight that some geographical correlations can be expected, but that the risks generally show little geographical correspondence. Tropical cyclones and sea level rise portray an expected regional difference, as these hazards are bound by geographical and meteorological features such as coasts or cyclone-prone oceans. The flood and precipitation change hazards both show a weak symmetric pattern around the central part of the continent, which is in accordance with the erratic changes in precipitation patterns expected in the climate zone by the theory.

The role of systemic vulnerability
The final scores illustrate that it is not necessarily the most hazard-prone nations that are most vulnerable, thanks to the inclusion of the systemic vulnerability hazards. A main driver of Somalia and South Sudan topping the list is because of their systemic vulnerability, which depicts the importance of the ability to cope with the consequences of climate change. While other nations may endure more perilous climate change impacts, these nations maintain the resources and organisational efficiencies to

handle the risks. The systemically vulnerable countries are already stressed in humanitarian and economic aspects, and additional adversities at the hand of climate hazards may overload the fragile systems which would mean more impact than for a more systemically resilient nation. Thus, these countries will require more loss and damage support and adaptive aid, and since the main objective is for the index to highlight the need for aid through policy and loss and damage support, this trait in the index is desirable.

The role of hazard exposure and sensitivity
The ACHA Index balances the exposure to expected climate hazards and the sensitivity to that specific hazard. This balance presumes some existing exposure since a highly sensitive nation without exposure will experience no impact. For example, a landlocked country such as Chad with highly vulnerable water security will still not be affected by the perils of water security that sea level rise or cyclones can cause. For the hazards where there is a clear divide between nations who do and do not experience exposure, this has been accounted for by giving non-exposed countries a minimum risk score. This type of clear split can be seen between coastal and landlocked countries when regarding sea level rise or the meteorological prerequisites for the occurrence of tropical cyclones. The same has not been done for the other hazards since the occurrence of floods, droughts or precipitation pattern changes cannot be ruled out in the same categorical way, and all African countries expect a temperature rise. The occurrence of coastal flooding is naturally bound to coastal countries, but since the hazard also includes flash and riverine floods, it is still accounted for by all countries. The identification of exposure indicators is more straightforward than the sensitivity assessment, which inevitably will be a subjective assessment that does not perfectly describe the true drivers of a country's vulnerability. However, the theory highlights the importance of all three pillars of exposure, vulnerability, and sensitivity is crucial for an effectual risk assessment and for identifying loss and damage aid needs.

The role of climate projections
The use of climate projections has aimed to highlight the expected changes in hazard exposure within a nation as well as the relative expected change compared to other nations in the region. The index uses the RCP8.5 and SSP5 projection scenarios and extended time horizons in order to fully capture these exposure effects while assessing sensitivity measures using mainly current and historical data. The exposure projections introduce trends that may seem contradictory at first but provide a key angle for differentiating between each hazard. One such trend is the expected increase in overall precipitation in countries near the Sahara historically known for their arid climate and droughts. While the total precipitation is expected to increase, the shift towards more erratic patterns of dry streaks and intense rainfall will still imply an increased exposure to droughts, highlighting the mutual exclusivity of the hazard structure in the index. By not using projections for sensitivity, the ability to capture future impacts will be limited and the relevance of the score will not fully stand over time. However, the difficulty in accurately predicting changes over time in the more complex sensitivity aspects renders the use of current and historical data necessary. Meanwhile, climate model projections are deemed sufficiently accurate to be included in the exposure indicators. It should be noted that the pessimistic projection scenarios are chosen as they help highlight the differences between countries thanks to the implementation of min-max scaling and that the risks because of this are relative to other African nations and should not be interpreted as absolute risks.

ACHA Index Differentiation
The ACHA index distinguish itself from global indices, such as ND Gain and INFORM Risk, by exclusively examining the climate vulnerability of African nations. This approach enables the index to reveal unique driver of vulnerability that may be diluted or disregarded in a global index. The ACHA focuses on the six most threatening climate hazards for the continent, outlines in the countries' NDCs, and then incorporates sensitivity factors that can be specifically attributed to this region. An example of its differentiation is the large inclusion of agriculture related indicators, which is a distinct characteristic for African countries' climate change vulnerability.

6.2 Sensitivity Analysis Insights

In the process of designing and conducting assessments like the one performed in the ACHA index, some extent of subjectivity will be unavoidable. Outside of the obvious subjectivity in choosing relevant indicators, one such major subjective decision in the design of the index is the threshold for geometric aggregation. The sensitivity and uncertainty analysis helps highlight the level of reliance of the final scores on some key uncertainties. Analysis of the correlation between indicators is common practice in the creation of an index, and the other analysed uncertainties were chosen as they were considered the main subjective decisions in the ACHA Index creation process.

Correlation Analysis
The correlation analysis included in the study investigated the relationship between the hazards and their subsidiary indicators. The analysis of the sub-dimensions revealed a strong correlation among the systemic risks, which suggests that the different systemic aspects are closely linked. One such strong positive correlation is observed between economic and humanitarian vulnerability, with a Pearson coefficient of 0,798. This is to be expected as the economic capacity of a country heavily influences and determines the level of health services that can be provided to the population. The more financial resources a country has and the more stable and efficient a government is, the better the ability to efficiently invest in healthcare facilities and welfare systems.

Among the correlations of the six physical climate hazards, floods show moderate to strong positive correlations with all systemic measures. This is in part due to the chosen sensitivity indicators, as several of them are also used as indicators for other hazards. This overlap in sensitivity to different climate hazards is also explained by the similarities in impacts, as similar sectors will be affected by several hazards. A flood surge mainly poses a threat to water and housing infrastructure as well as food security, which are sectors that are similarly impacted by many other climate hazards in the region. A strong correlation between indicators allows for the possibility of removing some redundant dimensions of the index that indicate the same thing, which could make the results more transparent. However, the inclusion of correlating indicators can in some cases be justified if the inclusion helps with interpretability and allows a better understanding of the impacted sectors. The correlation of the flood hazard may justify removing it, but at the cost of failing to address the lethal risk that floods pose as an African climate hazard. Some correlation between drivers of climate vulnerability will always be expected, and the decisions of inclusion or expulsion should always be in line with the objective of the index. As this index aims to highlight the vulnerability of African nations to the climate-induced hazards that are considered most severe by stakeholders in the region, the inclusion of all six hazards is deemed more important than the redundancy of some indicators.

Some hazards experience a slightly negative correlation, with the highest being between drought and sea level rise. This could be explained by sea level rise being limited to coastal countries, whereas Figures 29 and 30 suggest that droughts are more prevalent in landlocked countries. The occurrence of one climate event may also reduce the expected vulnerability of another, such as an increased occurrence of flood events increasing the total precipitation levels. However, the underlying indicators should be carefully examined to fully understand the drivers of sensitivity between different hazards.

Correlation with composite indices
The primary objective of all composite indices mentioned in this study is to assess countries' exposure to climate risks, which implies that some positive correlation is to be expected between these and the ACHA Index. Although, given that the indices follow distinctive structures, it is of interest to investigate any differences. The conducted correlation analysis indicated a significant positive correlation between the total score of the ACHA index and all three external indices used in the comparison. This shows that the ACHA index captures somewhat similar aspects of climate vulnerability even though it uses a hazard-based approach, which seems to be partly due to the inclusion of systemic vulnerability. The closest relationship, with a correlation coefficient of 0,7, was observed in the comparison against the

INFORM Climate Change index. Given that both indices incorporate the actual risk of exposure to climate physical hazards, this can be expected. The key role of different hazard exposures separates the ACHA Index from other sector-based indices such as ND-Gain, which is apparent in the lower observed correlation as well as the even lower correlation of the hazard-only variant.

Meanwhile the correlation analysis indicated close relationships with the other indices, they did not show a perfect correlation. The different structures of using sectors versus climate hazards as main pillars in the index are likely to have an impact on this as well as the use of different datasets. A higher correlation may be more in line with the solid theoretical frameworks of other similar indices, but at the cost of diluting the purpose of the ACHA Index and the attention paid to hazards, and therefore not providing any additional knowledge to the discussion on African climate change impacts. Meanwhile, a lower correlation may call the chosen indicators and theoretical framework into question.

Aggregation threshold
The choice of the minimum threshold used in the geometric aggregations has a profound impact on the final results and is not firmly tied to a theoretical framework. The issue could have been partly avoided if another scaling method had been used. Still, it would also deviate from the regional relevance objective that the scaling method choice was based on. The lower the threshold, the higher respect is paid to a nation being one of the most vulnerable. The sensitivity analysis shows this clearly as nations such as Egypt and Zimbabwe with a few high-risk hazards drop significantly in index ranking when increasing the threshold. A higher threshold implies a higher score for nations experiencing high risk across all sub-dimensions, highlighted by the ascent of nations such as Mozambique and Sierra Leone for higher thresholds. The choice of a lower threshold is deemed satisfactory, as the vulnerability to a single hazard can be enough to pose just as big of a risk as a consistent vulnerability against several hazards, and the true inference about each individual hazard should not be made based on the total aggregated score. Since some correlations between hazards are expected but not accounted for, some inferences about the key risks may be lost when employing a higher threshold.

