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Assessing Vulnerability to Transboundary Climate Risks and Adaptation Options.

A Case of East Africa Commission Countries

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Abstract

Increasing global interconnectivity, in terms of our economies, ecological systems and population dynamics, can reduce or amplify the risks posed by climate change. The ongoing Coronavirus 2019 crisis demonstrates how rapidly disasters and risks can cascade and escalate across countries to become a shared problem globally. Climate change impacts are increasingly being recognised not only as a national problem but also a transboundary issue. However, transboundary climate risks assessments have tended to focus on the risks that transmit through our shared biophysical resources and neighbouring states with limited discussion on climate risks that transmit through other pathways, such as trade, people, and finance and from far off nations. Despite growing awareness about these transmission pathways, and some assessments in developed regions, there is a lack of a guiding framework to help planners identify and assess the key factors that drive transboundary climate risk exposure at the country and regional level. This study aims to contribute to filling these gaps by proposing a holistic analytical framework that can be used to assess how countries may be exposed to transboundary climate risks through trade. The East African Community (EAC) countries are used as case studies to illustrate how such assessments may be carried out. As a result, the thesis identifies two sets of factors. First, *external risk factors*, which determine the level of risk that importing countries are exposed to through their interaction with markets beyond their borders. Second, *internal adaptive capacity factors* representing the importing country's capacity to respond to transboundary climate risks. The results show that EAC countries face high levels of transboundary climate risks as a result of their high import dependencies, which link them to climate vulnerabilities in other parts of the world. Further, the study demonstrates that regional differences and interdependencies in transboundary climate risks exist. This can be explored to determine policy coherence and comparative advantage opportunities, within the region as well as individual country actions. To enhance the accuracy of future assessments and robustness of responses, the study recommends use of qualitative and quantitative methods. The findings offer a step towards guidance for the EAC countries, its trade and investment partners working in adaptation and trade, so that trade in East Africa is made more resilient to current and future climate change.

Key Words: transboundary climate risks, vulnerability, adaptation, adaptive ability, international trade, risk assessment.

Executive Summary

The world is increasingly interconnected. As a result, climate change impacts, risks and vulnerabilities are also connected across space. While the direct impacts of climate change at the local level are well understood, indirect impacts present complex interconnections and are less appreciated. In fact, very little is known about how climate change impacts will spread across and between places. Interconnectivity may amplify or reduce climate risks. Therefore, planners will need to adapt to impacts that are observed or expected in one country as a result of climate change events in other countries. The risks that result from these cross-border impacts are in this study referred to as transboundary climate risks. Overall, these risks are transmitted through finance, people, trade, and biophysical pathways A key example of such impacts is the global food crisis of 2007/2008 that led to global food shortages and price hikes as a result of climate related impacts (among many factors) in faraway countries. It is therefore pertinent to understand such risks, which is the aim of this study. If transboundary climate risks are not recognized, and if we continue to lack frameworks for identifying and assessing them, then we will not make meaningful progress in reducing vulnerability to climate change worldwide.

Despite acknowledgement of the existence of such risks, several gaps remain in both scientific literature and practice, some of which the thesis responds to. First, current climate change responses have focused on greenhouse gas mitigation with limited focus on adaptation. Yet, for East African Commission (EAC) countries, adaptation forms the main response to climate change. A review of EAC national adaptation plans and programmes of actions reveals low coverage of transboundary climate risks (section 2.1.2 and 5.3.5). Secondly, there is lack of guiding frameworks for the assessment and management of these transboundary climate risks. Hence, an analytical framework that considers the environment, economic and social factors of transboundary climate risks could act as an important guide to support the assessment and management of these risks, especially for the trade pathway, through which most of the world shares its commodities and services. Further, the national assessments of risk that have been undertaken are to be found in developed countries, mostly in Europe. Some transboundary assessments show that indirect impacts can be at times be an order of magnitude higher that direct impacts. It is therefore an important omission that such assessments are lacking for developing countries. National adaptation plans, as well as international support for adaptation in developing countries, need to be based on a complete assessments of climate vulnerability and risk exposure – including, crucially, exposure to transboundary climate risk.

As the transboundary climate risk assessment fields is still nascent, the thesis takes both a theoretical and empirical research approach. It focuses on the trade pathway and particularly on the food security and health sectors, which are important dimensions of social stability and development in the six EAC countries. First, drawing on existing theories in risk assessment, trade and adaptation, the research develops a framework to assess how countries may be exposed to trade related transboundary climate risks. The factors identified allow the researcher to understand the various elements operating on and within the countries that give rise to different outcomes. Second, the thesis operationalizes this framework to assess the trade-related transboundary climate risk exposure of the EAC countries. This step allows an understanding of how EAC countries are connected to other countries, where these connections are strongest, the extent to which the connected countries are directly and indirectly impacted by climate change and finally the overall risk profile for each EAC country.

Previous trade pathway assessment as in the UK (Appendix C), consider market dynamics and sensitivity to climate change, this study offers a wider approach framework to enhance similar

future assessments by adding more layers of analysis to the assessment of climate risk and trade portfolios.

As a result, this research proposes a novel analytical framework for understanding how countries could be exposed to trade-related transboundary climate risks. It presents a typology of trade transboundary climate risks useful in guiding future assessment and adaptation planning for transboundary climate risks. These are a) external risk factors and b) internal adaptive capacity factors. First, *external risk factors* refer to ways in which importing countries may be exposed to transboundary climate risks. They include the sensitivity to climate change of the exporting countries' infrastructure and commodities. Second, *internal adaptive capacity factors* refer to the importing countries' adaptive capacity to transboundary climate risks. They include the importing countries' economic, institutional, and social mechanisms; their sphere of influence, their market dynamics; risk perception and domestic production capacity.

Applying the framework on the food security (via cereal imports) and health (via pharmaceuticals imports) sectors of the EAC countries, results indicate that the EAC countries are at high risk from transboundary climate risks. Scoping for the e*xternal risk factors* show that the EAC countries are at medium to high risks for the pharmaceutical sector and cereals sector. The scores are mostly determined by the EAC's reliance on just a few specific countries for trade in critical imports, which heightens their exposure to climate risks affecting these supply chains. For example, their average concentration ratio (a measure of reliance on suppliers) is 89% for pharmaceuticals and cereals. Especially where these suppliers face high climate risks to their production and trade infrastructure, this translates to a high risk for importing countries in East Africa.

Similarly, the EAC *adaptive capacity factors* scores are low for both cereals and pharmaceuticals trade. For pharmaceuticals, the low capacity result from their low supplier diversity and manufacturing capacity; this means it will not be easy or even feasible for EAC countries to switch to alternative suppliers or to substitute imports with domestic production of pharmaceuticals. For cereals, their low adaptive capacity results from their similarly low supplier diversity, high internal vulnerability (i.e. to agriculture, where domestic farming could be a potential substitute for imported cereal commodities) and generally low risk perception scores.

Further, just as the EAC countries are at medium to high transboundary risks in their cereal and pharmaceutical sector through transmission of risks from their exporting partners, the EAC countries also expose *each other* to these risks; as the top exporting partners for each EAC country are other EAC countries. This high level of *regional interdependence* is an important finding of this thesis and a crucial dimension to include in regional and national planning to build resilience to transboundary climate risk through adaptation.

Despite the regions similar trading patterns and overall regional scores, some differences emerge. First, the economic, social and institutional mechanisms scores play a major mitigating or insulating role in the context of transboundary climate risk. For example, South Sudan's high cereal production capacity is cancelled out by its low economic, social and institutional mechanisms scores, which need to be in place to effectively respond to the EAC transboundary risks for cereals from outside the region.

Specific to the case studies, the study highlights the importance of expanding adaptation measures into the pharmaceutical supply chain sector beyond the food sector. The study shows that the countries face potentially equal or higher health risks through their pharmaceutical trading, which may be higher than food security risks, hence a need to consider these risks in adaptation plans. This is important as the focus on adaptation is mostly placed on agriculture and imports, as well as diseases likely to be exacerbated by climate change such as risks.

In terms of contributing to transboundary climate risk assessment, the research confirms that the interaction of internal and external factors makes risk assessment complex. The study therefore recommends the use of both qualitative and quantitative assessment approaches as key to improving the results of future assessments. Important factors in the analytical framework developed as part of this thesis, such as sphere of influence and risk perception, are key considerations and require contextual stakeholder input, for example. Similarly, more granular data on factors such as the transportation pathways and trade re-exports of commodities, can expose more differentiated external risks that arise through the supply chain. For example, for countries dependent on their neighbouring country seaports in this study Rwanda, and the risks and or opportunities that arise through re-exports.

The final risk scoping approach in this study relies on a simplified risk matrix and scoring commonly used in risk assessment. This simplified approach is considered adequate for this study given that the aim is not to make a precise evaluation of the risk but rather to reveal the pattern of how EAC and other countries may be exposed to transboundary climate risks and to stimulate future dialogues on these risks. Future assessments could consider advanced modelling techniques combined with contextual information of other factors such as risk perception and sphere of influence. Similarly, future research could consider more granular data on factors such as the transportation pathways, price volatilities, manufacturing capacity and trade re-exports of commodities, which can expose more differentiated external risks and adaptive capacity that arise through the supply chain for each case study. Future research could thus benefit for example from re-export trade data and manufacturing data at commodity and product specific level, which may reveal new insights on relevant factors such as domestic production or manufacturing capacity potential. Similarly, for important factors such as sphere of influence, it was difficult to measure the influence of bilateral relationship between the trading partners which serve to influence the power dynamics. It would be interesting to see future assessments develop methodologies to include the sphere of influence in transboundary climate risk assessments.

The study makes recommendations that could address co-benefits between managing transboundary climate risks and the current prioritized national risks. These include the need for policy alignment between adaptation, climate change policies and other sectors such as trade as the interactions between them can either amplify or reduce the countries' risk exposure. Second, the study recommends enhanced collaboration between EAC countries. This would allow EAC member countries to exploit their different comparative advantages, which the study shows exist, as well as to work together to minimize the interregional spread of transboundary climate risks. The collaboration could be between trade, agriculture, health, environment ministries within and between the countries. Similarly, regional collaboration on adaptation – in East Africa but also in other world regions – has so far under-utilized regional economic organizations as a forum for collaborative resilience building. The lens of transboundary climate risk and the results of this specific thesis make the case to revisit regional collaboration for adaptation via the EAC and equivalent bodies in other regions.

In conclusion, the study shows that global interconnectedness will continue to raise the need to consider transboundary climate risks and to design appropriate adaptation measures that do not lead to maladaptation. It offers a guiding framework useful in the assessment and management of transboundary climate risks from trade and that could contribute to updating

EAC national adaptation plans and programmes of actions to consider both direct and indirect climate risks and responses.

Table of Contents

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS

AAI	Africa Adaptation Initiative
AfCFTA	African Continental Free Trade Agreement
CDP	Carbon Disclosure Project
CPIA	Country Policy and Institutional Assessment
CR_5	Concentration Ratio of top five exporting country
EAC	East African Community
EY	Ernst & Young
FAO	Food and Agriculture Organization of the, United Nations
HHI	Herfindahl index
IPCC	Intergovernmental Panel on Climate Change
ITC	International Trade Centre
MEN	Ministry of Environment, South Sudan
MENR	Ministry of Environment and Natural Resources, Kenya
MLEM	Ministry of Lands Environment and Mine, Rwanda
MLMTE	Ministry for Land Management, Tourism and Environment, Burundi
MWLE	Ministry of Water, Lands and Environment, Uganda
NAPAS	National Adaptation Programme of Actions
NAPS	National Adaptation Plans
ND GAIN	Notre Dame Global Adaptation Initiative
NDC	National Determined Contributions
PwC	PricewaterhouseCoopers
REMA	Rwanda Environment Management Authority
SEI	Stockholm Environment Institute
UK	United Kingdom
UNCTAD	United Nations Conference on Trade and Development
UNDESA	United Nations Department of Economic and Social Affairs
USA	United States of America
VPO	Vice Presidents Office, Tanzania
WB	World Bank
WEF	World Economic Forum

1 INTRODUCTION

1.1 Background and Significance

Environmental concerns now dominate the top long-term risks by likelihood and impact globally (WEF 2019) with climate change key among them. For Africa, projections indicate that Africa is anticipated to be the most negatively impacted as result of high negative impacts and low adaptive capacity (IPCC, 2014).This is expected to lead to various cross-sectoral impacts including reduced agriculture production, decreased water availability, extreme events such as flooding and human health risks. Consequently, the highest adaptation costs will be associated with water, infrastructure and agriculture (Schaeffer et al., 2013). These climate change impacts and risks are further complicated by the connectedness of countries through shared ecosystems, markets, infrastructure and people (Benzie et al., 2013; Liverman, 2016). Subsequently, climate change impacts in one country could introduce risks to other countries. These risks may even be higher than those resulting from direct, domestic climate change impacts, and in some cases may even present opportunities (PwC, 2013).

Despite the long-recognized fact that climate change impacts such as droughts and floods cross between geographical borders, adaptation responses and assessments have focused within national borders as outlined in National Adaptation Plans and Programmes of Actions. Moreover, transboundary climate risk has mainly been assessed by and for developed countries, especially in Europe (PwC, 2013; Schaeffer et al., 2013; Warner et al., 2013) with developing countries mainly focused on national specific risk assessments including for all six East African Community (EAC) countries assessed in this study. While still effective, these national approaches are narrow as research shows that both groups of countries face transboundary climate risks (Challinor et al., 2017, 2018; Hedlund et al., 2018). These risks are related to trade; biophysical elements for example river basins; people, through changes in tourism and migration; and financial, through disrupted returns on overseas investments (Benzie et al., 2018; Challinor et al., 2018). If these risks remain inadequately understood and addressed, progress will not be made in reducing vulnerability globally (Cardona, 2004; Magnan et al., 2016; Nadin & Roberts, 2018). Moreover, if adaptation is planned without considering these global interdependencies, it may lead to mal adaptation across borders and to the redistribution (than reduction) of vulnerability globally (Atteridge & Remling, 2017).

Varied responses to climate change have been employed with most of the efforts focused on mitigation of greenhouse gases and climate change governance (Benzie et al., 2018; UNCTAD 2019). A major response has been commitments by parties to the Paris agreement to limit warming to below 2^{o}C as communicated through their National Determined Contributions (NDCs) (UN, 2015). However, it is anticipated that achievement of targets outlined in the submitted NDCs would lead to a median warming between 2.6-3°C by 2100. This calls for additional mitigation and adaptation measures for countries (Rogelj et al., 2016). For example, countries have undertaken collective actions and responses to climate change. These include transboundary resource management which has been implemented over a long time. In Sub Saharan Africa, agreements for transboundary water resources including the Nile, Niger and Congo basin have been in place for decades. However, such efforts remain disjointed with transboundary risks inadequately quantified (Nadin & Roberts, 2018; Rogelj et al., 2016). These realities underpin the importance of adaptation, further moving from local approaches to national, regional, and global (transboundary) approaches.

For the first time adaptation has been recognized in the Paris agreement as a global challenge (United Nations 2015, Art 7.2) with urgent and immediate action required for developing countries. Persson & Dzebo (2019) propose adaptation as a global challenge due to the global nature of climate impacts requiring not only national responses but also coordinated regional, international, and transboundary responses. Likewise, adaptation has the potential to offer global and regional public goods through "cross boundary spill overs". Thus, the Paris agreement calls for the world commitment to the global goal on adaptation seeking to reduce vulnerability and increase resilience (UN 2015, Art 7.1). Consequently, African countries have prioritized adaptation and submitted an adaptation component as part of their NDCs. However, challenges remain among them funding and institutional arrangements. Additionally, there is a lack of adequate information on exposure, risk and vulnerabilities to people and livelihoods (AAI, 2016).

Responding to these adaptation challenges, the global goal on adaptation calls for actions to increase resilience, adaptive capacity and reduce the vulnerabilities of affected communities (UN, 2015). However, action in one country has the potential to impact other countries' ability to respond to climate change risks (Atteridge & Remling, 2017; Magnan et al., 2016). For example, the food crisis of 2007-2008 affected prices of wheat, rice and maize, as a result of poor harvest forecasts (among many factors) but made worse by the policy responses of various rice trading countries, with countries such as Senegal hit the hardest due to its heavy reliance on imported rice (SEI 2013). Similarly, countries such as Egypt, Mauritania and Gambia are highly vulnerable to the management actions of upstream countries where they source over 80% of their water (Chikozho, 2015).

Lastly, the researcher acknowledges the different terms employed in literature to refer to climate risks crossing borders, such as transnational (Benzie et al., 2016; Hedlund et al., 2018), systemic risks (Challinor et al., 2018; IPCC, 2012), transboundary (Challinor et al., 2017; Nadin & Roberts, 2018), teleconnections (Moser & Hart, 2015), international threats (PwC, 2013) and indirect impacts among others. This research uses the terms "transboundary" and "indirect"(Challinor et al., 2018) climate risks to refer to these types of risks

1.2 Problem Definition

As illustrated above, the world is increasingly interconnected politically, economically, socially through systems such as food, energy, biophysical environment, and economies. Consequently, global challenges such as climate change and adaptation to it, will occur in an interconnected world with impacts felt both locally and cascading through multiple systems and regions (Benzie et al., 2013; IPCC, 2012; Liverman, 2016; PwC, 2013). This interconnectivity may reduce or amplify vulnerability and climate risks. Similarly, if the associated climate risks are not assessed and presented in a way that attract stakeholders' attention, it is not possible to make progress towards reduction of climate change impacts (Cardona & Tibaduiza, 2011).

Despite this acknowledgment, several gaps and challenges remain. Firstly, current vulnerability and climate risk assessments do not fully appreciate these interactions especially those happening further from the origin of the climate event. Hence, when caught unawares, countries, companies and people risk incurring substantial life and investment losses. Some studies have assessed these interactions broadly for example in studies assessing land changes. Fewer studies have assessed the far off interactions as a result of trade, finance and people (Moser & Hart, 2015; Persson & Dzebo, 2019).

Secondly, climate change responses have included mitigation and adaptation with more focus placed on mitigation and governance issues with limited focus on adaptation. This is also observed in the flow of climate finance from developed countries where 72% is allocated to mitigation, 15% to adaptation, and 13% to other responses (UNCTAD 2019). This is despite the likelihood of not meeting the 1.5 °C and adaptation been identified in the Paris agreement as a key response in that regard (UN, 2015).

Thirdly, current adaptation commitments as outlined in National Adaptation Plans and Programme of Actions (NAPS/NAPAs) focus mostly on local and national climate risk and impact assessments and responses (Challinor et al., 2017; Nadin & Roberts, 2018). While local and national responses often yield results, there is increasing focus on the impacts of maladaptation as well as transboundary climate impacts and adaptation resulting from the increasing interconnectedness of the world today (Atteridge & Remling, 2017; Benzie et al., 2016; Challinor et al., 2018; Persson & Dzebo, 2019). For example, in a highly connected trade world, commodity dependent developing countries are cited as highly vulnerable to climate change (UNCTAD 2019).

Fourthly, methodological gaps exist. Assessing direct impacts of climate such as drought in a nation may be straight forward. Conversely, assessing transboundary impacts of climate change such as biophysical, trade, finance and people flows is more complex due to the interlinked nature and cascading aspects of these systems sometimes stretching across borders (Challinor et al., 2018). Current research on transboundary impacts have focused on sectoral impacts such as food and water. A few national level transboundary climate risks associated with the trade, finance and people flows have been assessed by and for developed countries, especially in Europe (Benzie et al., 2019; Dellink et al., 2017; EY, 2018; Hedlund et al., 2018; PwC, 2013) with developing countries mainly focused on national assessments, economies or people (REMA, 2015; Schaeffer et al., 2013; Warner et al., 2013). While still effective in identifying and minimising local risks, national approaches are narrow as research shows that both groups of countries face transboundary climate risks (Challinor et al., 2017, 2018; Hedlund et al., 2018). Moreover, Hedlund et al (2018) reveal that the divide between rich and poorer countries does not always hold when it comes to assessing transboundary climate risks. Their analysis notes that some highly developed countries such as the Netherlands and Luxembourg, ranked high in terms of the exposure to transboundary climate risks compared to lower ranked countries.

Further, risk evaluation and analysis is hampered by the lack of a multidisciplinary comprehensive conceptual framework. This further curtails effective and comprehensive climate change adaptation and mitigation responses (Cardona, 2004). Specifically, there is lack of transboundary adaptation frameworks that build upon existing international regulatory frameworks (Nadin & Roberts, 2018) This is important as risk management requires measuring the risk and taking into consideration the social, economic, and environmental factors to facilitate multidisciplinary responses to risks that cross borders (Challinor et al., 2018). A risk assessment framework has been developed by Cardona et al (2011) focusing on national and subnational scales. Similarly, the broad class of components and linkages to be considered in vulnerability assessment is presented (Turner II et al., 2003). However, these frameworks offer guidance on the broad components worth considering but do not capture the transboundary aspects of climate change specific to trade. Hedlund et al (2018) attempt to respond to this gap by presenting a global transboundary climate risk index. However, their assessment is spatially high level, hence cannot be used to inform regional or national approaches to transboundary climate risk. Thus, they, recommend more fine-grained country level assessment that consider specific factors through which countries are exposed to transboundary risks such as market dynamics which influence the countries' capacity to absorb import flow variabilities. The UK assessment partly responds to this gap, as it focuses on the transboundary risks to the UK, assessing these risks across the business, health, policy, trade and food security sectors. Proxy indicator factors are considered for each theme. But specific to trade, the assessment also considers market dynamics to assess the trade risks to the UK. The assessment does not consider adaptation responses adapted by the UK to trade related transboundary risks (PwC, 2013).

Likewise, disaster risks are often causally linked to existing environmental, economic, social risk factors (IPCC, 2012). Some studies (Challinor et al., 2017, 2018; Liverman, 2016) detail some of the factors worth considering in assessment of transboundary climate related trade risks. However, current transboundary assessments (Dellink et al., 2017; EY, 2018; PwC, 2013) focus on one or two of these factors with no study indicating or offering guidance on the range of factors worth considering or how to evaluate them. These represents a key guidance and decision gap on the assessment and management of transboundary climate risks and impacts in both developing and developed countries given that risks that, measures to reduce risks will likely not be put in place if the risks are not adequately understood by the decision makers.

This thesis responds to the above challenges. It addresses the lack of a comprehensive framework to guide the assessment and management of trade related transboundary climate risks. It presents an analytical approach to measuring each of the factors identified in the framework to obtain a risk profile for the country under study. To demonstrate the application of the framework the East African Commission countries are used as case studies.

1.3 Research Objectives and Questions

The research aim of this research is to contribute to knowledge on transboundary climate risks. The objective is to highlight how countries might be exposed to transboundary climate risks and demonstrate how these risks may be assessed. It further provides recommendation for responding to these type risks. This is important given the political and economic implications of transboundary issues and the need to understand how national, regional, and international mechanisms and organizations can cooperate to manage transboundary climate risk through their adaptation responses.

Specific research questions include:

1. **How can countries be exposed to transboundary climate risks?**
   Sub question 1a: **What factors might influence the trade related transboundary risks of countries?**
2. **What are the trade related transboundary climate risks for East African Commission countries?**

The research first assesses how countries may be exposed to transboundary climate risks through their interactions with other countries and how these risks transmit (research question 1). It then focuses on the trade transmission pathway (research question 1a). Second, it uses the six East Africa Community countries as case studies to demonstrate how such assessments may be carried out(research question 2). Specifically, the food security (via cereal imports) and health (via pharmaceuticals imports) sectors of the EAC countries are evaluated. The research integrated systematic literature review, qualitative analysis, and quantitative analysis. Further, the research identifies potential adaptation options in countries' current adaptation plans that could be employed to address transboundary climate risks.

1.4 Delimitation and Scope

This section details the limitations placed upon the research which together form the scope of the project. The focus of the thesis is transboundary trade related climate risks. Hence, the research was broadly guided by the four transboundary risk assessment pathways (trade, people, biophysical and finance) further focusing on the trade pathway.