Systemic vulnerability inclusion
The inclusion of the systemic vulnerability sub-dimensions are aligned with the objectives of the index but will partially cloud the direct impact of physical climate change-induced hazards. The sensitivity analysis includes a hazard-only score in which more developed nations such as Senegal and Egypt feature, especially for low geometric aggregation thresholds. The most distinct impact is however the decrease in ranking for nations such as South Sudan and the Central African Republic. These nations experience some severe hazards, but their vulnerability is mainly driven by their lack of ability to respond and adapt to these.

Exposure weighting
Finally, the analysis also evaluates the decision of weighting the exposure as 50% of the hazard vulnerability. When this weighting is removed, the sensitivity indicators play a bigger role and tend to penalise less developed nations. Even though these indicators are tailored to each specific hazard, they are still mainly driven by the existence of infrastructure and systems in place in order to handle the hazard, which ultimately is derived from the available systemic resources. When the weight is increased, the occurrence of the hazards is the nigh sole decider, which may underestimate the importance of community characteristics and the functionality of support services for combating hazards.

An argument could be made for weighting the exposure difference between different hazards. The occurrence will for some hazards be detrimental no matter the sensitivity, and for these, a heavier than equal weight could improve the index results. For example, the original weights in the index mean that Somalia is ranked second in tropical cyclone vulnerability even though their exposure is second lowest among those with any exposure, which is somewhat misleading. However, taking a stance on a specific weight would have to be soundly backed by the theoretical framework, which is not deemed the case. Choosing to weigh exposure and sensitivity equally means that no stance is being taken on the importance of exposure and sensitivity, and the final result avoids any noise that would be included in the case of an ill-advised choice of weights.

6.3 Using the Index

The index offers valuable insights into the factors that render African nations particularly vulnerable to climate change and provides guidance on allocating resources for adaptation and mitigation initiatives. The insights of the index have the potential to be applied by several actors in different ways, some of which are discussed below.

Loss and Damage Assessments
The index can be useful for loss and damage assessments, which aim to quantify the economic and non-economic losses and damages caused by climate change impacts as a basis for aid and a call to climate mitigation action. By highlighting what hazards a African nation is exposed to, the index can help loss and damage assessments become more transparent and more accurately allocate loss and damage resources. A nation such as Algeria, whom the index expresses as one of the most vulnerable to a slow-onset temperature rise, will need vastly different loss and damage response and adaptation measures compared to a nation facing more acute hazards, such as Egypt. In particular, the index exposure can help identify regions where the magnitude and extent of potential losses and damages are most acute, and where populations are at high risk of being disproportionately affected by the expected damages through the sensitivity dimension. By providing a holistic yet regional assessment, decision-makers can coordinate efforts in the region for upcoming African initiatives such as the Loss and Damage fund proposed during COP27.

Assessing Political Commitments and Policies
The index combines a plethora of indicators for complex exposure, sensitivity and adaptive capacity impacts with the aim to convey intricate climate change impacts in a way which is transparent and easy to understand while remaining relevant and actionable for policy-makers. The indicators used in the index can help guide policy-makers when assessing suitable adaptation efforts and identifying currently lacking areas, but also in evaluating and tracking progress over time. The connection of the chosen indicators to the sustainable development goals in the Paris Agreement allows for policy-makers to align their efforts with global goals and targets to develop resilience and thus legitimise their adaptation efforts.

Putting the risk assessments in a regional perspective allows regional actors to assess their progress in a relevant context and can find both suitable benchmarks and potential collaborations with other countries within it. The index helps in this regard by allowing for easy comparison with indicators that are tailored to the regional context of Africa, unlike many global counterparts. By starting a dialogue on climate adaptation in the region, governments can learn from each other and together find adaptation solutions which are applicable to the constraints of the continent. By integrating the findings from scientific climate modelling in a systemic context and with SDG indicators, policymakers can assess these strategies to improve resilience while remaining focused on both resourcefulness and evidence-based climate knowledge.

Aid, Financing and Investments Decisions
An index that assesses a country's vulnerability to climate change can be leveraged to facilitate financing and investment decisions by identifying regions that are particularly in need of development aid and emergency response support, as well as areas where effectively allocating capital towards adaptation initiatives may prove challenging. The systemic vulnerability allows for actors in financial aid to base resource allocations on a country's climate risks as well as their ability to nurture the received funding. A systemically fragile country may not be able to efficiently use the received aid because of lacking financial and governmental infrastructure and organisation, which is highlighted in the index. The index's ability to quantify different vulnerabilities for different hazards can provide a unique overview of where financial support is most needed and in what form. For example, areas with high exposure to acute hazards combined with a sensitive institutional system may require greater support in terms of preparedness and response, while aid targeting a country exposed to a chronic hazard may need to be adapted to the long-term impacts the hazard implies. Additionally, the respect the index pays to the

institutional capacity of each country highlights the key role of a functional systemic context and the need to aid these aspects as well. Reducing systemic vulnerabilities by improving aspects such as education and equality will have an important indirect effect on climate risk, and investments in climate adaptation should be balanced with development and aid in these areas.

For investors, the index can help to prioritise resource allocation by identifying the sectors that are most in need of climate change adaptation initiatives, and highlighting what hazard risks they are impacted by. By evaluating the role of different sectors within the sub-dimensions and indicators, such as agriculture, infrastructure or healthcare, the effects of a relevant investment in a sector can be mapped out and the progress can be tracked for each hazard. For example, an effort to improve coastal infrastructure could prove helpful for tackling the risks of both sea level rise, tropical cyclones and floods according to the indicators included in each sub-dimension, and a country with an expressed vulnerability within these hazards can thus find efficient investment strategies for reducing the vulnerability to multiple hazards at once through referring to the index. These risks can also prove to be opportunities, and an acceleration in the discussion on ways to adapt can enhance innovation and public engagement, making long-term investments even more viable and turning resilience into a proactive business decision rather than a humanitarian necessity.

Advance Academic Research

The index can be used as a tool for academic research on climate change hazards and their impacts on African nations. The index explores the relationship between a country's exposure to physical climate hazards and various socio-economic factors, and it may through this inspire much needed further research into African climate risks and adaptation. The importance of evaluating adaptation strategies and tracking progress is paramount when resources are scarce, and tools such as this index may help inspire further efforts in doing so. Finally, since this index structures climate risks based on the actual hazards while many currently existing variants evaluate different sectors, it may provide a new perspective that can further spark the discussion on the intercorrelation between the climate change impacts for hazards and sectors.

6.4 Further Research

A theoretical framework is the main engine of any comparative vulnerability assessment, and a more solid theoretical foundation allows for more correct assumptions to be made and additional respect to be paid to the many complex characteristics of climate change impact while still remaining objective. The established theoretical framework for this report does not necessarily suffice for some advanced design decisions that could improve the final product, and decisions in the design process have been adjusted or avoided so as not to introduce further bias. Given a more solid theoretical foundation, by including local stakeholders and further involvement of leading experts on climate and data analysis, the ACHA index could be further configured to more accurately describe the complex issue of climate change impacts.

Current assessments on African climate risk and vulnerability are failing to involve local stakeholders, which results in generalisations as well as a disconnection with the ones the inference aims to help. Further inclusion and engagement of local stakeholders will be key for assessing the true vulnerability as well as the regional and local key features, and the OECD stresses the need to use participatory methods when assigning weights for such an index. Involvement is even more important for designing efficient adaptation solutions and services that are appreciated and serviceable for intended communities. The lack of this local connection limits the function of this index to merely highlighting the climate vulnerability and calling to action. An extended focus on adaptation would be a great improvement for both the design of the index as well as the interpretation and implementation of the results.

The scarce collection of African climate data is hampering the possibility of accurately assessing climate impact, and financing for African climate research is severely lacking. With a greater access to data, more relevant indicators could be used and more indirect impacts and effects could be sufficiently regarded. Great strides are being made in improving data collection and documentation, such as the initiatives for documenting and centralising DRR strategies in the Sendai Framework. Still, a lot more needs to be done before African vulnerability can be fully entertained in assessments. A major barrier to data availability is the cost of data collection and allocating the resources on a regional scale to ensure data sufficiency and accuracy. The national scale of comparison that an index like this uses also limits data availability. A lot of research is done on spatial or regional levels, and simplifying the results to a national level may be both inaccurate and misleading. This is especially the case for assessment of natural systems, as biodiversities are hard to compare and topographic features can mean significant differences over small areas. The theoretical framework would preferably incorporate a methodology to include research on ecosystem impacts in a comparable and fair way, but the scope and resources of this project do not fully allow this consideration. The quality of data will also be further improved by the CMIP6 projection models when these are fully in place.