In assessing climate risks, it is important to consider sensitivity, vulnerability, adaptive capacity and exposure (Cardona et al., 2012) hence the assessment was bounded around these four criteria. The sensitivity to climate change of the exporting countries and to the prioritized commodities was assessed (referred to as external factors), in addition to the adaptive capacity and vulnerability of the EAC countries (internal adaptive capacity factors) to respond to transboundary climate risks.

The study focuses on the influence of climate change on trade and not trade on climate change. The research only considers climate change and its impacts as one among several factors that influence trade decisions. Hence, additional factors such as commitments to existing trade agreements are not considered. Consequently, the research serves to strengthen the existing narrative on the importance of incorporating climate change issues in economic and social development.

The research focuses on adaptation. This is due to the limited focus on adaptation compared to mitigation in climate change responses. Hence no consideration is made of mitigation responses. Further the decision is informed by EAC region's prioritization of adaptation responses. Moreover, it is unlikely we can limit warming to 1.5°C target under current Paris agreement commitments in the submitted national determined contributions (Rogelj et al., 2016) hence, need for adaptation measures.

Due to the borderless nature of transboundary climate risks requiring not only national but cross border scope (Benzie & Persson, 2019), the geographical scope of the research is EAC countries. Uganda, Rwanda, Kenya, South Sudan, Tanzania, and Burundi were deemed suitable to gain insights on the transboundary risks and assessment approaches for several reasons. Firstly, in case study research, a diverse set of cases is recommended to represent maximum spatial and temporal variability across the dimension under study (Sovacool et al., 2018; Yin, 2009). Spatial variability was achieved through selection of all the six EAC countries in addition to their individual 24 top trading partners for cereals and pharmaceuticals. This represented trading partners from Asia, America, Africa, Australia, and Europe. Temporal variation was achieved by using data from the last five-year period (2014-2018) where available. Secondly, the EAC region was suited for this case study due to limited research on the trade, finance, and migration pathways for developing regions. Currently, only the UK, Sweden, Germany, Netherlands, and Norway have conducted focused national level assessments of their exposure to transboundary climate risks and hence this thesis offers a different economic and social perspective. Thirdly, some transboundary climate risk studies indicate that second-order climate impacts as represented by transboundary climate risks can sometimes be more severe than direct first order impacts (PwC, 2013). It is therefore important for the already highly climate change vulnerable countries like the EAC (IPCC, 2007), to take up a proactive approach to understanding and managing their direct and indirect risks Lastly, the literature review indicates a gap on the trade pathway, yet this is a target sector for the EAC region in enhancing its economic and social development.

The research focused on products/commodities, since they are more directly impacted by climate change as compared to services. Moreover, trade in services often result from commodity trading, as services rarely operate in isolation from commodity trading. Moreover, focus is placed on imports since climate change assessments and adaptation responses to exports which are usually locally produced are already extensively captured in national climate change and adaptation plans. Further, transboundary climate impacts arise from climate change impacts to products or services outside the country of study, hence this will usually refer to imports for the trade pathway. Additionally, incomplete, and highly aggregated data on trade of services for the EAC community, further informed the focus on commodities Thus, pharmaceuticals and cereals which form the top ten imports for the EAC country were selected. The two group of products are taken to represent the health and food sectors which are highly susceptible to climate change (Boko et al., 2007; IPCC, 2012) and heavily traded on the international market (Dellink et al., 2017).

1.5 Cooperation with a research institute and ethical considerations

The research was conducted in collaboration with the Stockholm Environment Institute (SEI), and specifically with the Adaptation Without Borders project which aims to understand indirect impacts of climate change. The project aims to create visibility, build connections, and inspire actions around transboundary climate risks and adaptation. This research augments the projects' research and evidence base for transboundary climate risks in Africa.

This research borrowed insights from preliminary work done on global transboundary climate risk assessments and baseline transboundary climate risk assessments done for Kenya by SEI. There was no conflict of interest as the results aim at furthering the knowledge on transboundary climate risks on a broader level outside the project partners. Overall, the research design has been reviewed against the criteria for research requiring an ethics board review at Lund University and has been found to not require a statement from the ethics committee.

1.6 Audience

Risk assessment is among the starting points towards risk governance (IPCC, 2012). Thus, the research thesis is useful to government, business, civil society, and academia interested in improving their understanding on their exposure to and management of transboundary climate risks. The study presents a simple yet robust analytical framework that is useful in guiding future transboundary climate risks assessment. Further, the results could inform the assessment of risks in for example the next iteration of national adaptation plans and programmes of action.

1.7 Outline

Chapter 1 presents the problem addressed by this thesis, outlines the specific research questions, the delimitations and scope of the study as well as the ethical considerations and intended audience of the study. Chapter 2, presents the literature review and introduces the state of knowledge of transboundary climate risks further focusing on Africa. It presents the transboundary risks associated with trade, methodologies and concepts used to construct the analytical framework, and the gaps in literature that the thesis responds to. Chapter 3 presents an overview of the research design, data collection methods and the steps to taken to ensure the validity and reliability of the study. Chapter 4 presents the analytical framework detailing the rationale behind each factor and the steps taken to analyse it. Chapter 5 presents the results of the case study data analysis guided by the previous constructed analytical framework. Chapter 6 discusses the main findings of the analysis and their practical, theoretical, and methodological implications as well as the de-limitations of the research. Chapter 7 contains recommendations based on the results of the study and concludes with a summary of the thesis.

2 LITERATURE REVIEW

This chapter contains four sections. Sections 2.1 introduces transboundary climate risks and impacts further narrowing to the state of knowledge in EAC countries. Section 2.2 focuses on impacts of climate change on trade. Section 2.3 presents a review of the methods for assessing transboundary climate change risks, exposing the strengths and weaknesses in their application. Section 2.4 presents key concepts in climate risk vulnerability and assessment from which the analytical framework is constructed. Section 2.5 presents a summary and gaps in the literature.

2.1 State of Knowledge on Transboundary Climate Risks

2.1.1 Indirect Climate Impacts, Risks and Transmission

Climate change impacts can be defined as direct or indirect impacts. Direct impacts refer to impacts that occur within a defined geographical boundary or decision-making system (Benzie et al., 2013). A wide range of literature exist that assess direct climate change impacts and vulnerabilities for Africa. These include estimates of sea level rise, flooding risks, droughts, ecosystems degradation, agricultural productivity and, on economic sectors such as tourism and energy, as well as health and cities. Some assessments include economic costs of the impacts presented at regional or sub regional levels (Boko et al., 2007; IPCC, 2014; Omambia et al., 2012; Schaeffer et al., 2013; Warner et al., 2013; WB, 2013). A number of national level vulnerability assessments have also been conducted for example for Rwanda (REMA, 2015), Kenya (MENR, 2017) and South Africa (Madzwamuse, 2011). Other assessments have focused on specific sectors for example health investigating malaria prevalence (Onyango et al., 2016), food systems (Challinor et al., 2007) and cities (Herslund et al., 2016). Similarly, steering away from the mainly biophysical vulnerability assessments, Vincent (2004) conducts a social vulnerability assessment of African countries to climate induced variations of water availability where Niger, Sierra Leone, Burundi, Madagascar, and Burkina Faso emerge as the most vulnerable.

As the world becomes increasingly interconnected, so do the climate change risks and vulnerabilities. In contrast, to the direct impacts as listed above, indirect impacts of climate change and adaptation are less discussed. This raise concerns on the impacts of national and regional measures on other nations outside those boundaries (Challinor et al., 2017; Liverman, 2016). For example, what are the impacts of adaptation responses of large producer and consumer countries to other countries?

Indirect impacts allude to the international dimension of climate change. They are "impacts that are observed or expected in one place but are brought about by climate change or extreme events somewhere else" (Benzie et al 2013, p3). They occur when climate change impacts cross borders requiring adaptation in other countries. These impacts can be caused through climate change impacts in immediate neighbouring countries or further off countries (Benzie & Persson, 2019; Hedlund et al., 2018).

In examining transboundary climate risks, it is important to consider the transmission pathway. Framing of the risks transmission mechanism and component is important in determining what and how a risk is measured. It also informs policies worth adopting (Challinor et al., 2017, 2018; Moser & Hart, 2015; PwC, 2013). Climate risks transmission is rooted in climate systems (Challinor et al., 2018). Far off and near interactions between climate events happening in different parts of the world have long been recognized in biophysical sciences and include for example those resulting from biophysical processes such as interactions of oceans, freshwater, atmosphere, and land. Other interactions result from human systems such as human institutions and processes (Moser & Hart, 2015).

These transmission mechanisms are summarized in the Table 2.1 and described further in the following paragraphs.

Table 2.1: Transboundary climate risks transmission mechanisms.

PATHWAY	**Example climate impacts on:**
Finance	• Economy (extreme events) • Remittances
People	• Climate related migration • Tourist flows
Trade	• Raw materials disruption • Manufacturing disruption • Food price volatility • Reliability of supply
Biophysical	• River basin management • Invasive species
Global context	• Arctic resources • Access to water

Source: (Benzie et al., 2017).

Transboundary risks transmission can be grouped into two main mechanisms which do not act in isolation and often interact (Challinor et al., 2017). The first transmission mechanism is through environmental processes also broadly referred to as climate triggered risk transmission. For example, risks posed by the variability of the El Niño southern oscillation can transmit through the biological and physical processes in nature. The second mechanism is resource generated transmission which is triggered by climate perceived risks that may or may not exist. Resource generated transmission originates from anticipation of a future possible scarcity in a particular resource. These risks come from real systematic or observed climate patterns across space and time which, may or may not be measured. They can be driven by competition for resources as well as institutional and political competition. Hence, the transmission mechanism is amplified or even reduced through social systems e.g. trade, finance, or people through migration and tourism. This amplification or reduction may occur because of prior social, political, market, media and behavioural responses to these risks (Benzie et al., 2016; Challinor et al., 2017; Moser & Hart, 2015).

Further, risk transmission can be examined through three main components. The first component is physical structure such as roads, ports etc. through which a product or service is conveyed. Second, the process which refers to the reason behind the transmission of the product or service which may include market, travel, migration, social or cultural norms, desire for cheap labour, globalization of manufacturing etc. Third, the substance which refers to the transmitted product or service for example money, energy, people and information. Impacts from the interaction of these components can be positive and negative. The impact also depend on the ability of the impacted society, sector, country or actors to respond to the circumstances (Moser & Hart, 2015).

In managing transboundary climate risks, the private sector has in the past considered indirect risks arising from climate change along the supply chains and input resources such as water (Bailey & Wellesley, 2017; CDP, 2013; Tenggren et al., 2019). In contrast, national governments have considered indirect impacts to a lesser extent as seen through their national communications that mostly refer to direct impacts (Benzie et al., 2013; Challinor et al., 2017). Nevertheless, some approaches to transboundary resource management have been employed including the setup of regulatory and institutional frameworks. Regulatory approaches have included development of binding and non-binding multilateral, regional and bilateral treaties, and memoranda of understanding. These include the Rio Framework, the Convention on Biological Diversity, United Nations Watercourse convention, Convention on the law of the sea, among others. On an institutional level, institutions recognizing transboundary climate risks and in particular working towards transboundary adaptation include the International Network of Basin Organizations and the UN Economic Commission for Europe, among others.

2.1.2 Transboundary Climate Risks in Africa

The assessment of transboundary climate risks has mostly been conducted for Europe (EY, 2018; PwC, 2013). In Africa, focus has been placed on cross-border assessment of shared resources such as lakes, parks, and rivers. For example, the Nile basin management initiative across 11 countries in Africa, was established in 1967. While this initiative has had it has had some successes, communities do not still fully understand how their actions impact each other, leading to unsatisfactory results in some instances. This underscores the need to further understand existing climate risks and interdependencies (Chikozho, 2015).

Sub-Saharan Africa is increasing interconnected with other regions. This is seen through its trade, people, finance, and biophysical flows. In trade, the region's value of exports accounted for 319 billion US$ and imports accounted for 335 billion US$ in 2018. The main trading partners include Europe, East and South Asia and Northern Africa. The region is working to close the deficit year on end as seen through region trade pattern hence the interconnectivity through trade is likely to increase (UNDESA, 2019). Similarly, the region's population is estimated at 1.078 billion in 2018, with an estimated 18 million characterized as international migrants and refugees as at 2015. The regions inflow foreign direct investments in 2018 totalled 31 billion US dollars, with foreign direct investment outflows of 22 billion US dollars (WB, 2020). In terms of biophysical resources for example, the region is characterized as one of the most hydrologically interconnected regions of the world (Chikozho, 2015).

Several institutional and regulatory approaches exist in managing transboundary climate risks and impacts. The Africa Adaptation Initiative (AAI) signed into by all the 54 nations is one example. The AAI has committed to developing a guidance on vulnerability assessments for signatory countries. A key gap noted in vulnerability and risk assessment is lack of adequate capacity and infrastructure to manage and process climate data hence, limiting adequate climate change responses including adaptation. Additionally, the AAI notes that lack of information on exposure, risk and vulnerability to people and assets in Africa remains a key gap (AAI, 2016). Other initiatives include the great green wall aimed at addressing land degradation and implemented across 20 African countries (AU, 2016). Similarly, the African Risk Capacity allows the African member states to respond to disaster risks through collaborative risk finance mechanisms. It aims to model the impacts of droughts and tropical cyclones across the continent to be able to offer rapid and predictable financing to its members (AU, 2019). Others include the Collaborative Adaptation Research Initiative in Africa and Asia which has created regional climate hotspots and shares lessons learned on regional adaptation planning (Nadin & Roberts, 2018).

To understand the state of the art for EAC on transboundary climate risks and adaptation on the four transmission pathways- trade, biophysical, finance and people- the EAC regional climate risk plan (EAC, 2011b), National adaptation Plans (NAPs) and programmes of Action (NAPA) of the six countries were systematically evaluated. These were selected as they as they represent the countries' prioritized official national risks and planned responses to climate change impacts.

In the Kenya NAPs (MENR, 2017) and supplementary technical report, biophysical transboundary risks dominate. These include flooding from shared resources such as Lake Victoria. Flooding of some upstream parts of Ewaso Nyiro is considered a positive aspect due to the deposition of silts into flood plains creating new agricultural fertile lands. However, no acknowledgement of the impacts of these agricultural activities on downstream parts flowing into Jubba river into Somalia is mentioned. Similarly, concern over the impacts of sea level rise on Kenya coastal ports and infrastructure is highlighted. The risk to trade, export earnings, food imports and supply chains arising from climate change further curtailing private investment, affecting the manufacturing sectors, and disrupting the country's ambitions to alleviate poverty, is put forth as a concern. Others include transboundary risks to externally displaced persons through transboundary conflicts as a result of shared resources. Risks to foreign exchange earnings when exports and sectors such as tourism reliant on outside partners are affected is expressed as a concern. Suggested adaptation options include cross-border collaboration involving shared resources such as Mt. Elgon and Lake Victoria. Others include improving monitoring and evaluation capabilities to further support international negotiations, collaboration of regional meteorological services and reduced reliance on external funding through building domestic sources. Overall, transboundary responses outlined in both reports, are broad with no accompanying measurement of the magnitude of the risk in comparison to other risks. They are also nation (inward) facing where responsible actors and outlined indicators are restricted to national ministries and civil service. For example in response to the trade risks, the outlined actions include "Build the capacity of the private sector (formal and informal) so as to enhance the resilience of their investments for example, through the identification of new products and services that are more resilient to climate change impacts; by development of fiscal incentive measures to encourage businesses to undertake investment in adaptation and resilience building measures.; and by implementation of long- term private sector investment in adaptation and resilience building measures" (MENR, 2017, p40).

The Rwanda NAPA (MLEM, 2007) recognizes risks from shared natural resources such as Lake Kivu (used to mine methane gas) and climate moderating effects of cross border natural resources such as the Congolese. basin and Lake Victoria. The only explicitly mentioned transboundary adaptation response is the need for an integration of actions across the region and sectors. This is despite most of the mentioned priority national risks to sectors such as agriculture, energy, migration arising from natural resource disasters having potential transboundary risks.

The Uganda NAPA (MWLE, 2007) recognizes climate risks on food imports, shared natural resources, fish exports, energy security due to declining water levels of the Nile, regional conflict, biodiversity loss in shared resources such as the Ruwenzori mountains affecting wildlife migration patterns and ultimately risks to tourism. However, adaptation options to these transboundary risks are not explicitly mentioned.

The Tanzania NAPA (VPO, 2007) outlines risks to shared natural resources such as Lake Victoria, Tanganyika, Mara national park, shared water resources and disease transmissions. Prioritized adaptation responses however respond to only national climate risks.

The South Sudan NAPA (MEN, 2016) outlines transboundary climate risks arising from over reliance on oil exports, risks to shared transboundary resources such as the river Nile, and potential risks to these shared water resources from oil pollution. Transboundary adaptation options tailored to these risks are however not mentioned in the NAPA. This is the case even where adaptation options such as increased irrigation and dyking around the Nile have potential transboundary impacts.

The Burundi NAPA (MLMTE, 2007) outlines transboundary risks related to shared natural resources such as the Nile and Congo basin and risks to foreign income due to decreasing income from primary products such as coffee.

Lastly, the EAC climate policy (EAC, 2011b) takes a more transboundary approach compared to the individual country NAPAs and NAPs. It includes transboundary climate risks across economy, socio economic, agriculture and food, water, energy, tourism, human health, trade, and industry sectors. The master plan (EAC, 2011a) calls for integrated responses to regional climate adaptation across all the sectors. It however does not detail specific actions that the EAC intends to take.

2.2 Trade and Climate Risks

The production of commodities and services to meet human needs has contributed to climate change through for example, contribution to greenhouse gas emissions. However, the research in this thesis focuses on climate change associated impacts and risks on trade adding to the still scarce dedicated literature addressing this connection (Dellink et al., 2017; Tol, 2018). Climate change may in the short term bring some economic gains. For example, carbon dioxide fertilization may make plants more drought resistant in areas heavily dependent on rainfed agriculture. Similarly, warmer winters may lead to reduced costs of heating. In the long term however, the negative impacts outweigh the positive (Tol, 2018).

Specific to trade, the trade pathway is one of the most important and long-distance interconnectedness arising from our global interactions (Challinor et al., 2017; Moser & Hart, 2015). Climate change is expected to drive patterns of international trade through changes in yields, available arable land and water, energy developments and population growth adding pressure on domestic food production and imports (Huang et al., 2011; Nelson et al., 2013; Willenbockel, 2012). Through globalization, trade interdependencies can be both positive and negative. Positively, through trade, the world depends largely on wheat, rice, maize, sugar, barley, soy, palm and potato to meet approximately 74% of its calorie needs, yet production of these commodities is concentrated in a few countries (Challinor et al., 2017; FAO, 2013). Similarly, climate policy is predicted to impact international trade where, through policy increased funding to developing regions could have positive effects for both developed through improved terms of trade and developing regions through reduced climate change costs as the countries implement adaptation responses (Schenker & Stephan, 2014). In addition, through trade, opportunities arise for example for the UK through increased exportation of UK adaptation technologies and services and reduced shipping costs from the arctic opening (PwC, 2013).

Negatively, transmission of climate risks can occur through international supply chains. Thus, anyone involved along the trade chain is vulnerable to any disruptions. For example, when a producer or manufacturing country faces a climate change extreme event like flooding or drought, the destruction of transport and energy infrastructure, can have, ripple effects to importing countries as disruptions lead to price shocks especially on the price of food products (Nelson et al., 2013; Willenbockel, 2012). Similarly, disruption of major trade channels for example ports create trade risks through disrupted supplies. Similarly, threats to investment and business can arise as extreme events damage investments abroad and lead to increased insurance costs for the investing country. Further, climate change impacts may have impacts on factors of production including land, labor and capital consequently, affecting production structures and trade specialization. This transmission of risks is not always predictable and risks can result from long-term changes in the system as well as short term changes such as price shocks (Benzie et al., 2016; Challinor et al., 2017; Dellink et al., 2017; EY, 2018; Harland et al., 2003;PwC, 2013).

The above supply chain risks are impacted mostly by institutional arrangements along the chain but also by other factors including the law of supply and demand, political affiliations and policies, and organizational policies, which all play a role in determining the preparedness of the country to climate disasters that disrupt the trade chain (Benzie et al., 2013; Moser & Hart, 2015). For example, a national climate change response to drought related food or energy insecurity can lead to the restriction of exports which in turn interrupt global trade stability (Challinor et al., 2017). To measure these factors, Hedlund et al (2018) and Benzie et al. (2019) use in their analysis of the transboundary climate index proxy indicators including trade openness, cereal import dependency and embedded water risks to represent transboundary trade risks. PwC (2013) uses total imports and exports of the United Kingdom as well as the amount of investment abroad to measure the climate related trade risks to the United Kingdom.

Hence, climate change impacts on trade creates challenges and opportunities, new winners, and losers**.** Assessing these risks is important as countries face double exposure from not only direct climate change impacts, but also and indirectly by mitigation and adaptation actions pursued by themselves and by other countries (UNCTAD, 2019). Currently, assessing the financial risks of climate change among the business sector is more mainstreamed with, for example some governments requiring listed companies to disclose climate risks (WEF 2020).

Trade will play an important role in the development of the African continent. This is particularly relevant with the ratification of the African Continental Free Trade Agreement (AfCFTA) which brings together the 55 member states of the Africa Union, currently ratified by 30 member states, to form the largest free trade area since the formation of the WTO (AU, 2019). In the same vein, trade poses risks to these countries as they are characterized as highly commodity dependent. The EAC countries (Kenya, Burundi , Uganda, Rwanda, Tanzania and Rwanda) all lie within the United Nations commodity dependent countries which refer to countries that have based their development on primarily the agriculture, forestry, mineral ores and metals and fossil fuel base exports further exposing them to climate change vulnerability (UNCTAD, 2019).

2.3 Methodologies for assessment of transboundary climates risks

This section summarizes the methodologies used in risk assessment. Risk assessment refers to the processes undertaken to understand the nature and level of risks. It involves identifying the probabilities and consequences of risks. The aim is to be able to respond to possible future hazards and define appropriate response strategies and priorities (Challinor et al., 2018; Harland et al., 2003; IPCC, 2012; Tuncel & Alpan, 2010).

A summary of the strengths and weaknesses of the various methodologies are discussed below: Overall, quantitative, and qualitative approaches need to be employed to capture the various tangible and intangible aspects of vulnerability and risks. Similarly, a balance between a sophisticated rigorous analysis and simple implementable assessment process needs to be struck (Challinor et al., 2018; IPCC, 2012). Risk model are best applicable but only if they are transparent, applicable, easily presented and legitimate (Cardona et al., 2012; Pindyck, 2013). Hence, climate risks assessment may either adapt a narrowed approach which investigates specific risk pathways or a broader approach which addresses at a variety of components and risks. Similarly, a narrowed approach- as applied in this research- is preferred as it produces user specific needs. Conversely, a broader approach can be too broad to motivate specific action (Hedlund et al., 2018). The various methodologies include:

- Sectoral modelling risk assessment: This involves using modelling techniques analyzing a specific sector. It involves setting assumptions as well as exploring a wide range of measurements. Comparison of results across several models is difficult as there are differing methods and inputs. To improve the results, meta-analyses and model meta-analyses comparison studies can be used (Carrera et al., 2015).
- Integrated and cross- sector modelling approaches: Risk transmission pathways are complicated by the interactions between sectors and space. Bounding an analysis within a specific sector allows one to feasibly carry out an analysis, but at the same time risks ignoring important interlinkages. Trade, for example, cuts across sectors and hence there is a need for more integrated modelling approaches. These provide in theory a better method of risk assessment using integrated modelling techniques, however in practice qualitative assessment of non - quantifiable components of the system must be undertaken. (Challinor et al., 2018; IPCC, 2007). The accuracy of these models depends on the assumptions made as well as the modelling techniques adapted. When well-designed, the modelling approaches are considered more precise. For example, the assessment of climate-related risks to international supply chains has been done for major international companies has (CDP, 2013). Additionally, Wenz & Levermann (2016) conducted a trade assessment modelling population, socioeconomic and temperature

datasets. Both assessments find that supply chain risks are arising from extreme events such as drought and increased reliance on international trade could amplify climate losses under inadequate adaptation actions.

- Qualitative and systems approaches: This approach involves using analogues and scenarios. The approach captures a wide variety of variables and can identify different risks outside of quantitative models which can fail to capture "unknowns knowns" (Challinor et al,.2018, p 10). It involves identifying the analogue conditions (periods of time in the past when conditions were similar to the present) and using that data to predict the present or to make forecasts. They can be analogue in time or space. They are used to determine how risks are transmitted through complex socio environmental systems. Scenarios involve the engagement of stakeholder and expert judgement. Overall, qualitative studies fill key knowledge gaps when supplemented with quantitative studies as they allow incorporation of a set of parameters that are ordinarily hard to model (Tol, 2018). This approach was used to carry out a preliminary transboundary risk assessment for Kenya, results of which are used to augment this study. The assessment finds that Kenya faces transboundary climate risks across the four pathways and that current adaptation mechanisms are not prepared to the type of risks (SEI, 2019).
- Scoring mechanism: The approach as adapted by the UK assessment uses a combination of factors including magnitude of the risk, the extent to which it is already been managed and the benefits of actions beyond current plans (PwC, 2013). Risks are included based on their climate and resource transmission mechanisms. They should also be of significant policy concern under climate change. For example, The UK assessment uses five key themes (Appendix C): Business (trade and investment), infrastructure (energy), health and wellbeing and foreign policy. These are further disaggregated into sub themes and proxy indicators used to calculate a composite threat magnitude. The results revealed that transboundary climate threats for the UK could be more severe that threats and opportunities within the UK in some sectors. The methodology while sufficient in highlighting the high-level risk, could be advanced through modelling techniques (PwC, 2013).

2.4 Climate Risk Assessment Concepts

The section represents concepts that were selected based on a priori characteristics associated with climate vulnerability risks assessments and characterization. The concepts were used to identify relevant factors for transboundary climate risk assessment in trade and to construct the analytical framework.

2.4.1 Risks Definition

Risks associated with climate change pose substantial threats (Challinor et al., 2018; IPCC, 2012). The Intergovernmental Panel on Climate Change (IPCC 2012, p. 36) defines risk as "the potential for consequences when something of value is at stake and the outcome is uncertain, recognizing the diversity of values". Risk is often represented as probability of occurrence of hazardous events or trends multiplied by the impacts if these events or trends occur. Hence, disaster risks imply the possibility of adverse effects in the future (Cardona et al., 2012; Turner II et al., 2003). Risk can be expressed as a product of hazard, exposure and vulnerability (IPCC, 2012). Exposure is a determinant of risk but not by itself as the concerned system has to be vulnerable to be considered at risk, and to be vulnerable it is necessary to be exposed (Cardona et al 2012). Exposure refers to the broad range of elements in an area in which a hazard may affect. These elements include infrastructure, people and their organizing systems, economic resources etc. Thus, without these elements in an area, disaster risk does not exist (IPCC, 2007).

Brooks (2003, p.6) summarizes risks as the probability of occurrence of a hazard that trigger a series of events and leads to undesirable outcomes such as property damage. Hence, it is a function of the probability of the event and the consequences of the event. It can also be considered a function of "probability and consequence". Thus, risk is determined as a function of social vulnerability and climate hazard (Blaikie 1994). It includes the probability of occurrence of a climate hazard leading to climate disasters. Some analysis thus finds most vulnerable nations as those in sub-Saharan Africa and those experiencing conflict (Brooks et al., 2005; Chen et al., 2015; Omambia et al., 2012)

To conclude, these definitions highlight several concepts that we consider in this study of transboundary climate risks including probability of occurrence of climate hazards affecting cereal and pharmaceutical commodities, potential impacts/consequences of these hazards, the degree of exposure of the exporting countries to climate risks and their vulnerability.

2.4.2 Vulnerability

In order to effectively assess and manage risks, its critical to understand how vulnerability is generated (IPCC, 2012). Brooks (2003) argues that the examination of risk and vulnerability processes are essentially the same. These processes include examining the physical hazard that threaten the system and the outcomes of such a hazard as influenced by the vulnerability, sensitivity, resilience and coping ability. Blaikie (1994) defines vulnerability as the characteristics of a person or group and the environment that influence their ability to anticipate, cope with, resist and recover from the impact of natural hazard. This capacity is influenced by several factors that determine the extent to which the group or persons livelihood, property, etc., is put at risk by an extreme event. These factors include wealth, occupation, caste, gender, disability, health status, age, immigration status (legal or illegal) and ability to access social networks (Brooks, 2003). Blaikie (1994) refers to them as resources influencing the vulnerability of a community, and they include:

- Human capital: skills, knowledge and health
- Social capital: networks, groups and institutions
- Physical capital: infrastructure, technology, and equipment
- Financial capital: savings and credit
- Natural capital: natural resources, land, water, fauna, and flora

Access to these resources can be defined as an access profile for the group under investigation (Blaikie 1994). Hence those with, for example, the desired financial capital has more choice and flexibility hence raising their access profile. Moreover, vulnerability and exposure are broadly a result of how these factors and resources are distributed, and where issues such as environmental mismanagement, demographic changes, scarce livelihood options cumulatively influence the vulnerability of the exposed elements (IPCC, 2012; Turner II et al., 2003).

However, this high positive correlation between climate risks and human development does not always hold when it comes to transboundary climate risks. Being highly developed does not always mean that a country is at low risk of transboundary climate impacts. For example, even more developed economies such as Luxembourg may be at high risk to transboundary climate impacts than less developed economies such as Gambia and Liberia (Benzie et al., 2013; Hedlund et al., 2018). Thus, it is likely that in the future patterns of vulnerability will change as countries' economies, governance structures, infrastructure improve or degrade (PwC, 2013).

Vulnerability has a time dimension to it in order to include present occurring hazards as well future hazards (Blaikie 1994). Hence, in describing risks it is important to understand whether the hazard is discrete recurrent (e.g. storms and droughts), continuous (e.g. decrease in rainfall occurring over many years) or discrete singular (e.g. shifts in climatic regimes occurring over centuries or millennia) (Brooks 2003). Further, in explaining low probability and high intensity events, the intensity and exposure to the weather event serves as a better explanatory factor of the level of impact than vulnerability. In contrast for, high probability and lower intensity events, vulnerability of exposed elements is significantly more important (IPCC, 2012).

In this thesis, these resources and factors are used to represent climate-related "**external risk factors**" facing the exported product and exporting country.

2.4.3 Adaptive Capacity

The adaptive capacity of a population depends on the nature of the hazard and is an element of vulnerability (Brooks et al., 2005). It is defined as "potential of the system to reduce its social vulnerability and thus to minimise the risk associated with a given hazard" (Brooks, 2003 p. 13). The system accomplishes this through modifying or changing its characteristics or behaviour to better cope with existing or anticipated stresses (ibid, p8). A high adaptive capacity influences the system's ability to respond to future hazards or slow onset hazards. Adaptive capacity can be assessed as capacity to anticipate risk, to respond and capacity to recover and change (Cardona et al., 2012).

Thus, in determining the adaptive capacity of a system, one must assess the vulnerability of the system which includes a set of socio-economic factors that determine the ability of a population to respond to a climate hazard. It is measured by evaluating the governance, civil, political and literacy levels of the population. Further, an understanding of the adaptation processes that differentiates, for example, between adaptation of a household and a nation is key. Hence, whereas community adaptation is determined by factors such as health, education, access to information, as well as financial and natural resources, a nation's adaptive capacity is determined by factors such as relationships between governments, private sector and civil society, the regulatory environment, institutional mechanisms and their effectiveness, national wealth and economic autonomy (Brooks et al 2005, p.11). Access to markets for a nation also plays a role in determining the capacity to substitute. Markets help in allocating resources and market failures can lead to reduced adaptive capacity and increasing vulnerabilities. For example, markets and associated political mechanisms have been linked to famine without a natural event trigger. Similarly, drought has also been linked to famine in a country producing surplus but exporting all of produce. Hence a need to look for underlying factors is key (Blaikie et al., 1994; Brooks et al., 2005). Moreover, in evaluating adaptive capacity, political will of the affected systems is necessary and should not be ignored (Brooks, 2003).

In this research, the above factors are broadly represented by the **internal adaptive capacity factors** of the importing countries.

2.4.4 Risk assessment

Almost everyone has some inert capacity for self-protection and self-action hence the need for risk assessments. Risks assessments, prevention and responses have been deemed important as described through the precautionary principle which legally and morally binds people and governments to respond to a perceived risk even where insufficient evidence exist. This has been seen to limit innovative responses where, for example, risk assessments of climate extreme events have traditionally put more effort on damage and impacts to local and immediate points of impacts, yet these extreme events have impacts on far off regions (Blaikie et al., 1994; Challinor et al., 2017; Turner II et al., 2003) leading to second-order impacts (Challinor et al., 2018).

Risk assessment can be approached from an epistemological approach where it can be measured independently of the social and cultural processes. It can also be considered through social and cultural lenses which act as mediating factors, which are useful in determining the most significant risks, in particular how exposed a country is to global markets, policy structures and its ability to respond to these risks. (Blaikie et al., 1994; Challinor et al., 2017). This holistic view allows adequate consideration of vulnerability and risk factors and interventions (structural, non-structural) that exposed populations make to reduce their vulnerability (Turner II et al., 2003). This latter approach is adapted for this research.

Likewise, appropriate information and knowledge on risks is necessary for appropriate responses and decisions to be made. This information includes knowledge on (Benzie et al., 2016; Cardona et al., 2012):

- Processes by which persons, property etc are exposed to risks: This includes an understanding of the openness to and reliance on international flows.
- Factors and processes that influence vulnerability of people.
- An understanding of the climate risks of other countries to which a country is linked.
- Understanding of people's adaptive capacities. This includes the ability of a country to respond to climate risks and the climate sensitivity of the commodity to climate change.

Since it is difficult to achieve a comprehensive assessment through one single risk assessment method, the combined use of quantitative, hypothetical and qualitative methodologies is recommended. Similarly, consideration of the scale (local, national, regional) at which the assessment is made needs to be made due to the dynamic influences and linkages across scales. Different scales can be considered simultaneously but selection of an appropriate scale depends on the decision-making context (Cardona, 2004; Cardona et al., 2012; Turner II et al., 2003). Once the system boundary is determined, the methods need to take the following aspects into consideration (Challinor et al., 2018):

I. The known and unknown risks and their transmission mechanisms as indirect pathways can often lead to higher influence than direct ones.
II. Synthesis of expert judgments minimising biases and also integrating subjective expert views with quantitative evidence.

So far, risk assessments have been challenged when the systems are interlinked, resulting in a potential for cascading impacts. Assessment of these interactions has been hindered by the complexity of integrating these tele-connected risks in national impact assessments and adaptation planning. Further assessment of risks across borders and sectors complicate risk assessments. Hence techniques for these assessments are still limited by the multiple possible transmission pathways in addition to space and time relationships. Thus, systemic interactions that include social and policy elements make all risk assessments somewhat inaccurate when all factors are not fully accounted for (Cardona et al., 2012; Challinor et al., 2018; Moser & Hart, 2015). Moreover, for sectors such as trade, data is not always available and is considered proprietary or secretive. Another challenge is to attribute the impact to climate change. For example, a violent conflict cannot solely be attributed to climate change (Moser & Hart, 2015). To counter these shortcomings in risk assessments, some subjective assessment is necessary and can be applied by determining their tolerance of a particular risk (Challinor et al., 2018; Slovic et al., 1982).

In summary, this risk assessment definition raises several issues that are considered in this research. They include the decision making and assessment scale, transmission mechanisms, use of expert judgements, combination of methodologies, vulnerability and adaptive capacities of the system under study.

2.5 Summary and gaps in Literature

The literature review reveals that indirect impacts has mostly focused on the biophysical pathways with most of the focus placed on cross border, neighbouring resources such as lakes, parks, and rivers especially for Africa. This information has been useful in improving the management of these resources though some gaps exist where communities do not fully understand the impact of their actions on downstream users for example. Markedly less research has been conducted for the trade, finance, and people pathway. This phenomenon is demonstrated in the coverage of transboundary climate risks in the EAC adaptation policies. These gaps have partly been driven by the high interconnectedness of these pathways and the varying transmission pathways.

Further, the acknowledgement of transboundary climate risks is superficially done in the assessed policies. This is evidenced in the lack of implementation and monitoring measures, which raise concern on whether identification of the risks will translate into plan and actions. Hence, none of the NAPAs explicitly details the magnitude or level of these risks, which may inform prioritisation of actions. Moreover, priority adaptation options focus on national actions, even where adaptation options such as dyking and irrigation intensification involving transboundary water resources are concerned. However, the countries express the desire to implement integrated and regional actions from which future transboundary assessment of risks and responses could build upon. Based on these gaps and the importance of the trade sector on the national development of these EAC countries, the researcher chose to focus on the trade risk pathway.

Moreover, the review reveals that a combination of methodologies is necessary to capture the highly interconnected nature of transboundary climate risks. These include, interactive scenarios building, big data, global system science and integrated modelling to be able to capture the complexity of these risks.

To increase the robustness of any risk assessment, a combination of literature, expert review and stakeholder consultations is necessary. Some transboundary risk assessments have been conducted for developed countries, for example for the UK and Norway. Similarly, the review of methodologies for the assessment of transboundary climates risks reveals that a narrower, simple, robust, and multidisciplinary approach that captures the social, economic, cultural and political aspects of risks is adequate due to its ability to produce user-specific actions. Regardless, all risk assessments are deemed inaccurate to a degree due to the complexity of accounting for the various interlinkages. However, these shortcomings can be addressed to some degree by combining methodologies and by including some subjective assessment where one determines their tolerance of a particular risk and expert input.

The literature review informs the adoption of the scoring approach for this research. Unlike modelling approaches that are sometimes hard to decipher for the layman decision maker (Pindyck, 2013), the scoring approach is simple, intuitive, robust and implementable to decision makers. Further, this approach is selected as it allows for the inclusion of quantitative and qualitative approaches allowing us to capture the complexity of vulnerability and risks, including physical, social, economic, social and environmental factors that cannot be measured using one methodology (IPCC, 2012). Hence the thesis enhances the approach as applied by PwC (2013) further presented in Appendix C, by applying additional disciplinary perspectives to enrich the assessment specifically in trade.

3 Research Design and Methodology

This chapter details an overview of the research design and methodology. Section **3.1** presents the research design and paradigms adapted. Section **3.2** presents data collection and analysis overview. Section **3.3** presents how reliability and validity was ensured while section **3.4** presents the steps taken to develop the analytical framework.

3.1 Research Design

The research adapts an exploratory case study research design for the reasons outlined hereafter Exploratory research is appropriate for fairly less explored topics as is transboundary climate-related trade risks. Generally, it aims to increase the understanding of a problem allowing the researcher to adapt the research direction as new data and insights are gained (Saunders et al., 2012). Moreover, case studies allow for an in-depth examination of one or more cases using both quantitative and qualitative research techniques (Norman & Priest, 2019). They are also useful where there are no clear clear-cut boundaries between the concept and the phenomenon under investigation, and they enable consideration of both internal and external explanatory factors (Norman & Priest, 2019; Yin, 2009) as is the case for complex interconnected transboundary risks in this study.

Case studies are suited to studies where a broad range of theories is necessary to achieve desired research objectives (Norman & Priest, 2019; Yin, 2009). This is the case for transboundary climate risks that arise from a more globalized world resulting in diffusion of a diverse set of research factors and disciplines making it more difficult to make explicit correlation. Moreover, the approach allowed for the examination of a relatively new perspective of transboundary climate risks for trade that is yet to be fully explored (Dellink et al., 2017).

The research adapts an interpretism research paradigm which assumes some degree of subjectivity in interpreting reality. Additionally, an inductive and retroductive logic of inquiry was chosen. Inductive logic of inquiry allows the researcher to answer “what” questions and to derive generalization from collected data. Retroductive logic of inquiry allows the investigation of the underlying mechanisms responsible for producing an observed phenomenon. Retroductive logic of inquiry is particularly useful where the mechanisms surrounding an event or regularity are not directly observable hence evidence of the consequences of their existence can be used to explain certain events (Norman & Priest, 2019). This is the case for this study where disruption of supply chains can result from not only climate change factors but also underlying political, socio-economic and institutional factors. The two logics of inquiry were used interchangeably (Sovacool et al., 2018) to describe the transboundary risk, state of knowledge and exposure to these transboundary risks and assess the transboundary risk for selected cases (EAC countries).

3.2 Data Collection and Analysis Overview

Research revolves around a particular set of concepts and assumptions (Norman & Priest, 2019; Sovacool et al., 2018). Theoretical synthesis can be used to integrate these existing concepts into a new conceptual framework (Sovacool et al., 2018). Hence, the study used a variety of technical concepts to determine the factors for assessing transboundary climate risks in trade. These include adaptive capacity, vulnerability, risks, and risk assessment. During theory generation, a hypothesized set of relationships need to be determined in the beginning (Norman & Priest, 2019). Hence a set of assumptions for each of the factors was identified from previous assessments and peer review literature. This resulted in an analytical framework that allows representation of the data in a simplified form and guided data collection.

Secondary and tertiary data was used where data was drawn from a variety of sources including informal observations (stakeholder workshops) and qualitative data from previous reports on preliminary assessments of transboundary risks conducted by SEI. Additionally, to reveal patterns, trends, and associations the study relied on quantitative data that was gathered by reputable organizations on trade and climate. This approach allowed the researcher to expose new relationships between climate and trade for the exporting and importing partners. Although useful, these types of data also raise questions on the transparency, validity, quality and third-party verification (Sovacool et al., 2018). This was addressed by selecting data sources from globally recognized research institutions that employ transparent techniques of data review and cleaning.

Literature from both grey and peer reviewed literature was used. A set of key words in various combinations including risk assessment, transboundary, cross border, trade, climate change, etc., was used to identify the literature by using search engines such as Lubsearch, Scopus and Research gate, and Google scholar. Further, iterative reviews that modify the search strings based on ongoing results, leading to repeated searches was conducted. Such reviews are useful where both quantitative and qualitative data is relevant and multiple competing factors are at play (Sovacool et al., 2018). Altogether, the analysis investigated the existing methodologies, theories and frameworks related to transboundary climate risks, vulnerability and assessment.

Data analysis involves transforming data from one form to another (Norman & Priest, 2019). For example, quantitative data was combined and analysed in Microsoft excel and R programming to represent qualitative risk profiles. Quantitative vulnerability scores were also transformed using a defined criterion to represent a country's transboundary risk exposure. Further, data analysis involved organizing qualitative data into numerical categories, sorting data to locate patterns and describing the patterns as in the analysis of the East Africa Commission country adaptation policies (Section 2.1.2 and Table 5.1.1) and IPCC based commodity climate sensitivity (section 4.1.1 and 5.2.1).

The analysis also used contribution qualitative analysis to identify and analyse the internal and external risk factors. Here, the analysis does not follow a strictly defined recipe but rather reasoned judgement and weighing of the existing research evidence to examine reasonable connections between relevant factors (Patton, 2008). Contribution analysis is useful in analysing complex, interconnected and open systems as it involves identifying a range of "likely influences", assumptions and possible explanations to produce valid results and evidence. Contribution analysis was suited as it aims to make use of existing data with limited collection of new data, to construct a "performance story". Hence, to represent "likely influences" on transboundary climate risks for trade, risk factors were broadly categorized into internal and external factors. It is important to note that the aim is not to show attribution rather to show contribution. Hence, this research scopes how much influence the external and internal factors have on transboundary risk related to trade for the EAC case, as opposed to the extent to which these factors individually directly influence the transboundary risks.

Weighing was used and was primarily based on the share of import from a country. Similarly, indices were used to simplify quantitative data (Chakrabartty, 2017; Norman & Priest, 2019), for example by representing the adaptative capacity of country *n* by the ND-Gain index (Chen et al., 2015).

To allow for a holistic consideration of the internal capacities within the control of the importing nations, internal factors were evaluated against the Political, Economic, Socio-Cultural, Technological, Environment and Legal framework tool in addition to literature. The tool is used to analyse, monitor and coherently represent macro-level factors that have an impact on the development of the studied population. The political factors represent government decisions, economic factors represent factors influencing the economic development in this case of the nation, social factors represent the population dynamics, technological factors represent the state of technological innovation and conditions for application of these technologies, while the legal factors represent the applicable laws that govern the nation. External factors are evaluated against risk assessment theories and literature (chapter 2). The key components and elements of the analytical process are presented in Figure 3-1.

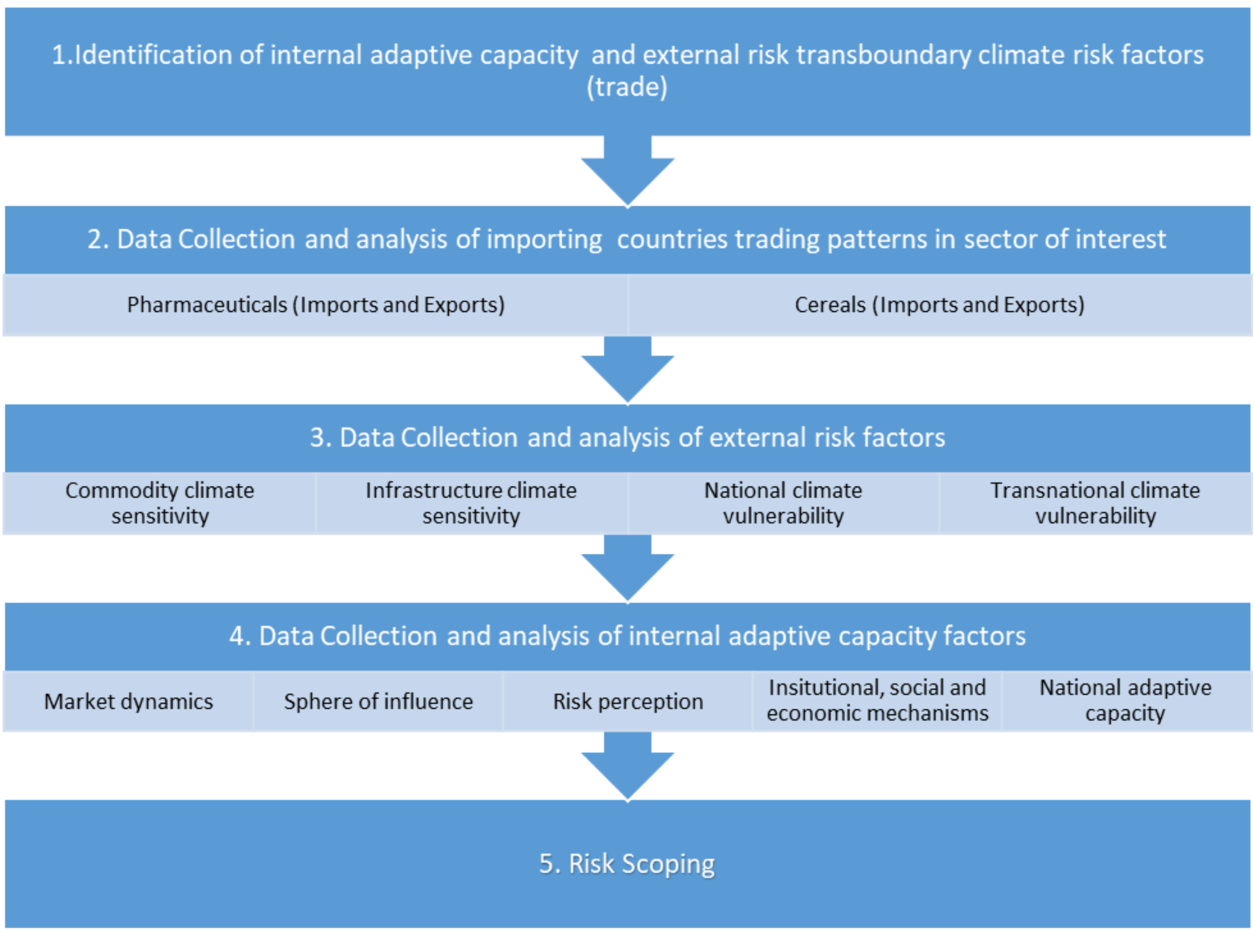


Figure 3-1: Data collection and analysis process.