Given the limitations in time and resources, the index has been constructed as a one-time aggregation of current vulnerability. For future work, an historical time series of index scores throughout the years would provide valuable insight into how different nations' sensitivity and adaptive capacity are changing over time and help decision-makers assess the impacts of their measures. Systemic circumstances can quickly change through shocks and geopolitical trends, showcased by the recent outbreak of conflict in Sudan which will severely hamper the nation and worsen its vulnerability. An assessment tool that is regularly updated and can account for systemic shocks will be more serviceable for decision-makers, though efforts in data collection will have to keep pace. Proper tools for measuring progress over time will be vital for evaluating support systems for loss-and-damage and adaptation investments, and will help attract future investment. A clustering analysis, where similarities and trends between nations' climate risk and vulnerability profiles can be identified, could also prove to be a useful tool for assessing investments and enhancing collaboration in adaptation efforts across the continent. Incorporating a comprehensive correlation analysis in the structuring of the index and in the indicator selection process would enhance the robustness of the index.

7. Conclusion

To summarise, the index developed in this research underscores the need to use a multidimensional approach when assessing climate vulnerability. The index demonstrates the balance between a nation's exposure to physical climate hazards and its systemic and constitutional resilience to the impacts of such hazard. The individual hazard scores highlight the different drivers that contribute to a nation´s climate vulnerability, and the aggregated score highlights what countries are most severely vulnerable across all included climate change impacts. For instance, a country projected to be exposed to multitude of hazards but at a lower degree might incur a different loss and damage and require a different aid structure than another country with significantly higher exposure to one or two of these hazards. Additionally, a nation with limitations in its systemic capabilities could be more vulnerable and face bigger impacts even though the exposure to physical hazards is lower due to low constitutional adaptive capacities. This is highlighted by the highest-ranked countries in the ACHA index being Somalia & South Sudan, partly due to their steep systemic vulnerability rankings.

Aligning the choices of indicators with the Sustainable Development Goals (SDGs) provides a valuable framework for policy-makers that allows the ACHA index to be used to prioritise and legitimise their climate change adaptation initiatives. The interconnection between climate change adaptation and development is further stressed by the inclusion of systemic vulnerability hazards. The index could be used for guiding the allocation of resources in initiatives such as the global loss and damage fund established at the international climate conference COP27 in Egypt in 2022. This climate finance initiative aims to push developed countries to support the global south in their response to climate change impacts. While the vulnerability assessment of the ACHA index helps highlight these needs in its vulnerability assessments and can act as a platform for further discussion on the issue, it should be complemented with local context and support when being applied by decision-makers.

Although the index could be improved with further stakeholder involvement and more comprehensive data collection, it serves its purpose of capturing the complex issues of African climate change impact and presenting it in an easy to understand way which can set in motion further dialogue for climate adaptation and act as a call to action. The future of African nations will be heavily impacted by climate change, and while efforts must be made to mitigate further greenhouse gas emissions, we must act now to help humanity adapt to the imminent consequences of climate change.

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9. Appendices

Appendix A - Hazard data sets

The underlying indicators and datasets for aggregation of the hazard scores can be found on the following open-source repository:
https://doi.org/10.5281/zenodo.7937089

Appendix B - Sensitivity Analysis

Table 12: Correlation analysis table showing the Pearson's coefficient for each hazard (moderate-strong correlations marked with bold numbers).

Total Score										
	Temperature Rise	Precipitation Change	Sea Level Rise	Drought	Flood	Tropical Cyclone	Humanitarian	Economic	Governance	Total
Temperature Rise	1,000	0,383	-0,303	0,317	0,290	-0,135	0,170	0,110	0,175	**0,470**
Precipitation Change	0,383	1,000	-0,019	0,168	0,207	-0,072	-0,078	-0,068	0,034	0,208
Sea Level Rise	-0,303	-0,019	1,000	-0,397	0,068	0,129	-0,202	-0,294	-0,159	0,105
Drought	0,317	0,168	-0,397	1,000	0,256	0,020	0,286	**0,428**	0,356	**0,467**
Flood	0,290	0,207	0,068	0,256	1,000	0,034	**0,692**	**0,500**	**0,565**	**0,678**
Tropical Cyclone	-0,135	-0,072	0,129	0,020	0,034	1,000	0,061	0,142	-0,027	0,266
Humanitarian	0,170	-0,078	-0,202	0,286	**0,692**	0,061	1,000	**0,798**	**0,635**	**0,638**
Economic	0,110	-0,068	-0,294	**0,428**	**0,500**	0,142	**0,798**	1,000	**0,663**	**0,601**
Governance	0,175	0,034	-0,159	0,356	**0,565**	-0,027	**0,635**	**0,663**	1,000	**0,598**
Total	**0,470**	0,208	0,105	**0,467**	**0,678**	0,266	**0,638**	**0,601**	**0,598**	1,000

Table 13: Correlation analysis table showing the Pearson's coefficient between each measure within Temperature Rise (moderate-strong correlations marked with bold numbers).

Temperature Rise

	Heat Stress Score	Malaria Score	Agriculture Share of GDP Score	Agriculture Employment score	Red List Index Score
Heat Stress Score	1,000	**0,550**	0,383	0,154	-0,103
Malaria Score	**0,550**	1,000	**0,495**	**0 ,641**	0,223
Agriculture Share of GDP Score	0,383	**0,495**	1,000	0,411	-0,105
Agriculture Employment score	0,154	**0,641**	0,411	1,000	-0,095
Red List Index Score	-0,103	-0,223	-0,105	-0,095	1,000

Table 14: Correlation analysis table showing the Pearson's coefficient between each measure within Precipitation Change (moderate-strong correlations marked with bold numbers).

Precipitation Change			
	Rainfed Agriculture Score	Hydropower Score	Water Stress Score
Rainfed Agriculture Score	1	0,265	**0,528**
Hydropower Score	0,265	1	0,166
Water Stress Score	**-0,528**	-0,166	1

Table 15: Correlation analysis table showing the Pearson's coefficient between each measure within Sea Level Rise (moderate-strong correlations marked with bold numbers).

Sea Level Rise			
	LECZ Population Projection Score	Vulnerable Land Population Score	WSS Infrastructure Score
LECZ Population Projection Score	1,000	**0,707**	**0,504**
Vulnerable Land Population Score	**0,707**	1,000	0,351
WSS Infrastructure Score	**0,504**	0,351	1,000

Table 16: Correlation analysis table showing the Pearson's coefficient between each measure within Drought (moderate-strong correlations marked with bold numbers).

Drought						
	Rural Population Score	Rainfed Agriculture	Crop Yield Score	Food Insecurity Score	Water Insecurity Score	Population Growth Score
Rural Population Score	1,000	0,240	-0,160	**0,485**	**0,578**	**0,506**
Rainfed Agriculture	0,240	1,000	-0,208	0,316	0,174	0,376
Crop Yield Score	-0,160	-0,208	1,000	-0,247	0,017	**-0,523**
Food Insecurity Score	**0,485**	0,316	-0,247	1,000	**0,435**	**0,434**
Water Insecurity Score	**0,578**	0,174	0,017	**0,435**	1,000	**0,462**
Population Growth Score	**0,506**	0,376	**-0,523**	**0,434**	**0,462**	1,000

Table 17: Correlation analysis table showing the Pearson's coefficient between each measure within Floods (moderate-strong correlations marked with bold numbers).

Floods					
	Disease Score	Infrastructure Score	Slum Population Score	Food Insecurity Score	Urban Growth Score
Disease Score	1,000	**0,618**	0,363	**0,464**	**0,670**
Infrastructure Score	**0,618**	1,000	**0,517**	**0,689**	**0,729**
Slum Population Score	0,363	**0,517**	1,000	**0,401**	0,349
Food Insecurity Score	**0,464**	**0,689**	**0,401**	1,000	**0,460**
Urban Growth Score	**0,670**	**0,729**	0,349	**0,460**	1,000

Table 18: Correlation analysis table showing the Pearson's coefficient between each measure within Tropical Cyclones (moderate-strong correlations marked with bold numbers).

Tropical Cyclones					
	Water-borne Disease Score	Infrastructure Score	Slum Population Score	Healthcare Expenditure Score	Healthcare Access Score
Water-borne Disease Score	1,000	**0,533**	0,273	**0,731**	**0,548**
Infrastructure Score	**0,533**	1,000	**0,511**	**0,724**	**0,691**

Slum Population Score	0,273	**0,511**	1,000	**0,435**	**0,493**
Healthcare Expenditure Score	**0,731**	**0,724**	**0,435**	1,000	**0,643**
Healthcare Access Score	**0,548**	**0,691**	**0,493**	**0,643**	1,000

Table 19: Correlation analysis table showing the Pearson's coefficient between each measure within Humanitarian (moderate-strong correlations marked with bold numbers).