Source: Created by the author

First based on the literature and theories, an analytical framework is constructed. Second, data collection and analysis of the imports and exports of the EAC countries is conducted. Data was obtained from the International Trade Centre (ITC) database. The data sets are also sourced from country national statistics agencies and hence were deemed adequate for this analysis. From this, a list of priority trade products (by USD value) and partners were analysed. Third and Fourth, data collection and analysis of the external and internal risk factors was conducted. Lastly, a risk scoping was conducted. Overall, the research considers the environment, climate change, risk management, trade and politics disciplines.

3.3 Reliability and Validity

To further validate the approach and analytical framework as well as the underlying assumptions, an expert review was conducted. This involved presentation of a draft analytical framework based on the priori theories, factors, and assumptions. The Stockholm Environment Institute experts were chosen based on their previous experience in transboundary climate risk and methodological approaches. Also, one of the experts had been involved in the preliminary transboundary climate assessments for Kenya. The experts were provided with a draft of the written analytical framework. This was followed by an oral presentation and discussion during which input was solicited and incorporated into the final framework. A second presentation of the final framework including preliminary results was done and inputs incorporated into the final thesis results. The measurement validity was enhanced through relying on various published sources of literature to derive the relationships and definitions of the key concepts and assumptions including climate risks, adaptive capacity, vulnerability and sensitivity, exposure.

To ensure a high level of transparency, reliability, replicability and consistency, quantitative data and indices utilised to represent the external and internal factors was selected based on (1) freely accessible data maintained by authoritative institutions that carry out data quality checks (2) use clear methodologies and assumptions and (3) have data available over the last five years so as to observe trends and account for skewed trading patterns in any one year where available. The data manipulation code, graphs and figures are available on the authors github account (@TabbyNjunge) to enhance reproducibility.

4 ANALYTICAL FRAMEWORK FOR TRANSBOUNDARY CLIMATE RISK ASSESSMENT AND ANALYSIS

This chapter answers research question 1a **What factors might influence the trade related transboundary risks of countries?** Risk and vulnerability analysis should consider the entire system that is responsible for producing and mediating risk and vulnerability, but this ideal is unrealistic due to constraints such as data availability (Turner II et al., 2003) and other delimitations detailed in section 1.4.

This thesis considers these delimitations but presents an analytical framework that attempts to capture relevant elements of an entire trade system, from production to consumption, and in this sense is holistic. Some factors are not included in the final risk scoping due to data limitations but are considered valuable to articulate the entire framework as a contribution to future literature on this topic and to set out the ideal conditions for assessing trade-related transboundary climate risk.

Section 4.1 presents the external risk factors, data collected, assumptions and analysis approach. These are summarized in Table 4.1. Section 4.2 presents the internal adaptive capacity factors, data collected, assumptions and analysis approach. These are summarized in Table 4.2. Section 4.4 presents the combined risk scoping approach.

Table 4.1:The external risk factors along with their definitions, assumptions ,methods and data sources.

	EXTERNAL RISK FACTORS	**Description**	**Assumption**	**Method**	**Data Sources and Coverage**
1	Commodity and infrastructure climate sensitivity	Susceptibility of human beings, infrastructure and environment to extreme climate events which results from their reduced resilience, adaptive capacity and intrinsic conditions and characteristics.	The higher the climate impacts to water, agriculture, and infrastructure in the trade partner country, the higher the transboundary risk to the importing country.	Qualitative and quantitative analysis using (i)the relative contribution of imports for top five exporters (ii) assigned IPCC sensitivity levels to water, agriculture, and infrastructure (Appendix A)	(i)Trade import data: ITC trade data 2014-2018. (ii) IPCC 5th report (2014) 2030-2040 near term impacts.
2	National climate vulnerability	Vulnerability to climate for infrastructure and agriculture risks of the exporting countries.	The higher the national vulnerability of the exporting country the higher the transboundary risk to the importing country.	Quantitative analysis of the weighted ND-Gain index score by share of imports for the exporting country. e.g. {Exporting country ND gain score *share of import}	(i)ND-Gain index (2017) (Chen et al., 2015) (ii)ITC trade data (2014-2018)
3	Transboundary climate risks exposure:	Exposure to transboundary climate risks for the exporting country	The higher the transboundary climate risk to the exporting country the higher the transboundary climate risks to the importing country.	Quantitative analysis of the weighted TCI index score by share of imports for the exporting country e.g. {Exporting country TCI score *share of import}	(i)TCI Index (2018)(Hedlund et al., 2018) (ii) ITC trade data (2014-2018)

Sources: Created by the author.

Table 4.2 The internal adaptive capacity factors along with their definitions, assumptions ,methods and data sources.

	INTERNAL ADAPTIVE CAPACITY FACTORS	**Description**	**Assumption**	**Method**	**Data Sources and Coverage**
1	Economic, institutional, and social mechanisms:	A measure of the importing country's economic, structural, social, equity and public sector management systems.	The better managed the systems (as represented by CPIA and readiness score) the higher the adaptive capacity of the importing country to transboundary climate risks	Descriptive analysis of: (i)World Bank Country Policy Institutional scores of importing countries (ii)ND Gain readiness scores of importing countries	(i)World Bank (2019) (ii)ND Gain (2017) (Chen et al., 2015)
2	Sphere of Influence:	Distribution of power among the trading partners and in the global trade system.	The higher the sphere of influence, the more able the importing country is to influence changes in other countries (e.g. exporting or other trading) countries to reduce its risk exposure, and the higher the adaptive capacity to transboundary climate risks for the importing country	Proxy indicators that could be used: (i)Military spending (ii) Gross National Product per capital, (iii)Education levels of the population and (iv) Location which may refer to access to marine routes, distances between trading partners and contiguity.	Not analysed
3	Market dynamics	A measure of the trading patterns among importing countries represented by (i)diversity of the market, (ii)market share and (iii)commodity price volatilities	(i)The higher the diversity of a market, the stronger the adaptive capacity of the importing country to transboundary climate trade risks (e.g. because there are more opportunities to diversify or substitute trade links affected by climate change). (ii)The higher the market share of the top exporting countries the lower the adaptive capacity of the importing country to transboundary climate risks (iii)The higher the price volatility, the lower the adaptive capacity of the importing country (e.g. because the more prone the market is to disruptions the greater the likelihood that climate disruptions will result in price spikes).	(i)Quantitative analysis of the Herfindahl index (HHI) of the exporting countries (ii) Quantitative analysis of the concentration ratio (iii)Descriptive analysis of the FAO cereal price index and producer price index	(i) and (ii) ITC trade data (2014-2018) (iii)FAO (2002-2019) and US Bureau of Labor Statistics (2006-2019)
4	Risk perception	Planners' and public's awareness and perception of transboundary climate risks	The higher the level of awareness, the higher the adaptive capacity of the importing country	Systematic literature analysis of the trade risk pathways (trade, people, finance and biophysical) identified in the National Adaptation Plans and Programmes of Actions for the importing countries	DoE, 2007; MEN, 2016; MENR, 2017; MLEM, 2007; MLMTE, 2007; MWLE, 2007
5	Domestic production and manufacturing capacity	Ability of the importing country to (i)produce or (ii)manufacture the imported commodity in response to trade shocks or shortages.	The higher the production and or manufacturing capacity the higher the adaptive capacity of the importing country (e.g. because of its ability to substitute risky imports with domestically produced commodities/ products, or the higher the capacity to balance import risks with domestic production risks).	(i)Crop suitability index for cereals (ii) Qualitative assessment of manufacturing capacity	(i)FAO and IIASA (2020-2050) AGEZ database (ii)Literature reviews

Sources: Created by the author.

4.1 External Risk Factors

In assessing risks, it is necessary to place the risk and social vulnerability to a "hazard-specific context" (Brooks, 2003). Hence, in this research, external risks factors are first analysed to be able to place the system (EAC importing countries) within the hazards they face through transboundary climate trade risks. Consideration of the risks to the commodities at the input, production, local processing and transformation stages as well as along the distribution pathway (i.e. supply chain) to the international market is made. The final selected factors are (a)the observed climate change characteristics affecting cereals and pharmaceuticals; (b) the vulnerability of transportation sectors to climate disasters (c) national climate vulnerability (of exporting country/ies) (d) exposure to transboundary climate risks for the exporting country.

4.1.1 Commodity climate sensitivity:

Climate sensitivity refers to the susceptibility of human beings, infrastructure and environment to climate events which results from their reduced resilience, adaptive capacity and intrinsic conditions and characteristics. Sensitivity is hence one of the functions of risk vulnerability among exposure, and adaptive capacity (Brooks, 2003; IPCC, 2007, 2012; Turner II et al., 2003).

The IPCC 5th Assessment report characterization of observed and projected climate change to agriculture, water and infrastructure is systematically assessed by region as presented by the IPCC. (Appendix A).

The *Assumption* is made that the higher the climate impacts to water, agriculture, and infrastructure in the exporting country, the higher the transboundary risk to the importing country because the higher the risk that production and/or export facilities will be disrupted.

Impacts to cereals in the exporting countries refer to IPCC identified impacts to agriculture and water. Impacts to pharmaceuticals, is related to impacts to infrastructure and manufacturing sectors in exporting countries. This is because, climate change impacts to crop production are mostly determined from observation of changes in yields as well as water availability. Moreover, at a global level, agriculture accounts for approximately 70% of all freshwater use, a share that in developing countries can reach up to 95% (IPCC, 2014). Climate change risks and impacts to manufactured pharmaceuticals is mostly determined from the anticipated disruption to the transportation pathways and industries in the exporting countries, although climate variables such as temperature and humidity can negatively affect the manufacture of sensitive products such as pharmaceuticals (IPCC, 2014).

For these two product groups, the risk level is analysed from the relative contribution of the top five importers to total imports and assigned IPCC sensitivity levels to water, agriculture, and infrastructure in the exporting country. This thesis focuses on the present near-term impacts (2030-2040). The A*ssumption* is made that the higher the reliance (as percentage of imports) on highly climate sensitive exporting countries, the higher the risks for the importing country. However, it is worth noting that in reality, transboundary climate risk may be higher than assessed here if global climate change rises beyond the levels used in the IPCC assessment, and/or if climate impacts on crop production and manufacturing are higher than assumed in current literature.

4.1.2 Infrastructure climate sensitivity:

Climate change heavily impacts the international commodity supply chain (Bailey & Wellesley, 2017; CDP, 2013). Consequently. climate change is anticipated to produce large impacts on infrastructure though detailed analysis is limited (IPCC, 2012). These climate risks to infrastructure arise from the failure of the infrastructure itself as well as, from the myriad management and regulatory processes which users of the infrastructure are expected to abide by (Keow & Hon, 2008). As a result of climate change impacts on trade infrastructure, exports might be delayed, rise in price, reduce in quality or even, under extreme circumstances, become unavailable. Similarly, climate change presents s compounding effects to socio economic and political risks due changes in maritime boarders and coastlines as sea level rises (Bailey & Wellesley, 2017).

Specific to international trade routes, these impacts can be both negative and positive. Positive impacts include the opening of the arctic shipping routes and opening up of exclusive economic zones in Canada, Denmark, Norway and Russia Federation and USA. Increased access to international maritime zones is also expected to increase from current 36% to approximately 48% by 2030 (IPCC, 2012). The opening of these routes presents significant cost savings and time saving for companies through reduced distances and perhaps for East Africa countries which import 25% of its cereals from Russia. Negatively, examples include climate change induced flooding in Australia and extreme cyclones in 2010-2012 that led to disruptions in the supply of minerals leading to global price hikes of coal exports and damaged transportation networks (IPCC, 2014).

The complexity of the supply chain (how the product reaches the importing country) either through a direct transportation pathway or an indirect pathway could raise the transboundary risks of the country (Bailey & Wellesley, 2017). For example, the reliance of landlocked countries such as Uganda on Tanzania's and Kenya's sea ports for product *x*, could be determined to put Uganda at a high climate trade risk should extreme climate events affect the Kenyan and Tanzanian ports and, the two countries choose to first secure their domestic supply. This interconnectedness was not explicitly analysed due to lack of detailed data on the transportation path of the product. Future analysis where this data is available could augment this factor analysis. Such analysis could be very revealing for assessing transboundary climate risk but requires time and data-intensive approaches at the commodity or product-specific supply chain scale.

The IPCC 5th Assessment Report characterization of observed and projected climate change to infrastructure for the exporting country is based on a qualitative systematic assessment (Appendix A). Impacts to pharmaceuticals, is related to impacts to infrastructure and manufacturing sectors in exporting countries. The *Assumption* is made that the higher the sensitivity to climate change of the infrastructure (in exporting country) the higher the risk to the importing country as a function of the percentage of total imports. So, the higher the contribution to total imports of a climate sensitive exporting country the higher the risk to the importing country.

4.1.3 National climate vulnerability

This represents the vulnerability to climate risks of the exporting countries. The A*ssumption* is made that the higher the vulnerability to climate impacts on agriculture and infrastructure (for exporting country) the higher the risks to the importing country

The ND-Gain Index has been widely accepted and used to represents a country's current vulnerability to climate disruptions (Chen et al., 2015) and was thus used for this research. The data on ND Gain results is also freely and easily available online. The score was deemed adequate because of the transparency in its methodology as well as a systematic analysis of its strength and weakness in the peer reviewed literature and a highly consultative approach during its development (Arnott et al., 2016; Chen et al., 2015). The index measures the country's readiness and ability to respond through leveraging economic, governance and social means. Geographical location, socio economic conditions affect a countries vulnerability potential. To assess the vulnerability, the index considers the exposure of key sectors to climate related hazards, the sensitivity of the sectors to the impacts of the hazard and the adaptive capacity of the sector. The higher the score on a scale of (0-100), the lower its vulnerability (Chen et al., 2015).

Other vulnerability indices such as the Global Climate Change Index (Eckstein et al., 2019) and World Risk Index the score exist but no peer reviewed literature of its methodology exists (Hedlund et al., 2018).

Hence the *assumption* is made that the more vulnerable the exporting country the higher the transboundary risk to the importing country.

To analyse and determine the weighted risk to the importing country *(WND_X,)* equation 1 below was used where the ND gain score of the exporting country was multiplied with percent share of its imports and divided by the total share of the top five imports (to EAC country). The sum was then divided by the total percent share of the top five imports.

$$wND_X = \sum(ND\ Gain\ score\ of\ exporting\ country * \%\ share\ of\ total\ imports)/ total\ share\ of\ top\ five\ imports \qquad (1)$$

The qualitative level of risk (low, medium, high) to the EAC country was determined based on their calculated quartile positions in the range of global ND- Gain scores (Appendix B: Summary statistics).

4.1.4 Transboundary climate risks Exposure:

The exporting countries do not only face direct national vulnerabilities (as measured by ND-Gain, for example) but also transboundary climate risks themselves. The Transnational Climate Impacts index (TCI Index) (Hedlund et al., 2018) takes into account exposure to transnational climate impacts and does not consider aspects such as sensitivity and adaptive capacity given the complexity of incorporating sensitivities and measuring adaptive capacity across the global scale (Challinor et al., 2018; IPCC, 2007). It analyses these risks based on four pathways represented through nine indicators which are then averaged to form a global index scored from 0-8.2 where 8.2 represents high exposure to transboundary climate risks (Hedlund et al., 2018). These pathways include:

- Biophysical pathway: This refers to the interconnectedness between countries arising from shared ecosystem services and resources. It is represented using the transboundary water dependence indicator that refers to proportion of water resources originating in transboundary upstream countries.

- Finance pathway: This refers to change in finance flows from overseas investments. It is represented by two indicators: remittance flows and bilateral climate weighted foreign direct investment.
- People pathway: This refers to impacts arising from people's movement through migration or tourism. It is represented by two indicators, namely openness to asylum and immigration from climate vulnerable countries.
- Trade pathway: This refers to the risks arising from the flow of goods and services through international supply chains. It is represented by three indicators: trade openness, cereal import dependency and embedded water risk.

Hence the *assumption* is that the more exposed to transboundary climate risks the exporting country, the higher the transboundary risk to the importing country.

To determine the transboundary climate risk to the importing country from the exporting country, the weighted TCI index $WTCI_X$ (by share of imports) of the top five exporting countries for the cereals and pharmaceuticals was calculated (equation 2). where the TCI score of the exporting country was multiplied with percent share of its imports and divided by the total share of the top five imports (to EAC). The sum was then divided by the total percent share of the top five imports (Appendix B-summary statistics)

$$wTCI_X = \sum (TCI\ score\ of\ exporting\ country * \%\ share\ of\ total\ imports) / total\ share\ of\ top\ five\ imports \qquad (2)$$

The qualitative level (low, medium, high) of transnational risk to the EAC country was determined based on their calculated quartile positions in the range of global TCI score (. (Appendix B-summary statistics).

4.2 Internal Adaptive Capacity Factors

Systems facing increasing risks may reduce their vulnerability overtime by taking up adaptation measures. Adaptation refers to "adjustments in a system's behaviour and characteristics that enhance its ability to cope with external stresses" (Brooks 2003, p. 8). Hence proxy factors can be used to represent the capacity of the system to respond and or accommodate climate change risks (Brooks 2003), including transboundary climate risk.

Hence for this study, internal adaptive capacity factors were identified and analysed. The adaptive capacity of a socioecological system in this case 'importing country *n*' is influenced by (a) economic, institutional and social mechanisms (b) sphere of influence (c) market dynamics (d) risk perception and (e) domestic production and manufacturing capacity.

4.2.1 Economic, social and institutional mechanisms:

The stronger the internal economic, institutional, and social mechanisms of a country the higher its adaptive capacity to climate risks. These support mechanisms may increase the country's capacity to manage climate risks (Brooks et al., 2005; Smit & Pilifosova, 2001).

Hence countries with efficient institutions can be determined to have related strong policies to respond to trade risks such as price volatility. Similarly, countries with strong institutional, social and policy mechanisms can be determined to support a stronger private and civil society sector, have stronger relationships with other governments and spheres of influence, and stronger regulatory mechanisms all of which allow the country to respond to trade risks through enhancing their capacity to manage and distribute risks fairly within society.

In this thesis, the Country Policy and Institutional Assessment (CPIA) scores (WB, 2017, 2019) and readiness score (Chen et al., 2015) are used to represent the economic, institutional and social mechanisms for the importing countries. The CPIA score measures a country's policy and institutional capacity across economic, public sector management, institutional and government spheres (WB, 2019). The readiness score measures the country's ability to make use of investments for adaptation actions due to effective economic, governance and social structures (Chen et al., 2015). For a detailed analysis of how the scores are calculated see (Chen et al., 2015; WB, 2017).

The analysis involved cross validation and comparison of the two indices. Use of the two indices allowed a more accurate representation of the importing country's adaptive capacity as opposed to a single measure of gross domestic product and human development index, which would double penalize developing countries (Chen et al., 2015; IPCC, 2012).

The CPIA score is scored from 1 representing poor social, economic, and institutional mechanisms and 6 the highest. For the readiness score, 0 represents lower readiness of the countries while the highest rating of 1 represents a high readiness capacity. The *assumption* is made that high scores for each of the indices represent high adaptive capacities to transboundary climate risks and vice versa.

4.2.2 Sphere of Influence:

Unequal access and distribution of resources exacerbates vulnerability and limits adaptive capacities. Inequality along the trade supply chain and among the trading partners can exacerbate trade climate risks. This is evident where in a fight to protect their national interests, countries with greater spheres of influence (hegemony) in a trade agreement, impose policies that negatively affect import prices and supplies in the global market (Dellink et al., 2017a; Zeitoun & Warner, 2006). Similarly, when facing a crisis, countries with an expansive sphere of influence are able to muster support and activate institutions or broker deals to address the crisis in ways that benefit them.

Traditional analysis of transboundary resources often ignores the different spheres of influences among the concerned parties. Hegemony can be achieved through pressure, restrictive policies and or unequal access to knowledge. In trade, factors influencing spheres of influence include economic distance, historical and cultural ties, tying of aid and preferential treatment of one country's exports over another. If inadequately addressed, hegemony in management of transboundary resources risks can be hidden under a perceived cooperation and power asymmetry (Zeitoun & Warner, 2006).

Power dynamics are the prime determinant of how transboundary resources are managed. Indeed, addressing these dynamics may lead to better management of transboundary resources. For example, in a shared transboundary water resource, downstream actors may use power to get more access to a transboundary water resource, while upstream actors may use first access rights to gain power. There is positive and negative hegemony. Positive hegemony refers to positions where benefits and sometimes burdens, associated with transboundary goods, services, equity accrue to both the hegemonic power and the non-hegemonic one. Negative hegemony occurs where the hegemonic state uses instruments of coercion towards the weaker state exploitatively. Thus, in evaluating hegemony it is important to consider the different perspectives to ensure that the weaker hegemony rights are not hidden under a cooperation approach that seem to be working on the surface. (Roemer, 1977; Zeitoun & Warner, 2006).

In international trade, hegemony and trade are closely related where power could predict trade and govern its change and growth. This power depends on a country's position in the international hierarchy (core , semi periphery, periphery), economic position and geographical location (Gaile & Grant, 1989; Grant, 2016; Roemer, 1977). To measure power several proxy indicators have been proposed including a combination of military spending, gross national product per capital, education levels of the population and location which may refer to access to marine routes, distances between trading partners and contiguity where the neighbour effect might influences trade (Grant, 2016).

In this research thesis, the *assumption* is made that the higher the sphere of influence, the higher the adaptive capacity of the importing country to transboundary climate risks. The sphere of influence was not empirically calculated for this study given the complexity of calculating the interrelationships between the above indicators, which would require an independent study. Similarly, it was difficult to measure the influence of bilateral relationship between the trading partners which serve to influence the power dynamics. It would be interesting to see future assessments develop methodologies to include the sphere of influence in transboundary climate risk assessments.

4.2.3 Market dynamics

Market dynamics in this study refer to the trading patterns among the exporting and importing countries. Factors considered include the diversity of the market, market share and commodity price volatilities (Dellink et al., 2017; EY, 2018; PwC, 2013). These are represented by globally utilised indexes including the Herfindahl index, concentration share and producer price index and cereal price volatility index, respectively. Data on imports was obtained from the ITC database and calculated as follows:

- **Herfindahl index (HHI):** The index measures how distributed the sources of a commodity for any given country are up to a maximum of 10,000 points. It represents the share of a source country relative to total imports. A country with a perfectly diversified import portfolio will have an index close to zero, whereas a country which imports mostly from one country (least diversified) will have a value of 10,000 (Andreas, 2005; Diallo & Tomek, 2015). Smaller or economically less diversified countries are likely to face added challenges in providing public goods in the face of risks or absorbing climate change shocks (IPCC, 2012). Similarly, policy and political responses can exacerbate a weather-related food shortage as was witnessed in the global 2007-2008 food crisis.

Hence a country with a diverse supplier list may be deemed less vulnerable and with higher adaptive capacity that one without (PwC, 2013). In this thesis the *assumption* is made that the higher the diversity of a market (low HHI), the stronger the adaptive capacity of a country to trade risks. An importing country adaptive capacity was thus scored as follows: Low , HHI >1800; Medium 1500 < HHI≤ 1800 and High 100<HHI≤1000.

The HHI is calculated for all importing countries for cereals and pharmaceuticals separately using the equation three.

$$HHI = \sum_{i=1}^{n} s\,i^2 \qquad (3)$$

where i = import value of product *x* (i varies from 1 to n) ; n = total value of all imports for product *x* ; Si = each exporting country's market share for product *x*.

○ **The Concentration ratio** of top five exporting countries (CR5): measures the combined market share of the top five source countries on a range of 0-1 which can also be expressed as a percentage (used in this study). A high figure closer to 100, implies that the importing country relies on a small number of suppliers and vice versa (Andreas, 2005).

The *assumption* is that the higher the CR_5 the lower the adaptive capacity to transboundary climate risks for the importing country. A value above >0.5 for the importing country is considered low adaptive capacity, medium $0.4<CR_5\leq 0.5$ and high <0.4.