Humanitarian											
	Slum Population Score	Vulnerable Population Score	Population Growth Score	IDP & Refugee Population Score	Water Mortality Score	Undernourishment Score	Food Import Dependency Score	Health Expenditure Score	Healthcare Access Score	HIV/AIDS Prevalence Score	Gender Inequality Score
Slum Population Score	1,000	**0,466**	0,397	0,374	**0,506**	**0,552**	-0,118	**0,440**	**0,506**	-0,267	**0,426**
Vulnerable Population Score	**0,466**	1,000	**0,872**	**0,644**	**0,749**	**0,518**	**-0,613**	**0,714**	**0,731**	-0,208	**0,655**
Population Growth Score	0,397	**0,872**	1,000	**0,552**	**0,609**	0,368	**-0,648**	**0,708**	**0,683**	-0,108	**0,603**
IDP & Refugee Population	0,374	**0,644**	**0,552**	1,000	**0,575**	**0,607**	**-0,528**	**0,683**	**0,475**	-0,291	0,354
Water Mortality Score	**0,506**	**0,749**	**0,609**	**0,575**	1,000	**0,618**	**-0,488**	**0,634**	**0,688**	-0,125	**0,707**
Undernourishment Score	**0,552**	**0,518**	0,368	**0,607**	**0,618**	1,000	-0,273	**0,639**	**0,488**	-0,143	0,291
Food Import Dependenc	-0,118	**-0,613**	**-0,648**	**-0,528**	**-0,488**	-0,273	1,000	**-0,547**	**-0,491**	-0,052	**-0,417**

Health Expenditure Score	**0,440**	**0,714**	**0,708**	**0,683**	**0,634**	**0,639**	-0,547	1,000	**0,643**	-0,305	**0,530**
Healthcare Access Score	**0,506**	**0,731**	**0,683**	**0,475**	**0,688**	**0,488**	**-0,491**	**0,643**	1,000	-0,215	**0,518**
HIV/AIDS Prevalence Score	-0,267	-0,208	-0,108	-0,291	-0,125	-0,143	-0,052	-0,305	-0,215	1,000	-0,014
Gender Inequality Score	**0,426**	**0,655**	**0,603**	0,354	**0,707**	**0,291**	**-0,417**	**0,530**	**0,518**	-0,014	1,000

Table 20: Correlation analysis table showing the Pearson's coefficient between each measure within Economic (moderate-strong correlations marked with bold numbers).

Economic									
	Poverty Level Score	Inequality Rate Score	GDP per Capita Score	Informal Employment Score	Education investment Score	Education Level Score	Debt-to-GDP Score	Unemployment Score	Infrastructure Score
Poverty Level Score	1,000	-0,057	**0,566**	0,229	0,177	0,314	-0,201	-0,210	**0,593**
Inequality Rate Score	-0,057	1,000	-0,026	-0,054	-0,240	-0,219	-0,014	0,330	-0,131
GDP per Capita Score	**0,566**	-0,026	1,000	0,111	0,106	0,605	-0,148	-0,296	**0,605**
Informal Employment Score	0,229	-0,054	0,111	1,000	0,187	0,121	-0,135	-0,168	0,296

Education investment Score	0,177	-0,240	0,106	0,187	1,000	0,130	0,081	0,004	0,077
Education Level Score	0,314	-0,219	**0,605**	0,121	0,130	1,000	-0,199	-0,377	**0,692**
Debt-to-GDP Score	-0,201	-0,014	-0,148	-0,135	0,081	-0,199	1,000	0,203	-0,289
Unemployment Score	-0,210	0,330	-0,296	-0,168	0,004	-0,377	0,203	1,000	-0,290
Infrastructure Score	**0,593**	-0,131	**0,605**	0,296	0,077	**0,692**	-0,289	-0,290	1,000

Table 21: Correlation analysis table showing the Pearson's coefficient between each measure within Governance (moderate-strong correlations marked with bold numbers).

Governance							
	Rule of Law Score	Voice & Accountability Score	Regulatory Quality Score	Stability Score	Control of Corruption Score	Government Effectiveness Score	Disaster Risk Reduction Score
Rule of Law Score	1,000	**0,768**	**0,918**	**0,705**	**0,880**	**0,935**	0,303
Voice & Accountability Score	**0,768**	1,000	**0,747**	**0,669**	**0,799**	**0,702**	0,194
Regulatory Quality Score	**0,918**	**0,747**	1,000	**0,629**	**0,822**	**0,903**	0,286
Stability Score	**0,705**	**0,669**	**0,629**	1,000	**0,700**	**0,660**	0,267
Control of Corruption Score	**0,880**	**0,799**	**0,822**	**0,700**	1,000	**0,890**	0,175

Government Effectiveness Score	**0,935**	**0,702**	**0,903**	**0,660**	**0,890**	1,000	0,232
Disaster Risk Reduction Score	0,303	0,194	0,286	0,267	0,175	0,232	1,000

Table 22: ACHA Index scoring for geometric mean threshold of 0,05.

Country Name	Chronic			Acute			Systemic			Total	
	Temperature Rise	Precipitation Change	Sea Level Rise	Drought	Flood	Tropical Cyclone	Humanitarian	Economic	Governance	Total	Hazard Total
Somalia	0,53	0,18	0,51	1,00	0,95	0,83	1,00	0,99	1,00	**0,87**	0,79
South Sudan	0,81	0,20	0,00	0,87	1,00	0,00	0,95	1,00	1,00	**0,83**	0,68
Liberia	1,00	1,00	0,77	0,48	0,96	0,00	0,59	0,70	0,58	**0,79**	0,84
Central African Republic	0,88	0,60	0,00	0,87	0,90	0,00	0,88	0,90	0,84	**0,78**	0,71
Democratic Republic of the Congo	0,76	0,92	0,50	0,66	0,94	0,00	0,86	0,72	0,85	**0,78**	0,76
Mozambique	0,77	0,76	0,79	0,68	0,93	0,83	0,67	0,78	0,61	**0,78**	0,81
Madagascar	0,65	0,59	0,87	0,48	0,81	1,00	0,68	0,79	0,57	**0,76**	0,79
Sierra Leone	0,92	0,87	0,77	0,67	0,96	0,00	0,60	0,53	0,52	**0,75**	0,81
Chad	0,76	0,32	0,00	0,91	0,90	0,00	0,91	0,76	0,80	**0,74**	0,67
Niger	0,88	0,42	0,00	0,93	0,81	0,00	0,89	0,83	0,58	**0,73**	0,69
Benin	0,90	0,42	0,95	0,51	0,88	0,00	0,68	0,50	0,48	**0,71**	0,77
Guinea-Bissau	0,60	0,89	0,97	0,52	0,79	0,00	0,51	0,58	0,69	**0,71**	0,75
Egypt	0,77	0,73	0,90	0,92	0,90	0,00	0,17	0,13	0,56	**0,71**	0,81
Nigeria	0,69	0,54	0,73	0,40	0,95	0,00	0,71	0,69	0,67	**0,68**	0,67
Eritrea	0,56	0,30	0,64	0,58	0,64	0,00	0,62	0,93	0,91	**0,68**	0,49

Mali	1,00	0,36	0,00	0,68	0,73	0,00	0,71	0,65	0,73	**0,65**	0,63
Burundi	0,76	0,28	0,00	0,80	0,80	0,00	0,76	0,70	0,81	**0,64**	0,56
Zimbabwe	0,71	0,62	0,00	0,96	0,37	0,35	0,40	0,69	0,74	**0,64**	0,64
Guinea	0,71	0,81	0,65	0,54	0,81	0,00	0,55	0,52	0,66	**0,63**	0,65
Malawi	0,66	0,51	0,00	0,79	0,82	0,76	0,57	0,65	0,38	**0,63**	0,66
Libya	0,75	0,64	0,37	0,78	0,20	0,00	0,38	0,57	0,94	**0,62**	0,54
Gambia	0,43	0,61	0,99	0,52	0,69	0,00	0,61	0,51	0,47	**0,62**	0,66
Sudan	0,64	0,51	0,32	0,51	0,71	0,00	0,63	0,83	0,80	**0,61**	0,49
Tanzania	0,66	0,47	0,53	0,67	0,78	0,61	0,56	0,57	0,47	**0,60**	0,63
Djibouti	0,49	0,06	0,89	0,69	0,46	0,00	0,54	0,80	0,64	**0,60**	0,54
Uganda	0,63	0,83	0,00	0,72	0,79	0,00	0,57	0,58	0,56	**0,59**	0,61
Comoros	0,40	0,46	0,76	0,64	0,57	0,62	0,45	0,43	0,73	**0,58**	0,59
Senegal	0,39	0,46	1,00	0,63	0,65	0,00	0,45	0,36	0,33	**0,57**	0,64
Republic of the Congo	0,39	0,43	0,28	0,51	0,85	0,00	0,67	0,62	0,76	**0,56**	0,48
Angola	0,57	0,64	0,31	0,63	0,70	0,00	0,62	0,67	0,59	**0,56**	0,52
Ethiopia	0,63	0,69	0,00	0,62	0,72	0,00	0,68	0,53	0,65	**0,56**	0,52
Burkina Faso	0,87	0,35	0,00	0,62	0,75	0,00	0,56	0,55	0,50	**0,55**	0,56
Mauritania	0,69	0,26	0,57	0,79	0,56	0,00	0,56	0,46	0,58	**0,54**	0,54
Namibia	0,70	0,76	0,25	0,88	0,40	0,00	0,36	0,50	0,19	**0,54**	0,60
Zambia	0,62	0,65	0,00	0,68	0,59	0,00	0,50	0,73	0,49	**0,53**	0,49
Cote d'Ivoire	0,65	0,66	0,61	0,60	0,54	0,00	0,55	0,35	0,48	**0,52**	0,55
Cameroon	0,52	0,51	0,43	0,47	0,69	0,00	0,57	0,52	0,69	**0,52**	0,47
Algeria	0,95	0,67	0,10	0,54	0,23	0,00	0,24	0,06	0,61	**0,52**	0,58
Togo	0,62	0,48	0,72	0,39	0,64	0,00	0,49	0,44	0,53	**0,51**	0,52
Morocco	0,62	0,87	0,33	0,85	0,23	0,00	0,09	0,16	0,39	**0,50**	0,60