The CR5 is calculated for the top five exporting countries for cereals and pharmaceuticals separately using the equation four.

$$CR_5 = \sum si_5 \qquad (4)$$

where Si_5= Top five exporting country's market share for product x

○ **Price volatility**: Price volatility measures the rate at which price rises or falls over a specific period of time. It affects the ability of the importing countries to afford the product (FAO, 2013; Hedlund et al., 2018; PwC, 2013) and consequently their adaptive capabilities. Countries that have mature economies with populations able to afford price spikes may respond better to price volatilities. However, countries with the majority poor population (percentage) are more negatively affected as the population is either not able to afford the high prices or able to buy in bulk and store even when prices are low due to low cash flow Similarly, price volatility makes it difficult for farmers in producing countries to make production decisions due to uncertain prices hence affecting their production capacities (FAO, 2013). Similarly, for importing countries, price volatilities can make it difficult to invest in domestic production for commodities that have high volatility.

Price volatility is affected by short term shocks to the product and structural shocks where low levels of trade in stable crops such as rice have higher impacts on prices. Additionally, increased volatility has wide political and policy implications. This is demonstrated in the 2007-2008 global food crisis where some developing countries responded by reducing import taxes, banning exports, and increasing export taxes. Major exporters on the other hand responded by restricting their exports while others stockpiled in the hope of higher prices (FAO, 2013; PwC, 2013).

Hence the *assumption* is made that higher price volatilities of commodities reduce the adaptive capacities of the importing countries.

The FAO cereal price index which monitors the global cereal markets for the period 2002-2019 for the importing countries is used. The index represents the monthly change in the price of major cereals products in the international market. Price volatilities in the market translate to higher indexes as seen in 2008. The cereal price index is appropriate as a proxy of food price volatility because two-thirds of food consumption globally is cereals (FAO, 2013). See FAO food price index[1] for details on the index calculation.

To represent the pharmaceutical price volatility the pharmaceutical Producer Price Index (PPI) was used to represent the changes in global pharmaceutical price index. The index represents the average change over time in selling prices of major products and commodities including, prescription and non-prescription drugs. It tracks the price received by the manufacturers themselves (U.S. Bureau of Labor Statistics, 2020). For details on the calculation of the pharmaceutical industry PPI see (U.S. Bureau of Labor Statistics, 2011)

4.2.4 Risk perception

People's perception of risks greatly influences (positively or negatively) their responses to climate risks. Perception of risks is driven by psychological, cultural factors, values, and beliefs. Thus, the public's understanding of risk signals can augment technical risk assessments. More specifically, while the experts in risk assessment may rely on more analytical tools such as models to make their judgments, the general public, politicians and decision makers rely to a greater extent on easily available and processed information including subjective judgements (IPCC, 2012; Slovic, 2016). Consequently, the planners' and policy makers' perception of transboundary climate risks is likely to influence their responses; if they perceive risks as high, they are also more likely to express a desire for strict regulation to reduce the risks, for example. Conversely, if a risk is high but it is not perceived as such, it is unlikely that a planner will utilise their capacities to implement an adaptation response. Tolerance of risk is also positively influenced by the perceived benefit.

Risk perception is influenced by a variety of factors including uncertainty on the level of risk, understanding of risk estimation techniques, information access and quality, personal experiences, catastrophic potential among others resulting in risk denial, risk overestimation or underestimation. These may be corrected through education, tailored risk communications and increasing the interest

[1] FAO Food price index revisited http://www.fao.org/fileadmin/templates/worldfood/Reports_and_docs/FO-Expanded-SF.pdf

of people on the risks. To examine risk perceptions public attitude studies may be employed to highlight their concerns and to foresee their actions to manage the risk (Slovic et al., 1982).

To assess the risk perception awareness on transboundary climate risks is a challenge given the lack of public attitude surveys and the relatively novel nature of the topic. The thesis research therefore carried out an examination of the national adaptation plans and programmes of actions (MEN, 2016; MENR, 2017; MLEM, 2007; MLMTE, 2007; MWLE, 2007; VPO, 2007) to produce a proxy measure of risk perception of transboundary climate risk at the national level in each EAC country.

The *assumption* is made that low risk perception of transboundary climate risks in general among the decision makers may translate to lowered adaptive capacity of the importing country. A low awareness represents lowered risk perception and consequently lower adaptive capability and vice versa.

The adaptation plans were analysed using a synthesis matrix grouped into nine sectors including agriculture, trade, finance, energy, water, ecosystem services, tourism, infrastructure and health emerging from the matrix. The transboundary climate risks were identified using any reference to the four transboundary climate risk pathways- biophysical, finance, trade, and people (Benzie et al., 2013). For example, a mention of climate risks to the flower exports sector as a result of reduced imports by Europe, the main market for Kenya, was marked as a risk awareness example for the trade pathway. Lastly, using this matrix, the adaptive capacity to transboundary climate risk to the EAC country as a function of their risk perception was scored as medium, high or low. High represented a mention of transboundary climate risks across all nine sectors including planned adaptation responses to these risks. Medium included a mention of transboundary climate risks for at least six of the nine sectors, and low included a mention of the transboundary risk in less than six of the nine categorised sectors.

4.2.5 Domestic production and manufacturing capacity:

This factor examines the capacity of countries to produce or manufacture an imported product (in this case cereal crops and pharmaceuticals) as an adaptation measure to trade related disruptions. In responding to trade and supply shocks, countries can choose to produce the imported product or manufacture as a way of substituting imports (Cardona & Tibaduiza, 2011; Turner II et al., 2003). In this research, production refers products that do not need industrial transformation before consumption, in this case cereals. Manufacturing refers to products that need substantial industrial transformation before consumptions, in this case pharmaceuticals.

In the case of food imports for example, the suitability of the country to grow the food commodity will be determined by land availability/ suitability and domestic climate[2]. This further may influence its ability and willingness to shift towards domestic production, all other factors held constant. Similarly, for manufactured products as in the case of pharmaceuticals, the country may choose to

[2] Other socioeconomic factors, including labor availability/cost, regulations, domestic infrastructure etc. are also relevant to domestic production capacity.

develop its manufacturing capacity in terms of human and infrastructural capacity and availability of raw materials. Both of these factors, however, will often require long term planning and investment by the country hence an evaluation of the suitability and manufacturing capacity should be made against the social, political, economic, and institutional capacity of the countries.

The *assumption* is made that the higher the production and manufacturing capacity the higher the adaptive capacity of the importing country

In this study, to represent the production capacity, crop suitability scores for cereals are evaluated for each of the importing countries. Data is obtained from the Food and Agriculture Organization of the United Nations (FAO) and the International Institute for Applied Systems Analysis. The organisations have developed the Agro-Ecological Zones methodology over the past 30 years for assessing agricultural resources and potential (FAO, 2019). The score uses the soil fertility and management practices as determinants of land productivity and agricultural exploitation potential. The fertility of the soils includes the soil nutrients and water retention capacity of the soil.

The crop suitability is categorised as optimal, suboptimal, marginal, and unsuitable. The categorisation is further subdivided into four input levels (high, intermediate, low, and mixed). Hence, crop suitability scores for each importing country where "'0" represents not suitable and "1" suitable are obtained for the IPCC A2 scenario under high input. The IPCC A2 scenario is selected. This scenario corresponds to a 2°C warming scenario (which is likely without immediate substantial reduced emissions), assumes a regionally oriented world, increasing population and low emissions (Nakićenović, 2000). Similarly, the high-input management approach is selected since the importing country will have to use advanced management approaches including improved seeds, fertilisers, pesticides and high mechanisation (Fischer et al., 2012) to meet the import deficit gap shifting from the largely subsistence low-input management approaches. Both of these assumptions may appear optimistic for a risk assessment but have been chosen as reasonable and un-controversial "middle of the road" scenarios to increase the robustness of the assessment.

The manufacturing capacity is assessed from systematic literature reviews where factors of production labour, capital and land/raw materials are used to determine the importing countries manufacturing capacity for pharmaceuticals.

The *assumption* is made that a high crop suitability score (representing production capacity) and manufacturing capacity increases the adaptive capacity of the importing country to transboundary climate risks.

4.3 Risk Magnitude Scoping

The main objective of this step is to facilitate discussion and support decision making in controlling transboundary climate risks. It offers a qualitative approach for combining the identified risk factors and adaptive capacity to determine an arbitrary level of risk for the country. Thus, it is important to note here that the aim is not to make a precise evaluation of the transboundary risk for the country.

The step uses a simplified risk matrix commonly used in risk assessment (Duijm, 2015). This is because the matrix provides a simple and practical framework for risk evaluation. It also promotes discussion around risks that may be used to further guide risk prioritization (Quintino, 2011; Talbot, 2017). The aim, similar to this study, is not to make precise estimates, but rather to support discussion and decision making as regards transboundary climate risks. Risk matrices are useful where limited quantitative approaches exist, where very different kinds of information are combined in the risk assessment process and to help in bringing to the front the difficulties in particular risk assessment methodologies (Duijm, 2015).

To calculate the external risk and internal adaptive capacity factor, 1 was scored as low, 2 as medium and 3 as high. The overall score was determined assessed based on the quartile position of the sum scores. (Appendix B).

Further, an adapted matrix (Table 4.3) is used where the vertical axis is switched over (from high to low) to represent the complementary role that adaptive capacity plays in mitigating against risks (i.e. low capacity = higher risk. The horizontal axis is taken to represent the risk factor (external) and the vertical axis the adaptive capacity (internal) which together represent the overall risk for the country. In this way, the two axes are roughly equivalent to the standard dimensions of risk namely likelihood (equivalent to external risk factors: how likely is the risk to materialize?) and magnitude (equivalent to internal adaptive capacity: how much damage would the risk bring about if it occurred, given the countries capacity to adapt?).

Table 4.3: Risk matrix.

Internal Adaptive Capacity	**Low**	M	H	H
	Medium	L	M	H
	High	L	L	M
		Low	**Medium**	**High**
	External Risk			

Source: Created by the author.

4.4 An analytical framework for assessment of trade related transboundary climate risks

As seen in Figure 3-1 transboundary climate risks related to trade are influenced by the external risk emanating from the exporting country through, climate risks to their production, manufacturing, or transportation. External risk factor proxy indicators used to represent these risks are the product's climate sensitivities (in this case to cereals), climate sensitivity to infrastructure (to represent pharmaceutical infrastructure), national and transboundary climate risk. Similarly, adaptive capacity of the importing country to transboundary climate risk can take the form of capacity to manufacture, produce, substitute, switch supply, reduce product dependence or absorb shocks, These capacities are represented by the proxies- market dynamics, institutional, social and economic mechanisms, risk perspective and sphere of influence.

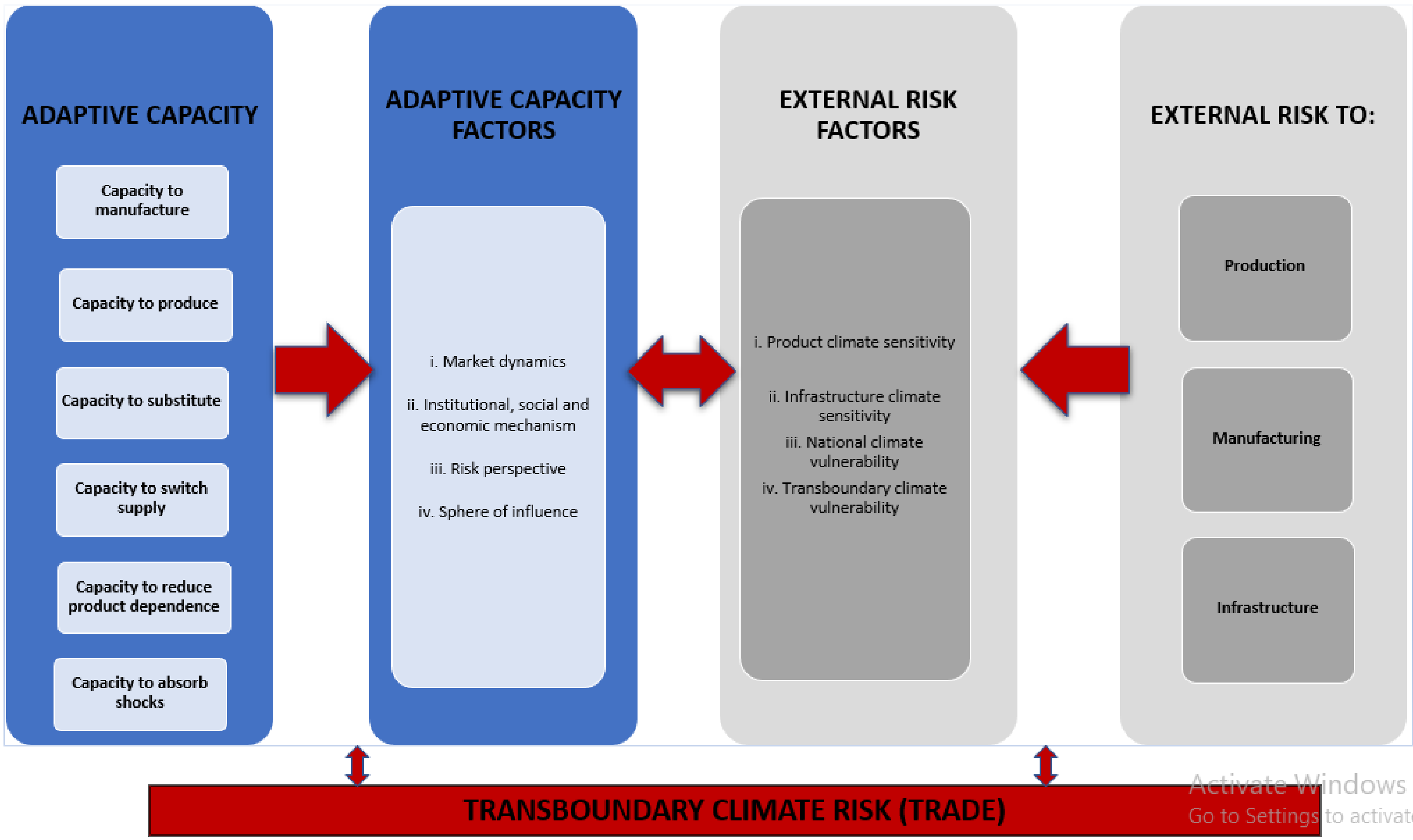


Figure 4-1: Analytical framework for trade related transboundary climate risk assessment and management.

Sources: Created by the author.

5 ANALYSIS AND RESULTS: EAC TRADE RELATED TRANSBOUNDARY CLIMATE RISKS

This chapter answers the research question: **What are the trade-related transboundary climate risks for East African Commission countries?**

It presents the analysis and results of the study, testing the framework discussed in the previous chapter using the EAC region as a case study. Thus, section **5.1** presents the EAC context. It focuses on cereals and pharmaceuticals trading patterns, which the internal and external factors analysis builds upon. Section **5.2** presents the external factors**.** Section **5.3** the internal factors result. Section **5.4** presents the risk scoping results as a risk rating for each EAC country. A summary of the results is presented in Table 5.1 and Table 5.2 for pharmaceuticals and cereals respectively.

Table 5.1: Pharmaceuticals external risk, internal adaptive capacity risk scoping results

EXTERNAL - pharmaceuticals		**Kenya**	**Uganda**	**Rwanda**	**Burundi**	**South Sudan**	**Tanzania**
Commodity and infrastructure		High	High	High	Medium	Medium	Medium
National climate vulnerability		Medium	Medium	Medium	Medium	Medium	Medium
Transboundary climate vulnerability		Medium	Medium	Medium	Medium	Medium	Medium
Score		7/9	7/9	7/9	6/9	6/9	6/9
External risk rating (A)		Medium	Medium	Medium	Medium	Medium	Medium
INTERNAL - pharmaceuticals		**Kenya**	**Uganda**	**Rwanda**	**Burundi**	**South Sudan**	**Tanzania**
Market Dynamic	*Concentration Ratio*	Low	Low	Low	Low	Low	Low
	Price Volatility-CPI	Medium	Medium	Medium	Medium	Medium	Medium
Economic, social institutional mechanisms		Medium	Medium	Medium	Low	Low	Medium
Manufacturing capacity		Low	Low	Low	Low	Low	Low
Internal vulnerability		Low	Low	Low	Low	Low	Low
Risk perception		Medium	Medium	Low	Low	Low	Low
Score		9/18	9/18	8/18	7/18	7/18	8/18
Internal adaptive capacity rating (B)		Low	Low	Low	Low	Low	Low
Overall risk rating (A+B)		**High**	**High**	**High**	**High**	**High**	**High**

Source: Created by the author.

Table 5.2: Cereals external risk, internal adaptive capacity risk scoping results.

EXTERNAL - cereals		**Kenya**	**Uganda**	**Rwanda**	**Burundi**	**South Sudan**	**Tanzania**
Commodity and infrastructure		Medium	Medium	Medium	Medium	High	High
National climate vulnerability		High	High	Medium	Medium	High	Low
Transboundary climate vulnerability		Low	Low	Low	Low	Medium	Low
Score		**6/9**	**6/9**	**5/9**	**5/9**	**8/9**	**5/9**
External risk rating (C)		Medium	Medium	Medium	Medium	High	Medium
INTERNAL - cereals		**Kenya**	**Uganda**	**Rwanda**	**Burundi**	**South Sudan**	**Tanzania**
Market dynamics	*Concentration Ratio*	Low	Low	Low	Low	Low	Low
	Price volatility-PPI	Medium	Medium	Medium	Medium	Medium	Medium
Economic, social institutional mechanisms		Medium	Medium	Medium	Low	Low	Medium
Production suitability		Medium	Medium	Low	Low	High	Medium
Internal vulnerability		Low	Low	Low	Low	Low	Low
Risk perception		Medium	Medium	Low	Low	Low	Low
Score		**10/18**	**10/18**	**8/18**	**7/18**	**9/18**	**9/18**
Internal adaptive capacity rating (D)		Low	Low	Low	Low	Low	Low
Overall risk rating- (C+D)		**High**	**High**	**High**	**High**	**High**	**High**

Source: Created by the author

5.1 EAC trading patterns

All EAC countries have a negative trade balance, meaning the value of their imports is higher than the value of their exports. This is an important feature for the current study, meaning that the economies of the EAC are fundamentally dependent on trade, especially imports, and therefore likely to be particularly exposed if climate change affects their import profile in any way. The heavy industry products including minerals, metals, cars and parts, electricals, plastics etc. makes up the largest share of imports (62%) by US dollar value (Figure 5-1) while other imports, the most valuable of which include textiles, oils and chemicals, contribute a further 30%. Pharmaceuticals and cereals each contribute 4%.

Despite them not representing the largest share of imports by value, cereal and pharmaceutical imports have been selected for this study for two main reasons: First, climate sensitivity, especially to cereal production; second, their critical importance to social stability and development, as key import dependencies for food security and health respectively. The working hypothesis here is that social welfare in the EAC will be more directly impacted by transboundary climate risk to food security and health, than to more indirect impacts on social welfare via industrial imports.

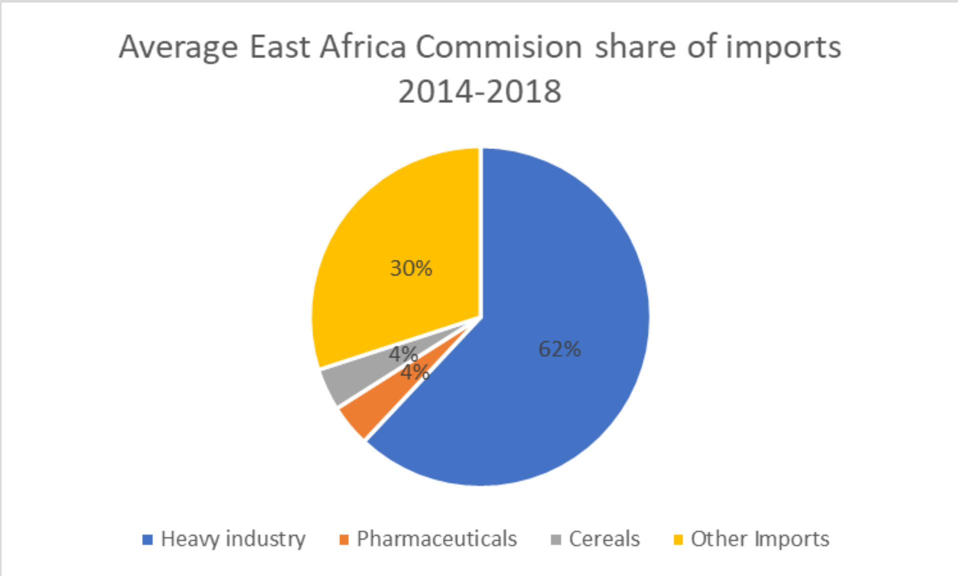


Figure 5-1: Average share of imports for the East Africa Commission.

Source: Created by the author, data based on ITC data 2014-2018.

The EAC countries have largely similar import trading patterns. They trade across six regions namely South and East Asia, North America, Africa, Australasia and Europe for both cereals and pharmaceuticals representing 24 countries Table 5.6. A minimal level of exports between the EAC countries occur where, Uganda contribute 3% and 63% to the cereal import share of Kenya and South Sudan, respectively. The total import value of the six countries (not illustrated) range widely with Rwanda and Burundi having the least amount in value of imports, probably as a function of their lower economies and population. Focusing on the prioritized products, the EAC is reliant (Figure 5-2), mostly on Russia for 25% and Pakistan for 16%, of the grain imports. Others include Canada (5%) and Ukraine (5%) which are all global cereal suppliers.

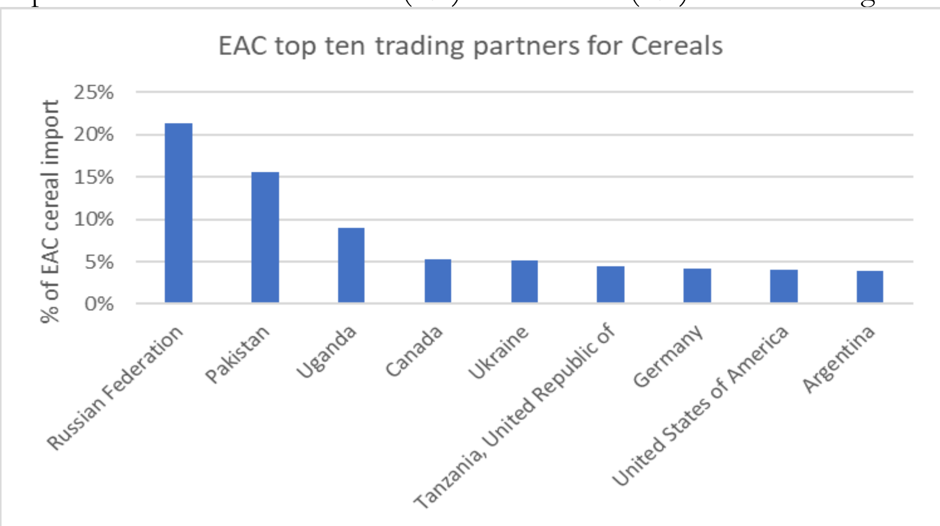


Figure 5-2: East Africa commission cereals share of imports by import partner.

Source: Created by the author, data based on ITC, 2014-2018.

For pharmaceuticals, Figure 5-3, it's important to note that the region is heavily reliant on India constituting 45% if its pharmaceutical imports, with the nine other exporting partners each contributing on average 4% of total import share.

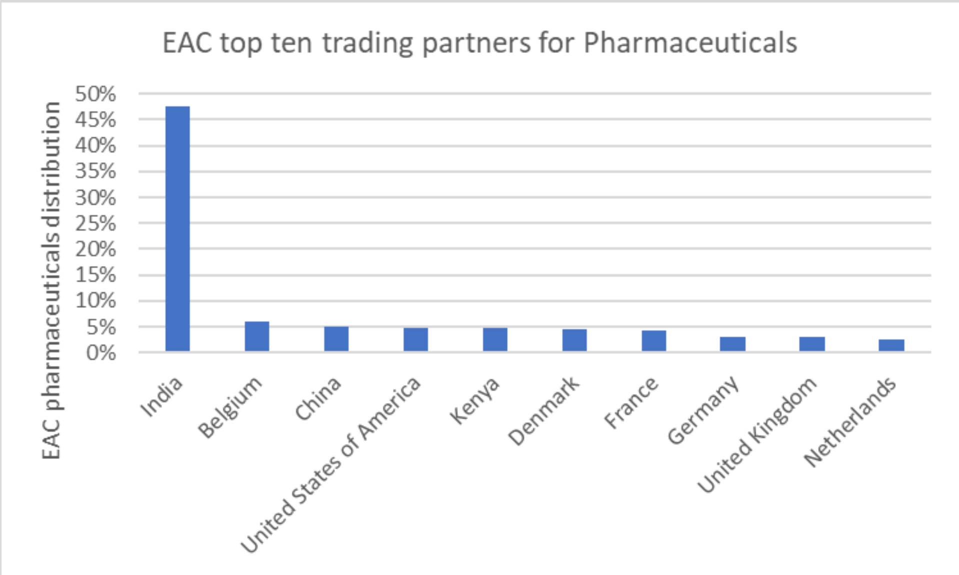


Figure 5-3: East Africa commission pharmaceuticals share of imports by import partner.

Source: Created by the author, data based on ITC, 2014-2018.

5.2 External Risk Factors Results

The external factors represent attempt to assess the transmission of climate risk from EAC trade partners to EAC countries. Thus, the framework described above proposes that key climate risk factors to exporting countries, holding all other factors constant, are the commodity climate sensitivity, the transport sector climate sensitivity, exporting economy's national vulnerability, and exporting country's exposure to transitional climate risks.

5.2.1 Commodity and infrastructure climate sensitivity

The potential for climate impacts to affect agricultural, water and infrastructure in exporting countries is assessed. The risk level is a combination of the relative contribution of the top five importers to total imports for the two products, and a summary of the IPCC assessment of regional climate change impacts for each exporter -high, low, medium. (Appendix A)

In summary- Table 5.3- the EAC countries external risks as a function of their exporting partners' commodity and infrastructure risks are ranked as medium to high. Rwanda and Burundi are slightly less at risk for both products; this is explained by the lower level of climate risk faced by their trade partners in comparison to the top trade partners of other EAC countries.

Table 5.3: Climate risks to pharmaceuticals and cereals based on commodity and infrastructure sensitivity of export partners.

Country	Climate risk to pharmaceutical imports	Climate risk to cereals imports
Kenya	High	Medium
Uganda	High	Medium
Rwanda	High	Medium
Burundi	Medium	Medium
South Sudan	Medium	High
Tanzania	Medium	High

Source: Created by the author.

a) Kenya

Kenya imports cereals from Thailand, Pakistan (South Asia), Russia (North Asia), Ukraine (Europe), and Uganda (Africa) which amount to 53% of its total cereal imports, with Russia and Pakistan constituting the largest share. According to the IPCC, Asia (South, North) is expected to experience a negative impact on crop production (medium confidence) though there are differing opinions on the impact of climate change on key cereals, with climate change reducing the plant growth constraints in the northern high altitude areas. South Asia is expected to experience the higher negative impacts from climate change on food production. Related impacts on water are mostly related to quality with reduced quantity (medium confidence) due to increased demand from irrigation and population increase in Thailand. Russia on the other hand is anticipated to have increase in water availability. There is however low confidence on the relationship between water quantity with climate change due to other overlapping causes such as damming. Moreover, Kenya imports cereals from Uganda which amount to 6% of the top five exporters. Similarly, food productivity is expected to reduce in Africa (high confidence). Water stress risks are medium to high in the near term (high confidence).

The transboundary climate risk is assessed as **medium** for cereal imports to Kenya since Pakistan, Russia, and Thailand are global cereal suppliers, hence impacts on their food production are likely to impact global food supply, further exacerbating transboundary cereal risks for Kenya as an import-dependent country, and as a result of risks to agriculture and water in Asia, which are characterized as high to medium respectively (Appendix A).

With regard to pharmaceuticals, Kenya also imports 70% of its pharmaceuticals by value from India (South Asia), Belgium, UK, Germany (Europe) and China (East Asia). Impacts on infrastructure in Asia are medium in the near and long term (medium confidence) and are expected to be felt mostly from increased frequency and intensity of extreme disasters such as cyclones as well as sea level rise leading to coastal erosion with most Asia countries ranking high globally in terms of risk from extreme flooding and asset exposure. In Europe, climate related risks on infrastructure are medium (high confidence) with main impacts resulting from communication disruptions from extreme events and no hard linkage evidence that rail delays, storm losses and hail losses are as a result of climate factors. Similarly, adaptive capacities of the European nations are high, which reduces the residual risk faced by importers of European exports, like Kenya in this assessment. In Africa, risks to physical infrastructure are medium to low (medium confidence) up to the near term.

The transboundary climate risk is determined to be **high** for pharmaceuticals given than risks to physical capital affecting pharmaceuticals in Europe and South and East Asia (India) are mostly medium to very high respectively and Asia constitute ~53% of the top share imports.

b) Uganda

Uganda imports 70% by value of its cereals from Russia (North Asia), Pakistan, Thailand (South Asia), Ukraine (Europe), and Uganda. Risks to cereal imports are similar to Kenya's given the overlap in the regional sources of their cereal trade. But due to a 20% higher share dependence on a few sources (compared to Kenya), Uganda's transboundary climate related risks to cereals is assessed as **high.**

Uganda imports 76% of its pharmaceuticals from India (South Asia), France, Belgium (Europe), China (East Asia) and Kenya (Africa). Risks to pharmaceuticals are similar to Kenya's given largely similar Asia sources which constitute 56%, with the addition of Africa due to imports from and through Kenya (7%) whose infrastructural risk is considered low.

The pharmaceutical transboundary climate related risks are thus considered **high**, that south Asia constitute ~56% of the top imports share and risks to infrastructure are characterized as very high to high there.

c) Rwanda

Rwanda imports 83% of its cereal from Pakistan, Thailand (South Asia), Russia (North Asia), Uganda and Tanzania (Africa) of which 68% is from South and North Asia. Transboundary climate risks to cereals for Rwanda are as described for Kenya due to similar trade links with Africa and Asia.

Transboundary climate related risks to cereals are determined as **medium** for Rwanda similar to Kenya and Uganda due to similar exporters whose risks to water and agriculture are medium to high.

Rwanda imports 74% of its pharmaceuticals from India (South Asia), Belgium, Denmark (Europe), USA (North America) and Kenya (Africa). Transboundary climate related risks to infrastructure which may affect pharmaceuticals are as described for Kenya due to similar sourcing patterns from Europe and Africa which are low to medium. Rwanda faces additional infrastructure climate risks from North America. Impacts on infrastructure in North America remains a huge concern and have been observed related to extreme events such as heat waves, droughts, and storms (high confidence). These impacts from for example, Hurricane Ike 2008 caused US$2.4 billion in damages to ports and waterways in Texas and Flooding in Tennessee and Kentucky, 2010 that caused US$2.3 billion in damages. Impacts on the manufacturing sector are less studied though some disruptions from climate extremes have been observed. For example, Hurricane Sandy caused plant shutdowns and supply disruptions as a result of compromised transportation networks. In the future, the drier conditions are projected to interrupt manufacturing operations, especially for those reliant on water for their operations. Heat waves are also anticipated to disrupt manufacturing labour force and associated productivity.

Transboundary climate related risks to pharmaceuticals for Rwanda are determined to be **high** given the very high to high risk to physical infrastructure in South Asia (43%) and North America and medium for Europe (19%).

d) Burundi

Burundi imports 68% of its cereal imports from Russia, Tanzania, China, UK and India. Risks thus arise from Africa, Europe, South and East Asia. Of this, 38% comes from South and East Asia whose climate related risks to food production are medium (medium confidence). A higher percent (20%) than the regional average come from Tanzania where climate related risks to food production in Africa are high (high confidence) according to the IPCC. Imports from UK are 6% where medium reduction in food production are expected in Europe (medium confidence). This results from the anticipated reduction in water availability and quality, impact from regular heat waves and reduced arable lands. Wheat yields in particular are expected to stagnate (medium confidence).

Transboundary climate risks to cereal imports is assessed as **medium** as the majority of imports are from Asia where risks are medium.

Burundi's top five pharmaceutical import links constitute 80% of its total imports and include Belgium, France, and Denmark (Europe-41%), India (31%) and China (8%). Risks to infrastructure in Europe is medium (high confidence) arising mostly from infrastructural communication disruptions. Risks to Asia infrastructure is high (medium confidence) in the near and long term.

The transboundary climate related risks to pharmaceuticals for Burundi is considered **medium** due to the distribution of risks mostly to Europe where risks to infrastructure and industrial infrastructure are considered medium.

e) South Sudan

South Sudan imports 97% of its cereals from Pakistan, China, Kenya, USA, and Uganda. Most of the risks arise from Uganda (63%) and USA (17%) and Kenya (11%). Risks to Africa cereals are considered high in the near term (high confidence). Reductions in food production are anticipated in North America (high confidence) arising from droughts and reduced water flows. Its status as a major global food supplier, further exacerbates risk transmission from North America for South Sudan.

Based on the above information transboundary climate risks to South Sudan cereals is assessed as **high.** This is based on the extremely high concentration (97%) of imports for its top five imports and over 50% of its imports coming from a high-risk country (Uganda) and the rest from medium risk countries.

South Sudan imports 74% of its pharmaceuticals from Sweden, Switzerland, Netherlands (47%), Pakistan (22%) and Kenya (15%). Risks to infrastructure in Europe are considered medium and high to low in South Asia and Africa, respectively.

Transboundary climate related risks to pharmaceuticals are considered **medium** given the distribution of risks within medium and low risk countries.

f) Tanzania.

77% of Tanzania's cereal imports are from Russia, Canada, Australia, Germany, and Zambia. Most of the imports are from North Asia (35%), North America and Australia (27%) and Africa (18%). Negative impacts to Asia's food production are expected, with Russia expected to experience a shortfall of over 50% with sea level rise leading to decreased arable lands (medium confidence). North America is also expected to experience reduced yields arising from droughts and water stresses with high risks and reductions experienced in Africa as well (high confidence). Australia is a major exported of food and changes in its production capacity have major influence on world supply and security (OECD 2011). In Australia risks to food production is considered low though reduction and water constraints are expected (high confidence). Water variability has been observed in parts of the continent, associated with variable river flows and droughts e.g. in the 1997-2009 drought in South-Eastern Australia. This is compounded by increasing demand for irrigation and household uses. There is high confidence that water resources in the future in south eastern and far southwest Australia will decline to a possible high of 40% and 70% respectively. Agriculture production in the region is sensitive to drought. Australian wheat is projected to be impacted by increased range of the invasive species specifically the Queensland fruit fly. There is however great uncertainty on the impacts on wheat yields, plant pests, weeds and diseases from carbon dioxide and temperature changes. Rice is heavily dependent on irrigation and expected climate changes to yields will be associated with water availability changes. Adaptation to climate related water variabilities has improved and is ranked high for Australia including policy and management changes in rural and urban water systems.

Transboundary climate related risks to Tanzania for cereal imports are therefore assessed as **medium** given the medium to low risks to Asia and North America.

Similarly, Tanzania imports 80% of its pharmaceuticals form India (51%), Kenya, USA, Denmark, and China. Risks to infrastructure in South Asia are considered high (medium confidence) and Tanzania obtains 60% of the pharmaceutical imports from India and China. North America and Europe (15%) climate related risks are medium (high confidence).

Transboundary climate risks for pharmaceutical imports are assessed as **high** given the high risks to Asia infrastructure where most of the imports originate.

5.2.2 National climate Vulnerability

Vulnerability to climate change is a function of a country's sensitivity and exposure to climate impacts and its adaptive capacity. High ND-Gain scores for exporting countries translate to lower transboundary climate risks for the importing countries. Hence the weighted (by share of imports) ND-Gain scores of the top five exporting countries for the two products was calculated. These were then used to determine the level of risk to the EAC country based on the quartile position in the global ND-Gain scores (Appendix B-Summary statistics) Scores in the upper quartile (56.7-76.1) are scored as low risk, median (48.4-48.5) are scored as medium risk and scores in the low quartile (20.3-39.3) as high risk.

The countries score relatively similar results, Table 5.4, with most lying in the medium range of risk. This could be as a result of the relatively similar sources of the products for all EAC countries, as well as closely similar shares of imports for the top five exporting countries. Tanzania's lower risk scores on cereals are the result of its trade partners' lower vulnerability (Australia, Canada, Russia, and Germany). Similarly, South Sudan's high-risk score is a result of its relatively high share of cereal imports (97%) coming from its top five exporters, with over 50% coming from a highly vulnerable country (Uganda).

Table 5.4: Climate risks to pharmaceuticals and cereals based on national vulnerability of exporting partners.

Country	Weighted ND-Gain score pharmaceuticals	Climate risk to pharmaceutical imports	Weighted ND-Gain score cereals	Climate risk to cereal import
Kenya	48.7	Medium	48.3	High
Rwanda	48.9	Medium	45.4	High
Uganda	46.5	Medium	49.1	Medium
Burundi	55.6	Medium	51.6	Medium
South Sudan	54.4	Medium	42.3	High
Tanzania	47.6	Medium	61.5	Low

Source: Created by the author.

5.2.3 Transboundary Climate Vulnerability

Exporting countries not only face vulnerabilities to direct, domestic climate change impacts, but also to transboundary climate risks.

Hence, the inclusion of weighted (by share of imports) Transnational Climate Index (TCI) scores for the top five exporting countries for the two products in this assessment. These were then used to determine the level of transboundary risk to the EAC country based on their global TCI quartile positions (Appendix B-Summary statistics). Scores in the upper quartile (>5.5-8.2) are scored as low risk, lying within the median (5.1-5.2) are scored as medium risk and scores in the low quartile (2.4-4.6) as high risk. The higher the score, the more exposed the exporting country is and therefore, subsequently, the importing country is to transboundary climate risks in general. The transboundary risk score is relatively similar (Table 5.5) across the EAC countries for pharmaceutical imports as a result of the relative similarity in the share and source countries such as Belgium and India, which both have relatively high TCI Index scores. A variation is noted in the cereal transboundary risk levels where most EAC countries score low risks as a function of the relatively lower TCI score of the major exporting countries such as Russia.

Table 5.5: Climate risks to pharmaceuticals and cereals based on transboundary climate exposure of exporting partners.

Country	Weighted TCI Index score pharmaceuticals	Climate risk to pharmaceutical imports	Weighted TCI Index score cereals	Climate risk to cereal import
Kenya	5.5	Medium	4.6	Low
Uganda	5.5	Medium	4.3	Low
Rwanda	5.6	Medium	4.8	Low
Burundi	5.4	Medium	4.2	Low
South Sudan	5.3	Medium	5.3	Medium
Tanzania	5.4	Medium	4.1	Low

Source: Created by the author.

5.3 Internal Adaptive Capacity Factors Results

The internal factors represent proxy variables that can be used to assess the adaptive capacity of the EAC country to transboundary climate risks. They include capacity to switch supply as determined by country's market dynamics; capacity to manufacture as determined through the readiness and institutional, social and economic scores; capacity to produce as represented by the suitability scores; the sphere of influence and; risk perception of the EAC countries to transboundary climate risks.

5.3.1 Market Dynamics

To understand the security of supply for individual EAC countries for the prioritized product, the HHI and CR_{-5} scores were calculated. The two indicators help to understand the availability of goods from key sources and the ease with which the EAC country can find alternative sources. High scores for imply difficulties in finding alternative supplies, hence a reduction in their adaptive capacity to transboundary climate risks.

Table 5.6: Market dynamics of EAC countries as represented by the Herfindahl and concentration ratio.

Country	**Product**	**Top 5 EAC Countries Trading Partners (by US$ Value)**					**CR-5**	**HHI (points)**
South Sudan	Cereals	Pakistan	China	Kenya	USA	Uganda		
		3%	4%	11%	17%	63%	97%	4383
	Pharmaceuticals	Netherlands	Switzerland	Kenya	Pakistan	Sweden		
		6%	6%	15%	22%	25%	74%	14%
Burundi	Cereals	India	UK	China	Tanzania	Russia		
		5%	6%	9%	20%	29%	68%	1440
	Pharmaceuticals	China	France	Denmark	Belgium	India		
		8%	12%	13%	16%	31%	80%	1609
Rwanda	Cereals	Tanzania	Thailand	Uganda	Russia	Pakistan		
		6%	8%	15%	24%	30%	83%	1867
	Pharmaceuticals	USA	Denmark	Kenya	Belgium	India		
		5%	6%	7%	12%	43%	74%	2217
Kenya	Cereals	Thailand	Uganda	Ukraine	Pakistan	Russia		
		5%	6%	6%	18%	18%	53%	894
	Pharmaceuticals	China	Germany	UK	Belgium	India		
		4%	5%	5%	7%	49%	70%	2585
Tanzania	Cereals	Germany	Zambia	Australia	Canada	Russia		
		8%	8%	13%	14%	35%	77%	1788
	Pharmaceuticals	China	Denmark	USA	Kenya	India		
		5%	7%	8%	9%	51%	80%	2849
Uganda	Cereals	Argentina	Tanzania	Ukraine	Pakistan	Russia		
		7%	7%	10%	21%	26%	70%	1300
	Pharmaceuticals	Belgium	China	Kenya	France	India		
		5%	6%	7%	7%	50%	76%	2730

Source: Created by the author, data based on ITC 2014-2018.

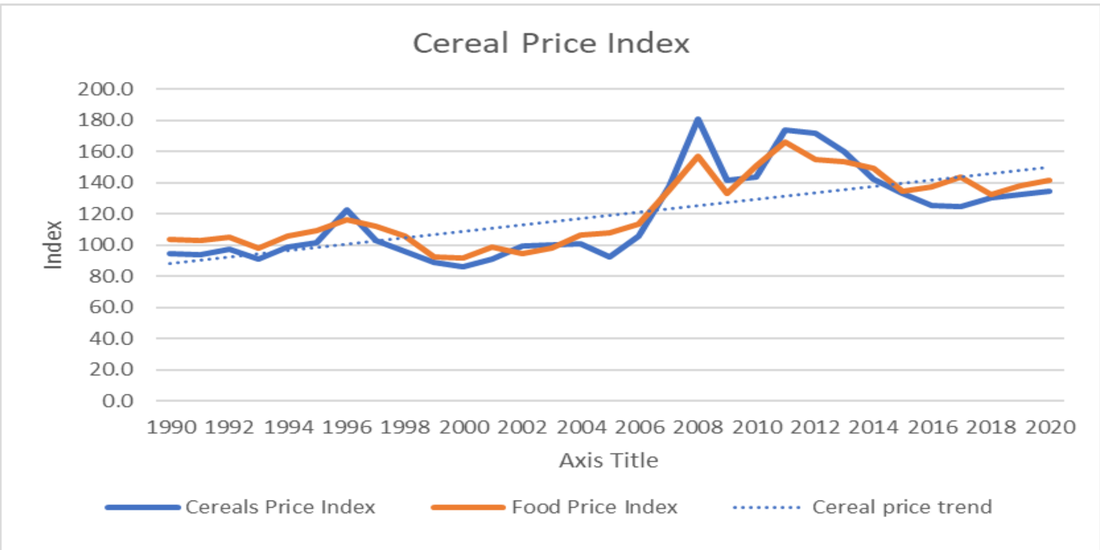
The adaptive capacity of all the EAC countries is ranked low as a function of the concentration ratio and HHI points for both cereals and pharmaceuticals. This is because of their high reliance (>50%) indicating lowered ability to find alternative sources in case of disruption and high reliance on a few exporting countries. For cereals, the exporting countries are also global food suppliers, further exacerbating the risks to EAC country since, any disruption from these trade partners is likely to affect several other importing countries and therefore to be part of a global increase in competition for cereals imports. The most highly exposed and least diverse for cereals is South Sudan. The most highly exposed for pharmaceuticals is Tanzania, though all countries score similarly, above 70% in terms of concentration ratio.

However, despite the low ranking for adaptive capacity across the countries, as a function of their high concentration ratio, regional differences exists, for example between Kenya and Uganda. Kenya scores better on the concentration ratio (53%) compared to Uganda's 74% implying Kenya's slightly higher adaptive capacity and ease of finding alternative sources. However, assessing their cereals trade balance, Kenya has a negative trade balance for all eight traded cereals except barley. Uganda has a negative trade balance only for three out of the eight (wheat, rice and barley) and a positive trade balance for the rest. These results could imply better adaptive capacity for Uganda despite the higher concentration ratio. Most interestingly, Uganda exports its cereals mostly within the EAC region to Kenya, Rwanda, Burundi, and Sudan. This indicates a regional interdependence as well should there be risks to Uganda. A similar trading pattern for cereals is observed between Tanzania and the other EAC countries. The trend is not observed for Rwanda, Kenya, and South Sudan. Overall. Based on this differentiated trading patterns, Uganda and Tanzania may be seen as having more internal adaptive capacity to transboundary climate risks that the others.

Similar regional differences and interregional dependence is assessed for pharmaceuticals where Kenya and Tanzania export the mostly to the region. This may be speculated to mean higher adaptive capacities for the Kenya and Tanzania countries. However, it may also be the case that the two countries are re-exporting these products which exposes them to transboundary risks in case of source disruptions.

Price volatilities as noted earlier could lower the adaptive capacity of the importing country to transboundary climate risks. Reduced volatilities or stable food import prices could help EAC countries to plan for and strengthen their food security as they are able to plan adequately. Reduced pharmaceutical prices could help them expand their basic health care without proportionate increase in cost.

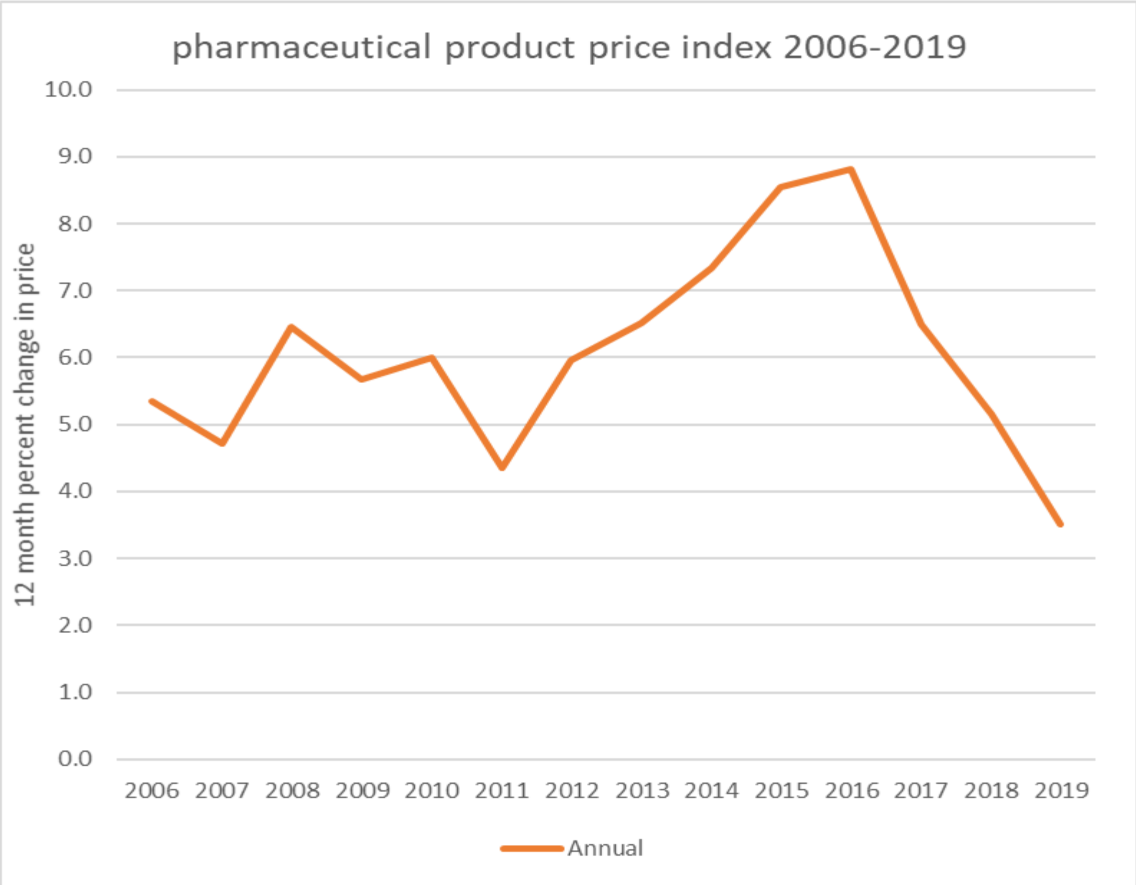
Figure 5-4: Cereal Price Index 1990 - 2020.