Botswana	0,95	0,57	0,00	0,58	0,26	0,00	0,47	0,37	0,09	**0,50**	0,57
Equatorial Guinea	0,54	0,36	0,44	0,32	0,51	0,00	0,41	0,52	0,84	**0,49**	0,38
Lesotho	0,64	0,55	0,00	0,74	0,30	0,00	0,57	0,55	0,46	**0,47**	0,45
Tunisia	0,83	0,57	0,50	0,76	0,34	0,00	0,00	0,07	0,37	**0,47**	0,57
Ghana	0,69	0,69	0,40	0,27	0,65	0,00	0,30	0,31	0,28	**0,44**	0,50
Kenya	0,39	0,38	0,43	0,64	0,62	0,00	0,47	0,34	0,45	**0,44**	0,44
South Africa	0,55	0,58	0,14	0,77	0,04	0,14	0,20	0,63	0,32	**0,43**	0,44
Gabon	0,37	0,36	0,49	0,25	0,59	0,00	0,44	0,43	0,56	**0,41**	0,37
Rwanda	0,50	0,45	0,00	0,62	0,43	0,00	0,42	0,61	0,31	**0,41**	0,37
Eswatini	0,37	0,31	0,00	0,48	0,25	0,25	0,40	0,60	0,55	**0,38**	0,29
Mauritius	0,36	0,43	0,64	0,12	0,02	0,84	0,09	0,01	0,00	**0,37**	0,49
Sao Tome and Principe	0,33	0,02	0,79	0,14	0,36	0,00	0,37	0,41	0,39	**0,36**	0,35
Seychelles	0,55	0,00	0,99	0,00	0,00	0,00	0,18	0,00	0,05	**0,36**	0,47
Cabo Verde	0,00	0,25	0,71	0,44	0,10	0,00	0,29	0,35	0,11	**0,29**	0,31

Table 23: ACHA Index scoring for geometric mean threshold of 0,1.

Country Name	**Chronic**			**Acute**			**Systemic**			**Total**	
	Temperature Rise	**Precipitation Change**	**Sea Level Rise**	**Drought**	**Flood**	**Tropical Cyclone**	**Humanitarian**	**Economic**	**Governance**	**Total**	**Hazard Total**
Mozambique	0,81	0,87	0,85	0,73	0,96	0,89	0,71	0,83	0,63	**0,82**	0,85
Somalia	0,56	0,21	0,56	1,00	0,93	0,77	1,00	0,99	1,00	**0,81**	0,73
Democratic Republic of the Congo	0,80	0,86	0,53	0,78	0,86	0,00	0,86	0,72	0,88	**0,77**	0,73
Central African Republic	0,87	0,59	0,00	0,79	0,84	0,00	0,90	0,92	0,88	**0,77**	0,65
Liberia	0,90	1,00	0,84	0,55	0,99	0,00	0,61	0,74	0,61	**0,76**	0,80

South Sudan	0,78	0,24	0,00	0,82	0,95	0,00	0,91	1,00	1,00	**0,76**	0,62
Madagascar	0,69	0,65	0,86	0,52	0,86	1,00	0,67	0,77	0,60	**0,76**	0,78
Sierra Leone	0,90	0,95	0,81	0,69	0,92	0,00	0,63	0,54	0,54	**0,74**	0,80
Niger	0,93	0,50	0,00	0,88	0,84	0,00	0,89	0,80	0,60	**0,73**	0,68
Chad	0,81	0,38	0,00	0,85	0,91	0,00	0,93	0,71	0,83	**0,73**	0,65
Guinea-Bissau	0,64	0,91	1,00	0,56	0,85	0,00	0,54	0,63	0,72	**0,72**	0,75
Benin	0,85	0,48	0,90	0,57	0,90	0,00	0,72	0,54	0,50	**0,70**	0,74
Guinea	0,75	0,88	0,70	0,59	0,88	0,00	0,58	0,56	0,68	**0,69**	0,73
Nigeria	0,73	0,66	0,79	0,44	1,00	0,00	0,67	0,69	0,70	**0,68**	0,68
Malawi	0,68	0,60	0,00	0,87	0,84	0,79	0,60	0,70	0,39	**0,68**	0,72
Egypt	0,78	0,77	0,89	0,86	0,80	0,00	0,18	0,14	0,58	**0,67**	0,77
Eritrea	0,58	0,36	0,69	0,62	0,64	0,00	0,62	0,91	0,90	**0,67**	0,52
Tanzania	0,69	0,56	0,58	0,74	0,86	0,69	0,59	0,61	0,49	**0,67**	0,71
Mali	1,00	0,43	0,00	0,72	0,82	0,00	0,75	0,63	0,75	**0,66**	0,62
Sudan	0,65	0,62	0,35	0,55	0,77	0,00	0,66	0,84	0,83	**0,65**	0,55
Burundi	0,73	0,33	0,00	0,82	0,82	0,00	0,73	0,70	0,82	**0,65**	0,57
Uganda	0,67	0,86	0,00	0,80	0,84	0,00	0,60	0,63	0,58	**0,64**	0,66
Comoros	0,43	0,55	0,81	0,74	0,64	0,67	0,48	0,47	0,75	**0,64**	0,66
Zimbabwe	0,73	0,71	0,00	0,93	0,42	0,39	0,42	0,69	0,77	**0,63**	0,62
Angola	0,59	0,77	0,34	0,70	0,80	0,00	0,66	0,71	0,61	**0,63**	0,61
Gambia	0,45	0,67	0,98	0,56	0,73	0,00	0,64	0,55	0,49	**0,62**	0,64
Libya	0,75	0,64	0,40	0,82	0,21	0,00	0,35	0,61	0,96	**0,61**	0,55
Djibouti	0,50	0,07	0,88	0,68	0,51	0,00	0,51	0,81	0,67	**0,60**	0,55
Republic of the Congo	0,40	0,52	0,31	0,50	0,87	0,00	0,67	0,67	0,79	**0,59**	0,52
Ethiopia	0,65	0,71	0,00	0,69	0,78	0,00	0,66	0,52	0,68	**0,59**	0,56

Zambia	0,64	0,76	0,00	0,73	0,67	0,00	0,53	0,78	0,51	**0,58**	0,56
Namibia	0,70	0,88	0,27	0,89	0,44	0,00	0,38	0,54	0,19	**0,58**	0,66
Burkina Faso	0,86	0,42	0,00	0,68	0,80	0,00	0,59	0,59	0,52	**0,58**	0,58
Mauritania	0,70	0,31	0,61	0,82	0,62	0,00	0,59	0,50	0,61	**0,58**	0,58
Togo	0,66	0,59	0,80	0,43	0,70	0,00	0,51	0,47	0,55	**0,56**	0,59
Cameroon	0,54	0,62	0,46	0,52	0,75	0,00	0,59	0,56	0,72	**0,56**	0,53
Cote d'Ivoire	0,70	0,73	0,66	0,59	0,59	0,00	0,58	0,37	0,50	**0,56**	0,59
Senegal	0,40	0,51	0,97	0,66	0,68	0,00	0,48	0,39	0,34	**0,56**	0,62
Morocco	0,63	0,94	0,36	0,82	0,24	0,00	0,09	0,17	0,40	**0,52**	0,62
Equatorial Guinea	0,57	0,42	0,46	0,35	0,57	0,00	0,44	0,47	0,85	**0,51**	0,42
Lesotho	0,65	0,62	0,00	0,80	0,34	0,00	0,55	0,59	0,47	**0,51**	0,49
Tunisia	0,83	0,65	0,53	0,79	0,35	0,00	0,00	0,08	0,38	**0,49**	0,60
Kenya	0,40	0,46	0,47	0,70	0,68	0,00	0,49	0,37	0,46	**0,48**	0,49
Algeria	0,84	0,76	0,11	0,56	0,25	0,00	0,26	0,07	0,63	**0,48**	0,52
Ghana	0,65	0,78	0,43	0,29	0,69	0,00	0,32	0,34	0,29	**0,47**	0,54
Rwanda	0,52	0,54	0,00	0,69	0,48	0,00	0,44	0,66	0,32	**0,45**	0,43
Botswana	0,84	0,63	0,00	0,61	0,29	0,00	0,47	0,40	0,09	**0,45**	0,49
South Africa	0,55	0,66	0,15	0,79	0,05	0,15	0,21	0,55	0,34	**0,44**	0,47
Gabon	0,38	0,43	0,52	0,27	0,62	0,00	0,43	0,46	0,58	**0,44**	0,40
Eswatini	0,37	0,37	0,00	0,52	0,29	0,28	0,36	0,65	0,57	**0,40**	0,32
Sao Tome and Principe	0,35	0,02	0,84	0,16	0,40	0,00	0,39	0,44	0,41	**0,40**	0,39
Mauritius	0,28	0,47	0,68	0,13	0,02	0,78	0,09	0,01	0,00	**0,35**	0,47
Seychelles	0,58	0,00	0,96	0,00	0,00	0,00	0,11	0,00	0,05	**0,31**	0,41
Cabo Verde	0,00	0,28	0,75	0,46	0,12	0,00	0,23	0,38	0,12	**0,31**	0,34

Table 24: ACHA Index scoring when the weighting for the exposure indicator is removed, sorted according to the aggregated risk scores.

Country Name	Chronic			Acute			Systemic			Total	
	Temperature Rise	Precipitation Change	Sea Level Rise	Drought	Flood	Tropical Cyclone	Humanitarian	Economic	Governance	Total	Hazard Total
South Sudan	0,87	0,24	0,00	0,83	1,00	1,00	1,00	1,00	0,99	0,95	**0,89**
Democratic Republic of the Congo	0,70	1,00	0,55	0,71	0,87	0,93	0,89	0,65	0,82	0,86	**0,88**
Liberia	1,00	0,91	0,74	0,56	0,84	0,69	0,56	0,62	0,56	0,81	**0,87**
Niger	0,77	0,46	0,00	1,00	0,86	0,91	0,92	0,88	0,55	0,84	**0,84**
Madagascar	0,63	0,46	0,94	0,47	0,75	0,99	0,71	0,79	0,55	0,79	**0,83**
Somalia	0,50	0,21	0,54	0,86	0,91	1,00	0,98	0,99	1,00	0,93	**0,83**
Central African Republic	0,91	0,79	0,00	0,95	0,84	0,79	0,86	0,87	0,81	0,83	**0,82**
Benin	0,90	0,42	0,94	0,56	0,81	0,81	0,65	0,44	0,46	0,74	**0,81**
Sierra Leone	0,83	0,71	0,68	0,74	0,88	0,72	0,57	0,47	0,50	0,71	**0,77**
Chad	0,71	0,36	0,00	0,92	0,85	0,90	0,90	0,74	0,77	0,78	**0,75**
Mozambique	0,70	0,69	0,75	0,63	0,83	0,84	0,63	0,69	0,58	0,72	**0,75**
Senegal	0,28	0,37	1,00	0,50	0,53	0,57	0,43	0,32	0,31	0,63	**0,72**
Burundi	0,84	0,32	0,00	0,80	0,79	0,84	0,81	0,72	0,77	0,73	**0,70**
Egypt	0,36	0,76	0,95	0,67	0,59	0,23	0,16	0,12	0,53	0,60	**0,70**
Burkina Faso	0,90	0,40	0,00	0,61	0,84	0,78	0,53	0,49	0,48	0,64	**0,69**
Guinea-Bissau	0,60	0,63	0,86	0,51	0,71	0,63	0,48	0,52	0,66	0,64	**0,68**
Malawi	0,55	0,50	0,00	0,75	0,80	0,89	0,54	0,58	0,36	0,62	**0,67**
Uganda	0,59	0,78	0,00	0,70	0,85	0,68	0,54	0,52	0,53	0,63	**0,67**
Ethiopia	0,52	0,84	0,00	0,63	0,73	0,81	0,67	0,47	0,63	0,64	**0,66**

Djibouti	0,37	0,07	0,95	0,72	0,51	0,66	0,56	0,75	0,61	0,66	**0,66**
Guinea	0,65	0,66	0,62	0,56	0,73	0,69	0,52	0,46	0,63	0,62	**0,66**
Nigeria	0,66	0,57	0,69	0,47	0,78	0,64	0,77	0,66	0,64	0,66	**0,65**
Tanzania	0,60	0,50	0,57	0,66	0,73	0,72	0,53	0,50	0,45	0,60	**0,64**
Cote d'Ivoire	0,63	0,56	0,61	0,74	0,55	0,60	0,52	0,31	0,46	0,57	**0,62**
Mali	0,85	0,40	0,00	0,56	0,72	0,72	0,67	0,57	0,70	0,63	**0,62**
Gambia	0,37	0,48	0,87	0,47	0,58	0,66	0,58	0,45	0,45	0,58	**0,61**
Eritrea	0,40	0,35	0,61	0,53	0,69	0,84	0,59	0,86	0,94	0,72	**0,61**
Togo	0,60	0,52	0,72	0,42	0,63	0,67	0,46	0,39	0,51	0,56	**0,60**
Comoros	0,45	0,50	0,69	0,69	0,62	0,62	0,43	0,38	0,70	0,58	**0,60**
Angola	0,48	0,64	0,35	0,64	0,71	0,66	0,59	0,60	0,56	0,59	**0,60**
Republic of the Congo	0,34	0,48	0,29	0,71	0,84	0,63	0,63	0,55	0,73	0,61	**0,60**
Ghana	0,75	0,61	0,36	0,31	0,58	0,67	0,29	0,28	0,27	0,49	**0,57**
Cameroon	0,45	0,55	0,43	0,52	0,65	0,72	0,53	0,46	0,66	0,56	**0,56**
Sudan	0,47	0,55	0,38	0,48	0,66	0,70	0,59	0,81	0,76	0,63	**0,55**
Zimbabwe	0,50	0,57	0,00	0,83	0,47	0,46	0,38	0,71	0,71	0,57	**0,53**
Zambia	0,47	0,63	0,00	0,61	0,64	0,63	0,48	0,65	0,47	0,53	**0,53**
Kenya	0,33	0,43	0,45	0,60	0,62	0,63	0,44	0,30	0,43	0,48	**0,53**
Mauritania	0,44	0,28	0,54	0,57	0,59	0,64	0,53	0,41	0,56	0,52	**0,52**
Seychelles	0,57	0,00	0,96	0,00	0,01	0,00	0,19	0,00	0,05	0,38	**0,49**
Rwanda	0,42	0,49	0,00	0,64	0,51	0,63	0,39	0,54	0,30	0,46	**0,48**
Equatorial Guinea	0,53	0,40	0,40	0,33	0,54	0,63	0,39	0,46	0,81	0,52	**0,48**
Namibia	0,32	0,69	0,26	0,63	0,45	0,37	0,34	0,44	0,18	0,43	**0,48**
Libya	0,32	0,81	0,36	0,62	0,16	0,12	0,36	0,50	0,90	0,55	**0,46**
Morocco	0,30	0,78	0,36	0,49	0,16	0,29	0,08	0,14	0,37	0,38	**0,44**

Mauritius	0,63	0,32	0,55	0,11	0,00	0,69	0,09	0,01	0,00	0,33	**0,44**
Lesotho	0,28	0,49	0,00	0,67	0,42	0,44	0,53	0,49	0,44	0,44	**0,42**
Sao Tome and Principe	0,34	0,02	0,73	0,19	0,44	0,47	0,35	0,36	0,37	0,40	**0,41**
Algeria	0,67	0,60	0,12	0,32	0,20	0,31	0,23	0,06	0,58	0,38	**0,41**
Gabon	0,34	0,41	0,42	0,30	0,51	0,42	0,42	0,38	0,54	0,42	**0,40**
Tunisia	0,37	0,53	0,43	0,58	0,17	0,23	0,00	0,06	0,35	0,33	**0,40**
Botswana	0,61	0,49	0,00	0,42	0,35	0,28	0,44	0,33	0,08	0,36	**0,39**
Cabo Verde	0,00	0,24	0,60	0,29	0,17	0,33	0,40	0,31	0,11	0,29	**0,30**
Eswatini	0,18	0,35	0,00	0,46	0,36	0,34	0,48	0,54	0,53	0,38	**0,30**
South Africa	0,29	0,52	0,16	0,37	0,06	0,14	0,19	0,76	0,31	0,36	**0,28**

Table 25: Risk Index scoring when the weighting for the exposure indicator is enhanced, sorted according to the aggregated hazard risk scores.