Source: Created by Author data based on FAO, 2020

As seen in Figure 5-4, the cereal price index has been stable with a more or less flat trend over the study period (2014-2018) However, assessing past trends, food cereal and food price shocks are experienced every 8-10 years with the highest recorded index in 2007/2008. Moreover, cereal prices are usually more volatile, hence actual risk may be higher. Likewise, climate change impacts in major crop exporting countries are expected to have more severe impacts in Sub-Saharan Africa (Willenbockel, 2012). However, since over the study period the prices are generally stable, the risk is assessed as medium across all the countries as the index is an indication of the global market rather than a specific country. Also, the medium score accounts for the EAC country's lowered purchasing power per capita and gross domestic product, which would mean that the country is unable to respond effectively if prices are high or buy in bulk if prices are low due to strained budgets.

Figure 5-5: Pharmaceutical product price index.



Created by author, data based on U.S Bureau of Labor Statistics, 2019.

The pharmaceutical product price index (Fig 5-5) shows a declining trend in prices over the study period. This trend is expected to continue as the generic medicine supply chains expand. Thus, the adaptive capacity of the EAC countries is ranked medium. This is due to in general, relatively stable pharmaceutical prices and advances in technologies including cheaper generic medicines which may serve to reduce vulnerability and increase the adaptive capacity of the country.

5.3.2 Economic, Social and Institutional Mechanisms score

Overall, the adaptive capacity of Rwanda, Kenya, Tanzania, and Uganda as a function of their the economic, social, and institutional mechanisms is assessed as medium. Burundi and South Sudan on the other hand are assessed as low (Table 5.7). Despite this similar trends Rwanda capacity is slightly higher, while South Sudan is on the extreme lower side. The rationale for this assessment is described below.
Rwanda, Kenya, Tanzania, and Uganda score median CPIA scores between 3.5-4. Burundi's score is average (3), while South Sudan scores lowest (1.7). This is due to the fact that it is characterized as a fragile state at higher risk of conflict which ultimately presents a challenging social, economic and policy environment (WB, 2019).

The economic cluster scores indicate that Rwanda, Kenya, Tanzania (4-5) and UG are more able to respond to external and internal shocks such as price instability. The score also indicates that the country is more able to allocate expenditure to public infrastructure and agriculture programmes, for example, and has relatively good debt management capacity and policy. Burundi's scores indicate that their approach to shocks is less effective while South Sudan's score indicates a capacity that is unlikely to respond effectively to internal and external shocks hence lower adaptive capacity to transboundary climate risks (WB, 2017). Hence, high scores could mean better adaptive capacity to such risks such as price volatility, exchange and interest rates and debt emanating from climate change induced risks.

The structural cluster scores for Rwanda, Kenya, Tanzania and Uganda (4-5) indicate a relatively transparent trade regime and trade facilitation processes with moderate use of non-tariff barriers. Similarly, the financial sector is moderately stable, efficient with adequate access to financial services for households and businesses. Burundi's trade regime is strong, though its financial sector is vulnerable to shock. South Sudan's scores (2) indicate highly restrictive trade regime and limited transparency with the financial sector making it highly vulnerable to shocks (WB, 2017). Related to transboundary climate risks, high scores could mean better adaptive capacity to such risks as the country is able to mobilize resources to address the risks or facilitate trade of commodities e.g. cereals through simplified, cost effect trade procedures.

The policy and social inclusion cluster scores for Rwanda, Kenya, Tanzania, Uganda and Burundi (3-4) indicate significant differences in access to human capital development though laws exist for countries such as Kenya. Similarly, there is some (medium) equity in public resource alignment differentiating the needs of the poor and vulnerable populations. The countries' policies and budgeting are relatively aligned to provide access to education and health services. Social protection systems to respond to risks including supportive saving policies, insurance access and safety net programs exist but some coordination limitations are noted. Sustainable management of environmental resources is uncoordinated with inadequate capacity of concerned authorities to deal with emerging environmental issues. South Sudan scores lower (1.6) on all of the factors under this cluster (WB, 2017). Related to transboundary climate risks, high scores for this cluster could indicate higher adaptive capacity for the internal populations as they are able to access resources such as education, health or stimulus packages to manage transboundary risks.

The public sector management and institutions for Rwanda, Kenya, Tanzania and Uganda score the lowest across the four clusters. This means that the policies are not well-aligned to the budget. Taxes on trade are a major source of revenue with a narrow income tax base, modest institutional capacity and poor transparency and accountability in the public sector with Rwanda scoring slightly higher on transparency and accountability. South Sudan again scores lower across all the factors (WB, 2017). Related to transboundary climate risks, high scores for this cluster could indicate high adaptive capacity of the public sector to for example set up effective cereal production programs to increasing its domestic capacity and reduce reliance on imports.

Comparing the above results with the country readiness score (Chen et al., 2015), a similar trend is observed where Rwanda again scores highest overall and Burundi the least. No scores are available for South Sudan.

The above scores are considered a good representation of the EAC countries' adaptive capacity to transboundary climate risks to trade. This is because they represent the countries' ability to self-organize financially and in terms of human capital in response to external shocks arising from transboundary climate impacts such supply chain disruptions.

Table 5.7: Economic social and institutional capacity scores.

Series Name (1=low to 6=high)	**Burundi**	**Kenya**	**Rwanda**	**South Sudan**	**Tanzania**	**Uganda**
CPIA economic management cluster average	2.8	4.2	4.0	1.3	4.0	4.1
CPIA debt policy rating	2.6	4.3	4.0	1.2	4.0	4.4
CPIA fiscal policy rating	3.1	3.8	4.0	1.3	3.5	4.0
CPIA macroeconomic management rating	2.8	4.5	4.0	1.3	4.5	4.0
CPIA structural policies cluster average	3.3	3.8	4.2	2.1	3.6	3.9
CPIA business regulatory environment rating	3.0	3.6	4.5	2.0	3.3	3.8
CPIA financial sector rating	2.8	3.7	3.5	2.2	3.5	3.5
CPIA trade rating	4.0	4.0	4.5	2.0	4.0	4.5
CPIA policies for social inclusion/equity cluster average	3.5	3.7	4.3	1.8	3.7	3.6
CPIA building human resources rating	4.0	4.0	4.4	2.4	4.0	3.7
CPIA equity of public resource use rating	3.7	4.0	4.5	2.0	4.0	4.0
CPIA gender equality rating	4.0	3.5	4.4	2.1	3.3	3.2
CPIA social protection rating)	3.0	3.5	4.0	1.3	4.0	3.5
CPIA policy and institutions for environmental sustainability rating	3.0	3.5	4.0	1.4	3.2	3.5
CPIA public sector management and institutions cluster average	2.5	3.4	3.7	1.6	3.3	3.1
CPIA efficiency of revenue mobilization rating	3.0	4.0	3.9	2.0	3.9	3.5
CPIA property rights and rule-based governance rating	2.1	3.0	3.5	1.5	3.4	3.5
CPIA quality of budgetary and financial management rating	2.8	3.5	4.0	1.3	3.1	3.3
CPIA quality of public administration rating	2.5	3.5	3.6	1.5	3.2	3.0
CPIA transparency, accountability, and corruption in the public sector rating	1.9	3.0	3.5	1.6	2.9	2.1
Overall CPIA Score	3.0	3.8	4.0	1.7	3.7	3.7
Readiness score	0.2	0.3	0.4	-	0.3	0.3
Economic, social and institutional adaptive capacity rating	**Low**	**Medium**	**Medium**	**Low**	**Medium**	**Medium**

Source: Created by the author, data based on Chen et al., 2015; WB, 2019.

5.3.3 Domestic, production and manufacturing capacity

In order to assess the countries' capacity to produce commodities and products that they currently import; production suitability (for cereals) in the near term was assessed. To interpret the suitability scores into adaptive capacity the below threshold matrix (Table 5.8) is utilised.

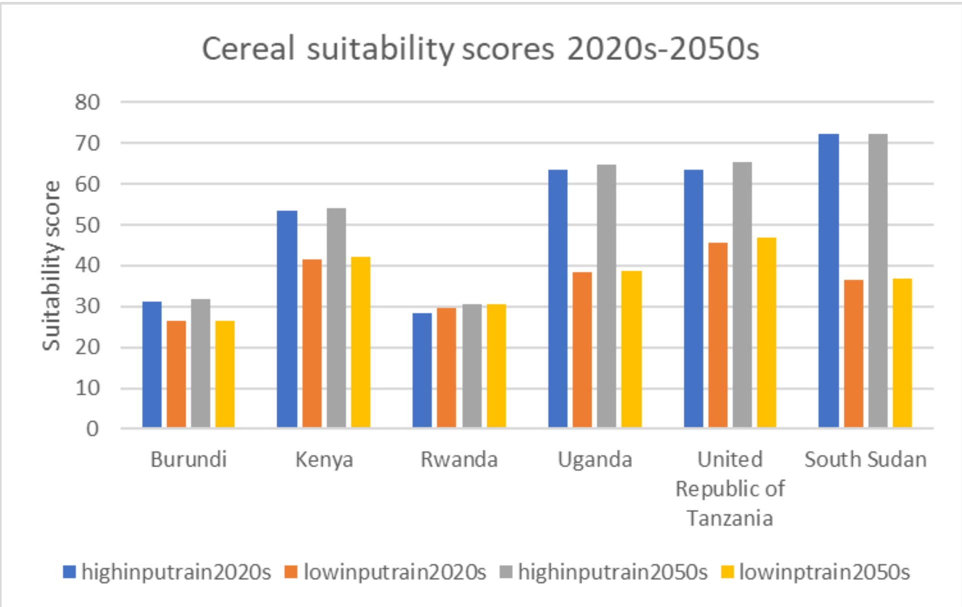
Table 5.8: Suitability threshold matrix.

Suitability score	Adaptive capacity to cereal import risk	Suitability score	Adaptive capacity to cereal import risk
SI>85-Very high	High	SI>25-Medium	Low
SI>70-High	High	SI>10-Moderate	Low
SI>55-Good	Medium	SI>0-Marginal	Low
SI>40-Medium	Medium	SI=0-Not suitable	Not applicable

Source: Created by author, data based on FAO, 2019.

Rwanda and Burundi cereal suitability are low, while Kenya, Uganda and Tanzania are above average with South Sudan been the most suitable across the countries, according to a scenario in which these countries were able to provide high "inputs" to agricultural production (Figure 3-1). A similar trend is observed under low input management approaches where country suitability scores remain within the same class but with markedly lower overall suitability compared to the high input scenarios. Specifically, South Sudan suitability scores under a low input approach are in the medium range compared to the high suitability under the high input approach. Tanzania shifts from being above average in the high input approach to good under low input approach.

Figure 5-6: EAC countries suitability scores 2020s-2050s.



Source: Created by the author, data based on FAO,2019.

Hence, the adaptive capacity for transboundary climate risks to cereals of Kenya, Uganda, and Tanzania as a function of their suitability is determined to be **medium, high** for South Sudan and **low** for Burundi and Rwanda (Table 5.9) whose suitability remain low even under a high input scenario

Table 5.9: Adaptive capacity to cereal import risks based on production capacity.

	High input 2020s		Low input 2020s		High input 2050s		Low input 2050s	
Country	Suitability score	Adaptive capacity	Suitability score	Adaptive capacity	Suitability score	Adaptive capacity	Suitability score	Adaptive capacity
Burundi	31.2	Low	26.5	Low	31.7	Low	26.5	Low
Kenya	53.6	Medium	41.4	Medium	53.9	Medium	42.1	Medium
Rwanda	28.3	Low	29.5	Low	30.5	Low	30.4	Low
Uganda	63.5	Medium	38.4	Medium	64.7	Medium	38.8	Low
Tanzania	63.4	Medium	45.6	Medium	65.3	Medium	46.9	Medium
South Sudan	72.4	High	36.6	Medium	72.1	High	36.9	Low

Source: Created by the author, data based on FAO 2019.

For pharmaceuticals, manufacturing capacity is more difficult to assess. This is because it depends on a more complex range of socio-economic factors, whereas agricultural production suitability is relatively more straight forward. In order to produce pharmaceutical products domestically instead of importing them, EAC countries would need to have high levels of manufacturing capacity including capital, labor and other resources. Given the relatively monopolistic nature of the pharmaceuticals industry, which is concentrated in a small number of relatively high-tech countries, rapidly developing suitability for domestic production is unrealistic for EAC countries. As such, the adaptive capacity for all EAC countries is ranked **low.**

5.3.4 Vulnerability to climate specific risks

The vulnerability of the EAC countries was assessed using their overall ND-Gain index where high ND-Gain scores are taken to represent high internal adaptive capacity to transboundary climate risks. Further, the countries' vulnerabilities of the agriculture and water sectors representing cereals and infrastructure sector representing pharmaceuticals were assessed. This represents the relative propensity of these sectors to be negatively impacted by climate change. Low vulnerability scores for any of the sector represents, higher adaptive capacity.

Table 5.10: Adaptive capacity to import risks based on vulnerability to climate specific risks.

Country	Adaptive capacity to import risks	ND-gain country index	Vulnerability agriculture	Vulnerability infrastructure	Vulnerability water_
BDI	**Low**	**32.3**	0.75	NA	0.19
KEN	**Low**	**36.9**	0.68	0.33	0.50
RWA	**Low**	**42.6**	0.68	NA	0.21
TZA	**Low**	**37.0**	0.70	0.36	0.37
UGA	**Low**	**35.7**	0.72	NA	0.33

Source: Created by the author, data based on data from Chen et al 2015.

As seen Table 5.10, the countries adaptive capacity is assessed as low, due to the fact that the countries ND-gain score relative to global scores indicate high vulnerability

Using the overall ND-gain index scores, Burundi and Uganda are seen as most vulnerable and Rwanda and Tanzania the least vulnerable. The agriculture sector is seen as more vulnerable to climate impacts compared to water and infrastructure sector. No scores were available for South Sudan; hence assumption is made that it will have relatively similar ND gain scores to the other countries.

5.3.5 Risk perception

Country's adaptation plans and programmes of actions which represent official commitments and intended actions by the countries were used to broadly represent the overall state of knowledge on transboundary climate risks... A high level of awareness of the risks could translate to high perception of the related risk and therefore count as a useful proxy of each country's willingness to invest in related adaptation options that increase their adaptive capacity. However, marked difference exists in awareness of transboundary climate risk among the countries as illustrated in the Table 5.11. Overall, awareness of transboundary climate risk is quite low, with few detailed assessments of these risks, the EAC countries' vulnerability and even less on the specific adaptation measures that could be implemented to reduce risks or build adaptive capacity. Nevertheless, as seen through the risks to the nine sectors, countries do recognize many of their characteristics that are relevant in the context of transboundary climate risk.

Biophysical transboundary risks arising from shared natural resources in particular water bodies, dominate the coverage of transboundary climate risk that can be found in EAC adaptation policies. The *people* pathway was heavily represented through risks to human health arising from conflict, disease, and associated migration. This is in addition to risks to food and livelihoods security from agriculture and fisheries. Risks to tourism as a result of ecosystem damage is also among the topmost acknowledged risks. The *finance pathway* which refers to risks to foreign investments and risks to foreign exchange earnings through remittances was mentioned only in the Kenya NAPA. Similarly, risks to cross-border infrastructure is only acknowledged by the EAC policy document (i.e. at the regional level, and not at individual country level) while *trade* and industry are only acknowledged in Kenya and Burundi NAPAs. Kenya and Uganda could be determined as having more awareness on the risks that transmit through these pathways as compared to the other EAC countries from a content analysis of the countries' adaptation plans.

Hence the adaptive capacity to transboundary climate risks as function of the level of perception and awareness to these risks is assessed as **medium** for Kenya and Uganda and **low** for Tanzania, Burundi, South Sudan and Rwanda.

None of the countries are scored as high due to the cursory nature with which the risks are outlined in the plans with no specific adaptation actions (with a few exceptions for shared biophysical resources). Further, the analysis reveals a low level of awareness for the trade related TCRs which is the focus of the study with only Burundi and Kenya mentioning trade risks to their supply chains and raw materials, food imports and foreign income crops and products such as coffee and flowers.

Table 5.11: Adaptive capacity to import risks based on risk perception

Emerging Transboundary theme /risk	**Kenya**	**Rwanda**	**Uganda**	**Tanzania**	**Burundi**	**South Sudan**	**EAC policy**
Agriculture (crops, livestock and fisheries and food security	✓		✓	-	✓	✓	✓
Water Security	✓	✓	✓	✓	✓	✓	✓
Energy Security	✓	✓	✓			✓	✓
Ecosystem Services and Biodiversity	✓	✓	✓	-	-	-	✓
Tourism	✓	-	✓	✓	-	-	✓
Infrastructure (buildings, road, railways, waterways, airways)	--	-	-	-	-	-	✓
Human Health, sanitation, settlements, peace and conflict	✓		✓	✓		✓	✓
Trade and Industry	**✓**	**-**	**-**	**-**	**✓**	**-**	**✓**
Finance	✓	-	-	-	-	-	-
Awareness and adaptive capacity score	**Medium**	**Low**	**Medium**	**Low**	**Low**	**Low**	**Medium**

Source: Created by the author.

5.4 EAC country risk scoping

The research aimed to examine how countries may be exposed to transboundary climate risks related to the trade pathway by developing and presenting an analytical framework of key risk factors. It goes further by testing and applying the framework using the EAC countries. An overall risk profile was produced for each country using the risk matrix below, where the colour corresponds to the risk level (High-red), (Medium-orange), (Low-green). The results from section 5.2 and 5.3 are combined to form the results in Table 5.13

Table 5.12: Risk matrix

Internal Adaptive Capacity				
	Low	M	H	H
	Medium	L	M	H
	High	L	L	M
		Low	**Medium**	**High**
	External Risk			

Source: Created by the author

Results (A, B, C, D) are derived from the individual factor results as summarized in the Table 5.1 and 5.2. Overall country results are derived from combination of A+B for pharmaceuticals and C+D for cereals using the risk matrix, as demonstrated in the Table 5.1 and 5.2.

Table 5.13: Overall transboundary climate risk for cereals and pharmaceuticals.

		Kenya	Uganda	Rwanda	Burundi	South Sudan	Tanzania
PHARMACEUTICALS	External risk rating (A)	Medium	Medium	Medium	Medium	Medium	Medium
	Internal adaptive capacity rating (B)	Low	Low	Low	Low	Low	Low
	Overall risk rating (A+B)	High	High	High	High	High	High
CEREALS	External risk rating (C)	Medium	Medium	Medium	Medium	Medium	Medium
	Internal adaptive capacity rating (D)	Low	Low	Low	Low	Low	Low
	Overall risk rating (C+D)	High	High	High	High	High	High

Source: Created by the author.

The countries are all ranked high for transboundary climate risk for pharmaceutical imports. This is mostly due to their score on adaptive capacity, which was ranked low for all countries, given the limited scope for increased pharmaceuticals manufacturing in the region and the high investment costs related to labour, capital and infrastructure.

For cereals, the countries ranked as high risk due to the overall low scores on their adaptive capacities. Tanzania, Burundi and Rwanda similarly score high risk overall despite having slightly lower external risk scores (5/9) on transboundary and national climate vulnerability scores. South Sudan despite having high suitability scores for cereal production, scores high risk, due to its lower scores on other internal adaptive capacities and highest external risks as a function of their trading partners, compared to other EAC countries.

6 DISCUSSION

The aim of this study has been to contribute to knowledge on transboundary climate risks. The objective has been to develop an analytical framework for exposing how countries are exposed to transboundary climate risks as well as assess transboundary climate risks related to trade. Further, the study operationalizes the framework to assess the transboundary climate related trade risks for East Africa Commission countries.

Hence this chapter discusses the study in two main sections: focusing on the results and the methodology, their strengths and limitations.

6.1 Discussion of Results

Building on previous theoretical approaches and transboundary climate risk assessments the thesis identifies several external and internal factors are key for assessing transboundary climate risks via trade. The results show that EAC countries face high levels of transboundary climate risks as a result of their high import dependencies for both cereals and pharmaceuticals which link them to climate vulnerabilities in other parts of the world. Adding to current assessment approaches, this research recommends including new and additional factors to enhance future transboundary climate risks assessments such as risk perception and sphere of influence.

6.1.1 Discussion of external risk factors

The research has identified 'external' risk factors that reveal how an importing country may be exposed to transboundary climate risks through risks to their trading partners. These include commodity and infrastructure climate sensitivity (4.1.1 and 4.1.2) and national vulnerability and transboundary climate vulnerabilities of the exporting country (section 4.1.3 and 4.1.4)

The analysis in this thesis has highlighted the importance of a country's trade profile as a factor in its own climate risk exposure. The vulnerability of infrastructure and production in exporting countries will determine the level of risk faced in importing countries. But this will be mediated by the structure and number of trade partners that the importer trades with. A diverse number of trade partners is likely to increase the resilience of an importer's trade portfolio to climate shocks.

Moreover, the results show that risks transmitting to the EAC countries are slightly lower for cereals compared to pharmaceuticals despite overall high risks across all EAC countries. These two commodities were chosen to represent the food and health sector in this study, respectively. This is important as the focus on adaptation is mostly placed on agriculture and imports, as well as diseases likely to be exacerbated by climate change such as risks. The study shows that the countries face potentially equal or higher health risks through their pharmaceutical trading, which may be higher than food security risks, hence a need to consider these risks in adaptation plans.

This result suggests that more complex manufactured products like pharmaceuticals are likely to embed higher levels of climate risk. This could be as a result of the more complex structure of their supply chains (which involve more supply tiers and therefore a higher number of countries, and are exported from countries that are relatively well connected globally and therefore more exposed to transboundary climate risk themselves).

Further, the higher risk to the pharmaceutical sector is of concern to the EAC countries given that all six EAC countries as a deeper dive into the traded pharmaceuticals reveal that, the most traded pharmaceuticals are prophylactic drugs (preventative medicine) and therapeutic drugs (related to the curing of disease). Hence, an interruption of their supply may impact the ability of the countries to offer health relief to its citizens. Additionally, the risks are of concern given the lower substitution capacity for pharmaceuticals, where for example a malaria drug may not easily be used to treat other illnesses (whereas food products are more substitutable, for example). This result highlights the need for EAC planners to consider such risks in their adaptation mechanisms. Pharmaceutical imports do not currently feature as key risks in national adaptation plans.

The risks to food sector as a function of risks from their cereals exporting partners is overall high but, varies on individual external risk factors from low to high and is seen to be influenced most by the distribution of imports across the exporting countries and the vulnerability of the exporting country. For example, risks to South Sudan is high as a function of its high (97%) share of import concentration on five exporting partners, some of whom also have high climate risk vulnerability. Conversely, Tanzania's low risk score on national and transboundary climate vulnerability scores is a function of its lower concentration ratio and lower vulnerabilities of its exporting partners. These results are similar to those of Dellink et al.,(2017) who find Sub Saharan Africa trade will be impacted by climate change through international spill overs where import costs rise as a result of climate damages in exporting countries, more than the macroeconomic effects such as changes in gross domestic product and income.

6.1.2 Discussion of Internal adaptive capacity factors

The research has identified 'internal' adaptive capacity factors of the importing country. These include economic, institutional, and social mechanisms (section 4.2.1), its sphere of influence (section 4.2.2), market dynamics (section 4.2.3) risk perception (section 4.2.4) and the domestic production and or manufacturing capacity of the importing country (section 4.2.5).

All EAC countries have a negative trade balance, meaning the value of their imports is higher than the value of their exports. This is an important feature for this study, meaning that the economies of the EAC are fundamentally dependent on trade, especially imports, and therefore likely to be particularly exposed if climate change affects their import profile in any way. Further, the EAC countries show high reliance on a few suppliers translating to high transboundary climate risks and lowered adaptive capacity due to reduced options for substituting suppliers in case of climate related disruptions.