Country Name	**Chronic**			**Acute**			**Systemic**			**Total**	
	Temperature Rise	**Precipitation Change**	**Sea Level Rise**	**Drought**	**Flood**	**Tropical Cyclone**	**Humanitarian**	**Economic**	**Governance**	**Total**	**Hazard Total**
Egypt	0,76	0,46	0,84	0,93	1,00	0,00	0,16	0,12	0,53	0,74	**0,84**
Liberia	0,86	1,00	0,60	0,40	0,80	0,00	0,56	0,62	0,56	0,74	**0,80**
Madagascar	0,45	0,55	0,81	0,43	0,63	1,00	0,71	0,79	0,55	0,76	**0,79**
Somalia	0,39	0,10	0,36	0,97	0,77	0,83	0,98	0,99	1,00	0,90	**0,72**
Niger	0,68	0,23	0,00	0,99	0,59	0,00	0,92	0,88	0,55	0,75	**0,68**
Zimbabwe	0,65	0,48	0,00	1,00	0,19	0,25	0,38	0,71	0,71	0,66	**0,68**
Mauritius	0,30	0,42	0,60	0,11	0,04	1,00	0,09	0,01	0,00	0,52	**0,67**
Algeria	1,00	0,56	0,06	0,51	0,21	0,00	0,23	0,06	0,58	0,57	**0,66**
Guinea-Bissau	0,39	0,86	0,90	0,46	0,65	0,00	0,48	0,52	0,66	0,63	**0,66**

Mozambique	0,57	0,61	0,65	0,61	0,74	0,73	0,63	0,69	0,58	0,65	**0,66**
Sierra Leone	0,58	0,80	0,70	0,58	0,72	0,00	0,57	0,47	0,50	0,59	**0,62**
Gambia	0,35	0,57	0,93	0,48	0,60	0,00	0,58	0,45	0,45	0,57	**0,60**
Senegal	0,35	0,43	0,93	0,58	0,58	0,00	0,43	0,32	0,31	0,53	**0,59**
Botswana	0,98	0,49	0,00	0,55	0,13	0,00	0,44	0,33	0,08	0,51	**0,59**
Seychelles	0,35	0,00	1,00	0,00	0,00	0,00	0,19	0,00	0,05	0,44	**0,57**
South Sudan	0,65	0,11	0,00	0,72	0,92	0,00	1,00	1,00	0,99	0,88	**0,56**
Central African Republic	0,68	0,49	0,00	0,90	0,58	0,00	0,86	0,87	0,81	0,69	**0,56**
Benin	0,66	0,30	0,82	0,44	0,64	0,00	0,65	0,44	0,46	0,54	**0,55**
Democratic Republic of the Congo	0,54	0,81	0,30	0,53	0,64	0,00	0,89	0,65	0,82	0,66	**0,54**
Tunisia	0,81	0,45	0,46	0,71	0,36	0,00	0,00	0,06	0,35	0,43	**0,53**
Guinea	0,53	0,73	0,55	0,47	0,64	0,00	0,52	0,46	0,63	0,53	**0,53**
Namibia	0,70	0,60	0,19	0,83	0,26	0,00	0,34	0,44	0,18	0,47	**0,52**
Morocco	0,62	0,68	0,24	0,81	0,22	0,00	0,08	0,14	0,37	0,43	**0,51**
Nigeria	0,47	0,31	0,62	0,34	0,84	0,00	0,77	0,66	0,64	0,58	**0,51**
Malawi	0,54	0,37	0,00	0,68	0,54	0,63	0,54	0,58	0,36	0,50	**0,50**
Libya	0,75	0,53	0,32	0,72	0,19	0,00	0,36	0,50	0,90	0,56	**0,49**
Djibouti	0,43	0,03	0,84	0,70	0,30	0,00	0,56	0,75	0,61	0,55	**0,49**
Chad	0,53	0,18	0,00	0,85	0,68	0,00	0,90	0,74	0,77	0,64	**0,48**
Tanzania	0,50	0,28	0,35	0,58	0,59	0,43	0,53	0,50	0,45	0,48	**0,47**
Mauritania	0,65	0,17	0,48	0,74	0,39	0,00	0,53	0,41	0,56	0,48	**0,46**
Comoros	0,24	0,27	0,68	0,52	0,35	0,57	0,43	0,38	0,70	0,48	**0,46**
Mali	0,80	0,21	0,00	0,63	0,52	0,00	0,67	0,57	0,70	0,53	**0,45**
Cote d'Ivoire	0,46	0,58	0,46	0,62	0,38	0,00	0,52	0,31	0,46	0,44	**0,44**
Uganda	0,46	0,47	0,00	0,62	0,58	0,00	0,54	0,52	0,53	0,45	**0,40**

Ghana	0,51	0,58	0,36	0,23	0,54	0,00	0,29	0,28	0,27	0,36	**0,40**
Burkina Faso	0,70	0,20	0,00	0,55	0,55	0,00	0,53	0,49	0,48	0,43	**0,40**
South Africa	0,54	0,48	0,09	0,74	0,03	0,12	0,19	0,76	0,31	0,43	**0,40**
Republic of the Congo	0,30	0,24	0,22	0,54	0,73	0,00	0,63	0,55	0,73	0,49	**0,39**
Burundi	0,63	0,15	0,00	0,68	0,48	0,00	0,81	0,72	0,77	0,56	**0,39**
Lesotho	0,65	0,45	0,00	0,67	0,13	0,00	0,53	0,49	0,44	0,42	**0,38**
Eritrea	0,51	0,17	0,53	0,52	0,39	0,00	0,59	0,86	0,94	0,61	**0,38**
Ethiopia	0,51	0,53	0,00	0,54	0,45	0,00	0,67	0,47	0,63	0,46	**0,38**
Zambia	0,55	0,46	0,00	0,62	0,37	0,00	0,48	0,65	0,47	0,44	**0,38**
Angola	0,47	0,42	0,21	0,54	0,46	0,00	0,59	0,60	0,56	0,45	**0,38**
Sudan	0,57	0,29	0,19	0,46	0,56	0,00	0,59	0,81	0,76	0,53	**0,38**
Togo	0,43	0,28	0,52	0,34	0,46	0,00	0,46	0,39	0,51	0,39	**0,36**
Cameroon	0,41	0,29	0,35	0,41	0,54	0,00	0,53	0,46	0,66	0,43	**0,35**
Kenya	0,31	0,21	0,32	0,58	0,44	0,00	0,44	0,30	0,43	0,35	**0,33**
Gabon	0,28	0,21	0,46	0,21	0,50	0,00	0,42	0,38	0,54	0,35	**0,30**
Equatorial Guinea	0,37	0,20	0,39	0,29	0,35	0,00	0,39	0,46	0,81	0,41	**0,28**
Cabo Verde	0,00	0,19	0,68	0,41	0,03	0,00	0,40	0,31	0,11	0,28	**0,27**
Rwanda	0,41	0,25	0,00	0,53	0,25	0,00	0,39	0,54	0,30	0,32	**0,27**
Sao Tome and Principe	0,23	0,01	0,68	0,12	0,20	0,00	0,35	0,36	0,37	0,29	**0,26**
Eswatini	0,38	0,18	0,00	0,43	0,11	0,18	0,48	0,54	0,53	0,34	**0,23**

Appendix C - RCP Projections

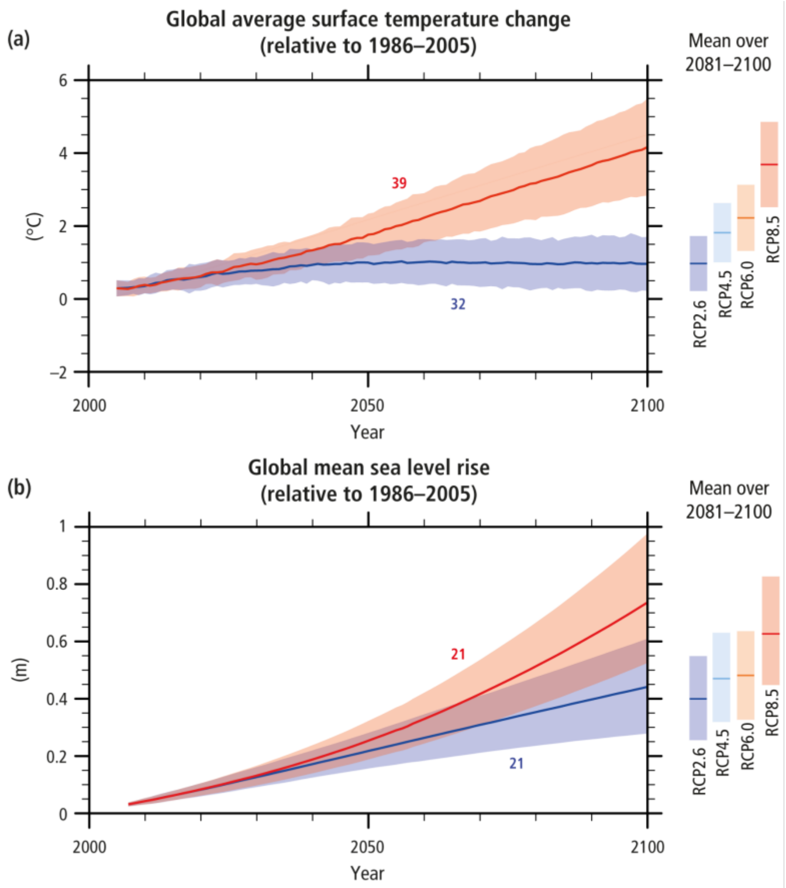

Figure 37: Future projections based on the four RCP Scenarios (IPCC 2014a).

Appendix D – ND-GAIN Indicators

Table 26: Vulnerability indicators in the ND-GAIN index.

Sectors	**Exposure component**	**Sensitivity component**	**Adaptive Capacity component**
Food	Projected change of cereal yields	Food import dependency	Agriculture capacity
	Projected population change	Rural Population	Child malnutrition
Water	Projected change of annual runoff	Freshwater withdrawal rate	Access to reliable drinking water
	Projected change of annual groundwater recharge	Water dependency ratio	Dam capacity
Health	Projected change of deaths from climate change induced disasters	Slum population	Medical staffs
	Projected change of length of transmission season of vector-borne diseases	Dependency on external health service resources	Access to improved sanitation facilities
Ecosystem Services	Projected change of biome distribution	Dependency on natural capital	Protected biomes
	Projected change of 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	Projected change of hydropower generation capacity	Dependency on imported energy	Electricity access
	Projection of sea level rise impacts	Population living under 5m above sea level	Disaster preparedness

Table 27: Readiness indicators in the ND-GAIN index.

Component	Description	Indicators			
Economic	Ability to accept investments that could be applied to adaptation that reduces the vulnerability.	Ease of Doing Business Index, World Bank			
Governance	Captures institutional factors that enhance the application of investments	Political stability and non-violence	Control of corruption	Rule of law	Regulatory quality
Social	Social inequalities, ICT infrastructure, education & innovation	Social inequality	ICT infrastructure	Education	Innovation

Appendix E - INFORM Risk Index Indicators

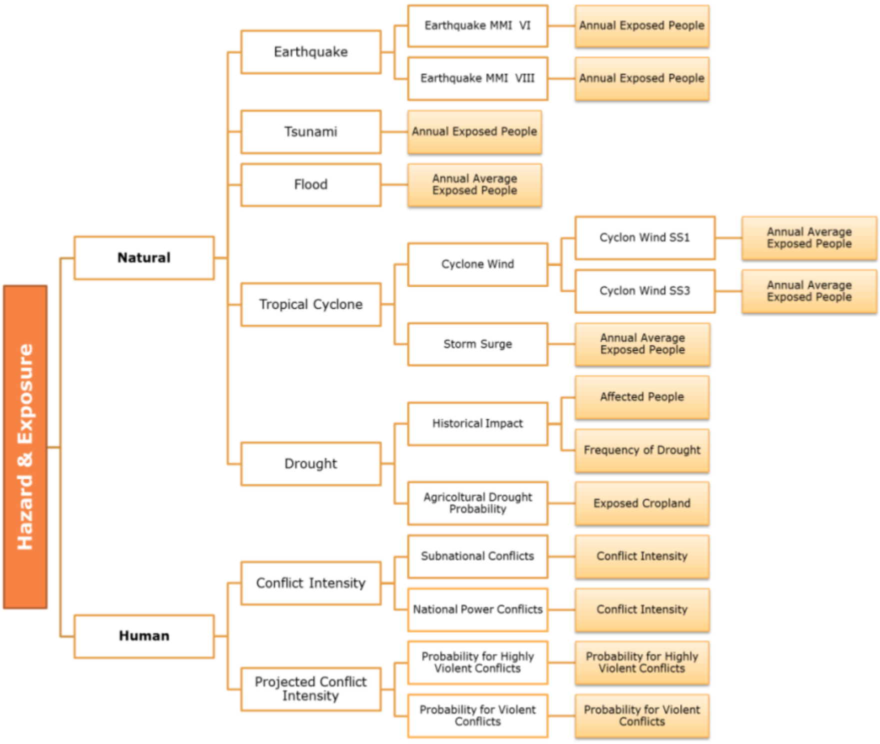

Figure 38: Indicators within Hazard & Exposure in the INFORM Risk Index.

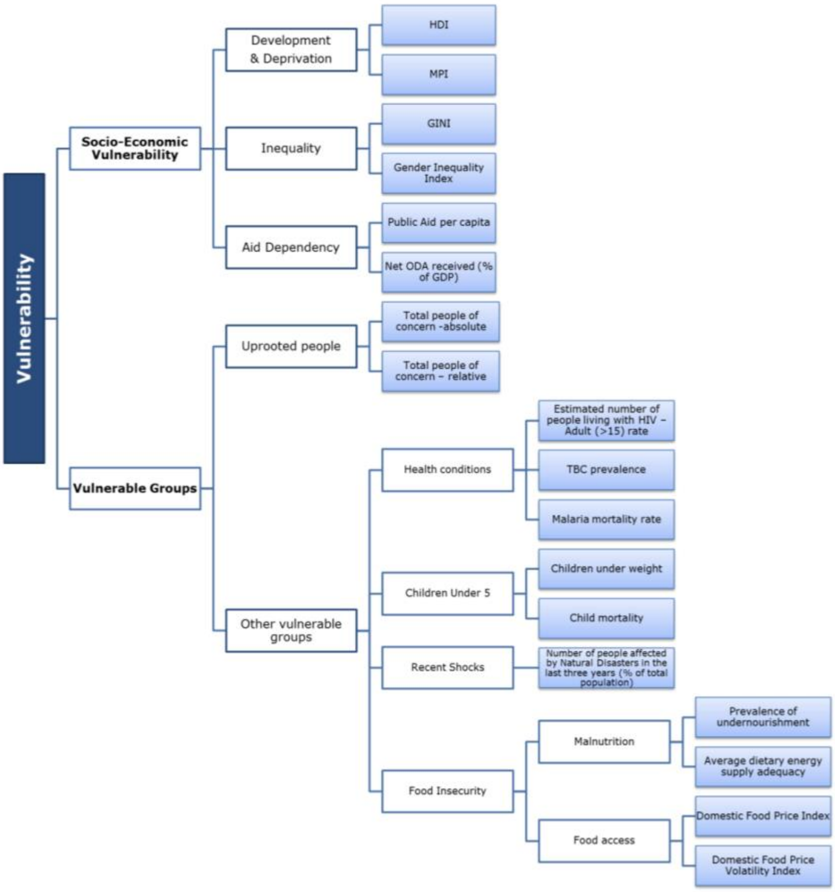

Figure 39: Indicators within Vulnerability in the INFORM Risk Index.

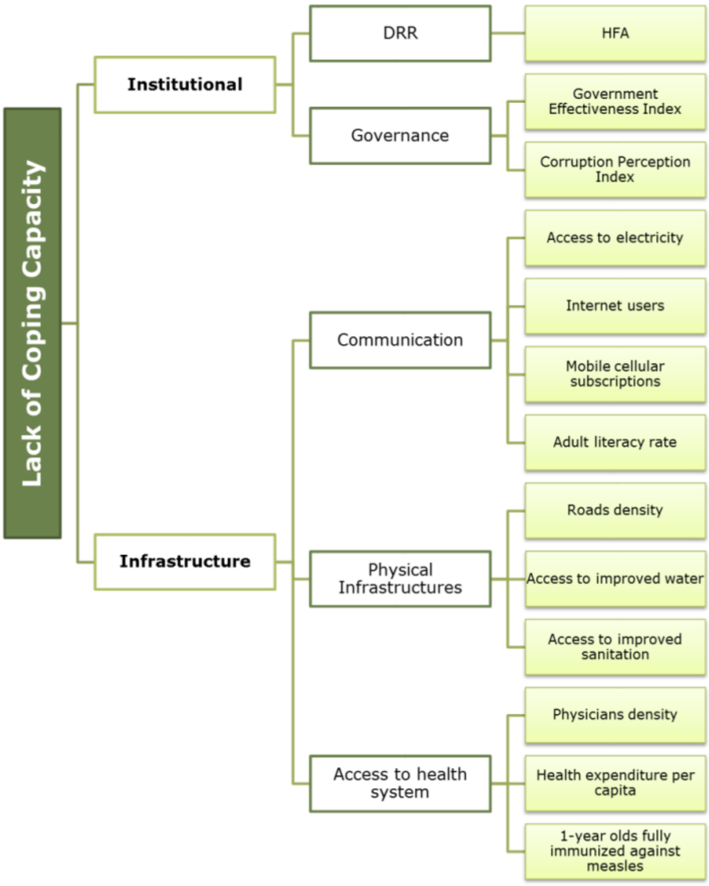

Figure 40: Indicators within Lack of Coping Capacity in the INFORM Risk Index.