It is therefore important to extend national climate change impact and vulnerability assessments for other African countries, and globally, to consider the dimension of climate risk via trade. It is likely that other countries will also have fairly concentrated import profiles for critical supplies such as food and pharmaceuticals, which may exacerbate their vulnerability to climate related disruptions. Adaptation planning at the national level and international support for and cooperation on adaptation will need to better take account of these interdependencies if this turns out to be the case.

The results reflect the high concentration of pharmaceutical imports to the EAC from a small number of exporting countries. This high dependence on key exporters may be reflected for other critical imports in EAC countries in sectors that were not examined in this thesis. The assessment of manufacturing capacity for pharmaceuticals in the EAC revealed that substituting risky imports with domestically produced alternatives is unrealistic. It is therefore important to increase the resilience of pharmaceuticals supply and possibly to consider risk management measures such as storage or regional cooperation on pharmaceuticals supply. Where EAC countries all face similar dependence, such as in the case with pharmaceutical imports from India, there may be scope for the EAC itself to act on behalf of its members to improve the reliability of critical supply chains.

It is thus important for planners in trade agreements to consider the climate risks -national and transboundary- of the exporting country. It will not be possible for any country to fully insulate itself from trade related climate risks. Thus, in managing transboundary climate risks, moving beyond national and regional groupings is important. International cooperation is necessary to successfully manage and reduce transboundary climate risk and this result should inform EAC countries approach to adaptation at the global level.

Overall, the EAC countries rank relatively the same on their overall adaptive capacity to transboundary climate risks. However, the study reveals some regional differences and interdependencies. just as risks are transmitted to the EAC from its exporting partners, the EAC, may also transmit risks to each other. If inadequately assessed, the region's trade risks may be amplified when it faces risk from within and outside the region.

As an example of this interdependence, Uganda's exports cereals to all other EAC country just as Kenya exports pharmaceuticals within the region. This may indicate better domestic production or substitution capacity for Uganda and Kenya compared to their neighbours. Thus, there are also likely to be opportunities for regional cooperation on adaptation, which are currently under-explored. Highlighting the important role of trade in determining climate risk at the national level helps to motivate new efforts at regional adaptation cooperation.

Moreover, the results demonstrate that in identifying and assessing transboundary climate risks it is important to look beyond regional scores which may obscure differentiated transboundary risks and opportunities for regional collaboration in enhancing climate risks transboundary adaptive capacity. As an example, in the capacity to produce /manufacture adaptive capacity, South Sudan may enhance the regional capacity to transboundary climate risks for the food sector. This is if it is able to or helped to take advantage of its high cereal suitability, and thereby contribute to its own, as well as regional, food security by balancing high import dependence. However, to be able to fully tap into this potential the country will need to enhance its capacity across other factors such as social, economic, and institutional, otherwise the transboundary climate risk will remain high. Hence, Rwanda which scores the highest for the economic, social and institutional mechanisms may serve as a leader.

Moreover, the study reveals low levels of transboundary risk perception across the EAC countries as the focus, understandably, is on national climate risks. Risk perception could enhance the adaptive capacity of a nation as decision makers who understand the risk, are more likely to proactively invest in mitigating and or responding to it, including via enhanced regional cooperation on transboundary climate risk.

These findings serve to enhance the importance of this study, as it serves as a springboard on raising the awareness on transboundary climate risk along the finance, people and trade pathways, as most of the current focus is on the biophysical pathway. Similarly, in enhancing understanding and management on transboundary climate risk, the regional bodies which are legally mandated through their climate policy, as the EAC climate policy, may be used to raise awareness on transboundary issues. This is important even as the results show capacity for regional collaboration to enhance overall regional production capacity for example in cereals.

Lastly, price volatilities are important to consider as different countries as a function of their gross domestic product, purchasing power etc. can increase or lower the adaptive capacity of a country. In this study, the adaptive capacity of all the EAC countries is scored medium for cereals and pharmaceuticals. However, future ranking of this factor may consider quantitative assessment approaches in order to retain case-specific details to assess country differences that may exist.

6.2 Discussion of methods in transboundary climate risk assessment

In the development of the analytical framework and assessment of transboundary climate risks related to trade, several methodological decisions were made. The study uses the four risk pathways as defined by Benzie et al. (2013) to guide the study. These include biophysical pathway, people pathway, finance pathway and trade pathway (the latter being the focus of this study). Further, the study borrows from existing theories of climate and trade risk assessment. This approach set the foundation for the researcher to develop a holistic analytical framework for exposing and analysing transboundary climate risks that considers both the economic, social, and climate perspectives.

However, it is important to note that trade decisions and patterns are highly complex. They are influenced by a myriad of evolving factors including political, cultural and social factors such as gross domestic production, income levels, and historical ties which are not considered in the study (Andreas, 2005; Roemer, 1977). Despite this limitation, the study shows that consideration and screening of the propagation of climate risks via trade is important or understanding climate risks at the national and regional level.

Further, the study confirms that assessment of transboundary climate risks is a complex undertaking (Challinor et al., 2017; Liverman, 2016). A consideration of both quantitative and qualitative assessment approaches is key. Indeed, assumptions have to be made to be able to assess the risks, which are sometimes difficult to define and measure objectively. Inevitably for a study that is as novel as this in such an immature research field, some assumptions and selections are made without the benefit of quantitative or even substantive evidence to support the selection. Similarly, the transboundary nature of climate risks, is further complicated by geo-political factors such as spheres of influence and risk perceptions that are hard to definitively measure. However, proxy indicators for these factors are suggested in this study. More importantly, future research studies could benefit from stakeholder input. This may involve surveys and interviews which were not carried out, which is an inevitable limitation of a study of this depth.

The research attempts to make the process as simple and transparent as possible through use of regularly updated data by credible institutions, for example on trade (ITC), vulnerability (ND-Gain) and climate sensitivities (IPCC regional assessments). The approach allows future comparison of results on a larger scale beyond the EAC region considered in this study. Moreover, the study complements existing research on transboundary climate risks by (Benzie et al., 2019; Dellink et al., 2017; EY, 2018; Hedlund et al., 2018; PwC, 2013) by offering a practical approach to assessing trade related risks. Previous trade pathway assessment as in the UK, consider market dynamics and sensitivity to climate change, this study offers a wider approach to enhance similar future assessments by adding more layers of analysis to the assessment of climate risk and trade portfolios. However, trade-offs in granularity are made as country level differences for example in IPCC regional summaries are not assessed. Future assessments could make use of, where available, projected country level product-specific data on climate change impacts

Likewise, the risk scoping is built from a combination of existing data sources and country-level indices such as the ND-Gain used to measure vulnerability, the TCI Index to assess transboundary climate risk exposure and CPIA scores used to represent adaptive capacities. These presents new challenges as the results may vary depending on the indices chosen. However, care was taken to select indices that are globally accepted and that quantitatively summarize and represent the global differences in climate vulnerabilities to risks and economic capacities.

The risk scoping relies on a simplified risk matrix and scoring widely used in risk assessment. The approach is considered adequate for this study because it is intuitive and easy to understand (high communication value) and enables easy comparison and integration between different indicators without giving a false impression of high statistical sophistication. Furthermore, the aim is not to make a precise evaluation of the risk rather to reveal the pattern of how EAC and other countries may be exposed to transboundary climate risks and thereby to stimulate future discussions on these risks. A limitation of the approach however is that, the level of differences in external risk and internal adaptive capacities scores between the countries is lost. This is seen in the relatively similar scores across the EAC countries, yet the assessment of the internal and external factors for example, between Kenya and Burundi indicate some substantial differences. This detail is lost in the simplified method employed in this study to combine different indicators. Future assessments could consider advanced modelling techniques complemented with expert reviews and stakeholder input, for example as recommended in Challinor et al., (2018).

Finally, the study uses aggregated data where disaggregated data was not possible, which may limit the results leading to overestimation or underestimation of the risk levels. Future research could thus benefit for example from re-export trade data and manufacturing data, which may reveal new insights on relevant factors such as domestic production or manufacturing capacity potential.

7 CONCLUSION AND RECOMMENDATIONS

7.1 Recommendations for adaptation to trade related transboundary climate risks

The study focused on transboundary climate risks for EAC countries related to trade and adaptation. The scoping of the risks indicates that these countries face risks as a function of their trading patterns. Hence, this section focuses on adaptation options that the countries may adapt to reduce these types of risks. The focus on adaptation is informed by the fact that while mitigation efforts have historically been viewed through transboundary lenses (e.g. a bigger focus on carbon leakage and international carbon markets), adaptation efforts have mostly been seen through national lenses, yet scope for adaptation responses in transboundary climate risks exist as outlined below. The following recommendations highlight co-benefits that arise by addressing transboundary climate risks but also national identified climate risks. They include trade related transboundary climate risks adaptation options involving changes in comparative advantage, domestic and international trade policy and macroeconomic changes.

First, policies alignment across adaptation (climate change policies) in general and other sectors including trade can serve to either reduce or amplify the exposure to transboundary climate risks. This is demonstrated through the various external and internal factors considered in the analytical framework. Hence the study recommends inclusion of stakeholders from such sectors in assessing and managing transboundary climate risks specifically, in adaptation plans and programmes of actions given that adaptation is considered the priority response measure to climate change in these countries. This is important as governments can broadly be considered the owners of assets and policies that are exposed to transboundary climate risks and, risks that are not planned for will rarely be managed. For East Africa countries, the study shows that all face transboundary risks not only from trade partners outside the region, but also expose each other to transboundary risks through their import, export, and re-exporting. Further, bilateral as well as intra and interregional agreements and agencies such as the East Africa Community, Common market for East and Southern Africa, Africa Union, Intergovernmental Authority of Development among others can play a key role in managing transboundary climate risks through coordination of national adaptation plans and discussions on regional resilience building.

Second, opportunities exist for EAC countries to collaborate in reducing their exposure to transboundary climate risks by exploiting their different comparative advantage. This is seen in the differentiated adaptive capacities in cereal suitability and economic, social, and political mechanisms of South Sudan and Rwanda, respectively. Thus, EAC countries can build each other’s capacities to enhance the region’s overall adaptive capacity and reduce their regional risks. Such approaches have been piloted by the Africa Risk Capacity, an African Union initiative which among other activities runs risks pools and offers insurance for climate related disasters for its members. In harnessing these comparative advantages, caution should be taken to ensure that they do not lead to maladaptation for other countries, for example through overexploitation of shared natural resources to meet the increased (regional) cereal demand or enactment of protectionist measures to meet import shortages. Specific to transboundary trade related risks, trade units in the national and interregional organizations above could play a leading and convening role.

Third, countries trade ministries can enhance their macroeconomic capacities as part of their adaptation strategy to manage transboundary climate risks. These can involve setting up more stable trade facilitation mechanisms which make it easier to quickly self-organize in response to these risks. Specifically, trade ministries and economic trading institutions in EAC and Africa region need to increase their market dynamics including diversification of suppliers. Similarly, better macroeconomic capacity may allow the country to better allocate expenditure or raise required internal or externa investment. This investment can be used to enhance domestic production capacities for example or to enhance national infrastructure resilience.

Methodologically, the previous discussion section and section 7.2 below highlights the key challenges in transboundary climate risk assessment and recommends areas for future research. The lack of data to assess factors such as sphere of influences and risk perception is key in designing adequate response measures. Hence future assessments should adequately assess these contextual factors. Similarly, as highlighted in other studies, lack of disaggregated data on the transportation routes of commodities and source countries further curtail the accuracy of transboundary climate risks assessments in the future. National governments could play a role in improving data collection, disclosure, transparency and knowledge management for such disaggregated trade network analysis.

7.2 Future research

The study presents a novel, simple yet robust analytical framework that is useful in guiding future transboundary climate risks assessment and for understanding how countries could be exposed to trade-related transboundary climate risks. However, several gaps exist that future research on the topic could augment.

To enhance the accuracy of future assessments and robustness of responses, future studies should use qualitative and quantitative methods. These methods could help capture some of the risk factors and adaptive capacity responses not adequately assessed in this thesis research. For example, sphere of influence and risk perception, are key considerations and require contextual stakeholder input. Similarly, quantitative methods such as advance modelling techniques could complement the risk scoping matrix used in this thesis research, to tease out the specific differences between individual countries even where they all score medium.

Similarly, future research could consider more granular data on factors such as the transportation pathways, price volatilities, manufacturing capacity and trade re-exports of commodities, which can expose more differentiated external risks and adaptive capacity that arise through the supply chain for each case study. For example, for countries dependent on their neighbouring country seaports in such as Rwanda, and the risks and or opportunities that arise through re-exports. Future research could thus benefit for example from re-export trade data and manufacturing data, which may reveal new insights on relevant factors such as domestic production or manufacturing capacity potential

The complexity of the supply chain (how the product reaches the importing country) either through a direct transportation pathway or an indirect pathway could raise the transboundary risks of the country (Bailey & Wellesley, 2017). This interconnectedness was not explicitly analysed due to lack of detailed data on the transportation path of the product. Future analysis where this data is available could augment this factor analysis. Such analysis could be very revealing for assessing transboundary climate risk but requires time and data-intensive approaches at the commodity or product-specific supply chain scale.

In this research thesis, the *assumption* is made that the higher the sphere of influence, the higher the adaptive capacity of the importing country to transboundary climate risks. The sphere of influence was not empirically calculated for this study given the complexity of calculating the interrelationships between the above indicators, which would require an independent study. Similarly, it was difficult to measure the influence of bilateral relationship between the trading partners which serve to influence the power dynamics. It would be interesting to see future assessments develop methodologies to include the sphere of influence in transboundary climate risk assessments.

Previous trade pathway assessment as in the UK, consider market dynamics and sensitivity to climate change, this study offers a wider approach to enhance similar future assessments by adding more layers of analysis to the assessment of climate risk and trade portfolios. However, trade-offs in granularity are made as country level differences for example in IPCC regional summaries are not assessed. Future assessments could make use of, where available, projected country level product-specific data on climate change impacts

7.3 Conclusion

Transboundary climate risks will increasingly be important as global interconnectedness continues across all key sectors. The assessment of these risks is complex, both methodologically and also due to the political and economic nature of the risks stretching across multiple borders, which have been identified and assessed in this study. Despite these complexities, it is important to raise awareness of the risks, as well as to make strides forward in their assessment, as risks that are not identified cannot be assessed, which reduces the likelihood that they will be managed. Hence the study highlights the need to consider transboundary climate risks in trade and climate change adaptation decisions. Specific to the case studies, the study highlights the importance of expanding adaptation measures into the pharmaceutical supply chain sector beyond the food sector. The study shows that the countries face potentially equal or higher health risks through their pharmaceutical trading, which may be higher than food security risks, hence a need to consider these risks in adaptation plans. This is important as the focus on adaptation is mostly placed on agriculture and imports, as well as diseases likely to be exacerbated by climate change such as risks.

This study contributes to the theory on transboundary climate risks. It offers a step towards guidance for the EAC countries, its trade and investment partners working in adaptation and trade. It reveals that these types of risks are under explored. It provides a preliminary analysis of the trade related risks for East Africa that goes beyond any existing studies in the region

Further the study, demonstrates that regional differences and interdependencies in transboundary climate risks exist. This can be explored to determine policy coherence and comparative advantage opportunities within the region as well as individual country actions. Moreover, disaggregated data and assessments is necessary in enhancing the assessment and robustness of response actions. Such opportunities may exist for regional bodies already tasked and mandated to work in climate risks across borders. However, where such transboundary adaptation approaches are taken, opportunities for maladaptation also arise and should be considered. For example, when increased agriculture to meet the needs of a region could place pressure on shared water resources.

Methodologically, the study highlights that both qualitative and quantitative approaches need to be adapted in the assessment of transboundary climate risks. Key among these approaches is the need to calibrate the results using the insights of sector experts and stakeholders in these as the transboundary nature of the risks crosses several disciplines. Similarly, where more disaggregated data exist, the data should be replaced to enhance the accuracy of the results, for example in trade, data on the distribution routes of commodities, re-exports, original suppliers, manufacturing capacities etc. could enhance the assessment of transboundary climate risks.

The study has added detail to the current literature on the factors that influence trade-related climate risks from the perspective of importing countries. It has combined data from a number of different sources, across a number of disciplines, from climate change, climate change vulnerability, economy, institutional, social, trade, supply chains, infrastructure, agriculture and manufacturing. By developing an analytical framework, it contributes to future studies of trade-related climate risk just as this topic is beginning to rise up the political agenda in Africa and worldwide.

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APPENDIX A: CLIMATE IMPACTS OF EAC TRADING PARTNERS

AFRICA				
Key Risks: CEREALS		Present (2014)	Near Term (2030-2040)	Longterm2080-2100(2^{0}C
Water stress	Confidence	High		
	Risk level current adaptation	-	Medium	High
	Risk Level with high adaptation	Low	Low	High
Reduced crop productivity due to drought and associated pests and diseases	Confidence	High		
	Risk level current adaptation	Medium	High	High
	Risk Level with high adaptation	Low	Medium	Medium
Adverse effects on livestock including associated effects from increased range of pests and diseases	Confidence	Medium		
	Risk level current adaptation	Medium	High	Very high
	Risk Level with high adaptation	Low	Low	Medium
Key risks: HEALTH				
Increased water and vector borne diseases	Confidence	Medium		
	Risk level current adaptation	High	High	Very high
	Risk Level with high adaptation	Medium	Low	Medium
Undernutrition	Confidence	Medium		
	Risk level current adaptation	High	High	High
	Risk Level with high adaptation	Medium	Medium	Medium
Key Risks: INFRASTRUCTURE/TRANSPORT				
Transport disruption	Confidence	Medium		
	Risk level current adaptation	Low	Low	Very high
	Risk Level with high adaptation	Very Low	Very Low	Medium
EUROPE				

Key Risks: CEREALS		Present (2014)	Near Term (2030-2040)	Longterm2080-2100(2^{0}C
Reduced water availability and quality coupled with increased demand for irrigation, energy, industry, and domestic purposes	Confidence	High		
	Risk level current adaptation	Medium	High	High
	Risk Level with high adaptation	Medium	Medium	Medium
Impact on crop productivity from heat waves	Confidence	Medium		
	Risk level current adaptation	Medium	High	High
	Risk Level with high adaptation	Medium	Medium	Medium
Key risks: HEALTH				
Increased impacts on health from heat waves affecting labour productivity and increased temperatures affecting drug storage and transport.	Confidence	Medium		
	Risk level current adaptation	Medium	High	High
	Risk Level with high adaptation	Medium	Medium	Medium
Spread of climate related infectious diseases (inferred from pg. 1291,1304)	Confidence	Low		
	Risk level current adaptation	Low	Medium	Medium
	Risk Level with high adaptation	Low	Medium	Medium
Key Risks: INFRASTRUCTURE/TRANSPORT				
Transport disruption and economic losses from increased flooding in coasts, increased sea levels, forest fires, storms,	Confidence	High		
	Risk level current adaptation	Medium	Medium	Medium
	Risk Level with high adaptation	Very Low	Very Low	Very Low

ASIA				
Key Risks: CEREALS		Present (2014)	Near Term (2030-2040)	Longterm2080-2100(2^{0}C
Crop failure and reduced crop production	Confidence	Medium Confidence		
	Risk level current adaptation	Medium	Medium	High
	Risk Level with high adaptation	Low	Low	Medium
Water shortage in arid areas of Asia	Confidence	Medium		
	Risk level current adaptation	High	Very high	Very high
	Risk Level with high adaptation	Medium	High	High
Key Risk: HEALTH				
Increased risk of flood related deaths, injuries, infectious diseases, and mental disorders.	Confidence	Medium		
	Risk level current adaptation	Low	Medium	Medium
	Risk level with high adaptation	-	Low	Low
Increased heat related mortality	Confidence	High		
	Risk level current adaptation	Low	Medium	Medium
	Risk level with high adaptation		Low	Medium
Increased risk of water and vector borne diseases	Confidence	Medium		
	Risk level current adaptation	Medium	Medium	Medium
	Risk level with high adaptation	Low	Low	Low
Key Risks: INFRASTRUCTURE/TRANSPORT				
Coastal, riverine, urban flooding leading to	Confidence	Medium		

widespread infrastructure, livelihoods, and settlements		confidence		
	Risk level current adaptation	High	Very high	Very high
	Risk Level with high adaptation	Very Low	Very Low	Very Low
AUSTRASIA				
Key Risks: CEREALS		Present (2014)	Near Term (2030-2040)	Longterm2080-2100(2^{0}C
Significant reduction in agriculture in Murray Darling Basin and far south eastern and south western Australia in wet/Dry scenario	Confidence	High		
	Risk level current adaptation	Low/Very Low	Low/Medium	Low/Medium
	Risk Level with high adaptation	Very Low/Very Low	Very Low/Low	Very low/Low
Constraints on water resources in Southern Australia	Confidence	High		
	Risk level current adaptation	Low	Medium	Medium
	Risk Level with high adaptation	Very Low	Very low	Very low
Key Risks: INFRASTRUCTURE/TRANSPORT				
Increasing risk to coastal infrastructure leading to damage for Moderate/High-end sea-level rise	Confidence	High		
	Risk level current adaptation	Very low/Very Low	Low/Low	Low/Medium
	Risk Level with high adaptation	Very low /Very Low	Very low/Very Low	Very low/Low
Increased infrastructure damages during heat waves during heat waves	Confidence	High		
	Risk level current adaptation	Low	Low	Medium
	Risk Level with high adaptation	Very Low	Very Low	Very Low
Increased frequency of flood damage to infrastructure and settlements	Confidence	High		
	Risk level current adaptation	Medium	Medium	Medium
	Risk Level with high adaptation	Very Low	Low	Low
NORTH AMERICA				
		Present (2014)	Near Term (2030-2040)	Longterm2080-2100(2^{0}C
Key Risks: INFRASTRUCTURE/TRANSPORT	Confidence	High		

Flooding in coastal and urban areas leading to infrastructure damage, supply chain, health disruptions (high confidence	Risk level current adaptation	Medium	Medium	High
	Risk Level with high adaptation	Low	Medium	Medium
CENTRAL AND SOUTH AMERICA				
Key Risks: CEREALS		**Present (2014)**	**Near Term (2030-2040)**	**Longterm2080-2100(2^{0}C**
Water availability in glacier dependent regions, flooding, landslides in urban and rural areas	Confidence	High		
	Risk level current adaptation	Medium	High	Very High
	Risk Level with high adaptation	Low	Medium	High
Decreased food production and food quality	Confidence	Medium		
	Risk level current adaptation	High	Very High	Very high
	Risk Level with high adaptation	Medium	Medium	Medium

APPENDIX B: SUMMARY STATISTICS- ND-GAIN, TCI RANK AND RISK SCORING

ISO3	Name	TCI_rank	Internal risk level score	ISO3	Name	ND_Gain score	Adaptive capacity score
AFG : 1	Afghanistan : 1	Min. :2.430	Low	AFG : 1	Afghanistan : 1	Min. :20.27	High
AGO : 1	Albania : 1	1st Qu.:4.560	Low	AGO : 1	Albania : 1	1st Qu.:39.28	High
ALB : 1	Algeria : 1	Median :5.140	Medium	ALB : 1	Algeria : 1	Median :48.42	Medium
ARE : 1	Angola : 1	Mean :5.191	Medium	AND : 1	Andorra : 1	Mean :48.54	Medium
ARG : 1	Antigua and Barbuda: 1	3rd Qu.:5.765	High	ARE : 1	Angola : 1	3rd Qu.:56.65	Low
ARM : 1	Argentina : 1	Max. :8.220	High	ARG : 1	Antigua and Barbuda: 1	Max. :76.05	Low
(Other):183	(Other) :183	NA's :18		(Other):186	(Other) :186	NA's :11	

	Score	External risk	Internal risk	Quartile	External risk quartile	Internal adaptive capacity quartile
High	3	1,2,3,4,5 (Low)	1,2,3,4,5,6,7,8,9,10 (Low)	1st	3	5.25
Medium	2	6,7 (Medium)	11, 12, 13, 14 (Medium)	2nd	5	10
Low	1	8,9 (High)	15, 16, 17, 18 (High)	3rd	7	14.25
		The higher the score, the higher the external risk	The higher the score, the higher the adaptive capacity	4th	9	18

APPENDIX C: UK TCR ASSESSMENT FRAMEWORK