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Climate Migration under the aspect of the Water-Energy-Food Nexus

A Master's Thesis submitted for the degree of
“Master of Science”

supervised by
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Affidavit

I, **STEFANIE ECKELHART, BSC**, hereby declare

1. that I am the sole author of the present Master's Thesis, "CLIMATE MIGRATION UNDER THE ASPECT OF THE WATER-ENERGY-FOOD NEXUS", 67 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted the topic of this Master's Thesis or parts of it in any form for assessment as an examination paper, either in Austria or abroad.

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Abstract

The Water-Energy-Food Nexus is facing challenges on a global scale. Resources are increasingly asked for due to an increasing number of population and changing environmental conditions. Focusing on the interlinkage of the Water-Food Nexus it becomes clear that agriculture is responsible for the major part of water usage in this sector but challenges and agricultural dependency differ when comparing various geographical regions and changing environmental conditions thereby affect countries differently. The economies of some countries in sub-Saharan Africa rely to over half of their GDP on their agricultural output. Lacking water resources, rainfed agriculture and missing irrigation systems provide additional challenges to the region. Crop failures therefore endanger food security as well as the maintenance of a reliable income and due to this may lead in increased migration. Predicted climatic conditions provide the basis for a simulation, where the effect of a temperature increase on a specific crop sort is analysed and the effects of climate change on the most popular crop species are analysed. Possible climate migration streams, as a result of these developments, are determined based on already existing migration flows and predicted direction trends. Political measures already emplaced and possible instruments to mitigate and counteract these developments are further discussed. Focusing on slow-onset changes, the thesis concludes that challenges in the water-food nexus, especially in the agricultural sector, significantly influence climate migration leading to increased population movements within the own country and geographical area.

Keywords: water-energy-food nexus, climate migration, sub-Saharan Africa, agriculture

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List of Abbreviations

CAADP	Comprehensive Africa Agriculture Development Programme
COMESA	Common Market for Eastern and Southern Asia
EAC	East African Community
ECOWAS	Economic Community of West African States
FAO	Food and Agriculture Organization of the United Nations
ICMPD	International Centre for Migration Policy Development
IEA	International Energy Agency
IOM	International Organization for Migration
LDC	Least developed countries
LDCF	Least Developed Countries Fund
LEG	LDC Expert Group
SADC	Southern African Development Community
UN	United Nations
UNDP	United Nations Development Programme
WAM	West African monsoon
WEF-Nexus	Water-Energy-Food Nexus

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1. Introduction

Water, energy and food security are inseparably linked to each other. These interlinkages are described by the water-energy-food (WEF)-nexus, which recognizes the complex connections between the sectors and their dependency on each other. Each category has its own influences, impacts and challenges but they all (separately and combined) affect people, ecosystems and landscapes. Obstacles in providing and securing these resources are factors which together with other aspects significantly influence peoples decision to migrate. Poverty, the search for better living conditions, disparities between north and south, conflicts, lack of jobs and economic possibilities, demographic development and urbanization are other influences. The environmental factors which till now are considered to play a secondary role in the resulting migration, their influence on the economic situation as well as on food security and the resulting migration are analysed in this thesis.

Unstable environmental conditions due to climate change and rising temperatures put pressure on each of the three mentioned sectors which are further amplified by a growing population and an accompanying growing demand for resources. Overexploitation of groundwater and increased use of fertilizers leading to water contamination, more and more water being used for the generation of energy and greater competition within the agricultural sector due to an increased production of biofuels are just few of these pressures (cf. Siala et al. 2017). While the specific impacts and circumstances differ between different global regions, the affected population has to adapt to the changing conditions with the help of policy makers and institutions in every case. When dignified living conditions are no longer provided, people will try to improve their living circumstances otherwise. One possibility to do so is to migrate and to seek better life conditions either somewhere else within the own country or abroad. This thesis aims at looking at the connection between the water-energy-food nexus and the mentioned climate migration, taking into consideration the demographic development as well as climate change. Due to the fact that the economic situation is a major influence on migration, the geographical focus will be put on countries whose GDP heavily depends on agriculture. Many countries in Western Africa rely on agricultural products as commercial goods but their production is based on rainfed agriculture. With increased temperatures, a decrease in mean precipitation and scarce water resources, this production is increasingly at risk. Additionally, a vast amount of harvested crops is required to meet local food demands and consequently counteracts food insecurity. Without large improvements in agricultural productivity, substantial poverty reductions in the major part of Africa is hardly possible and sustainable living conditions can't be provided (cf. Schlenker and Lobell 2010).

While concrete numbers on the global growth of population differ, most of it is expected to take place in developing countries. An increased number of population will lead to a growing demand of food production which results in an increase of water demand. Due to this, the linkages between the sectors water and food are analysed in more detail with a focus being put on the water supply required to meet the growing food demand. Accounting for 70 percent of water withdrawals (cf. Siala et al. 2017), agriculture is the largest consumer of the earth's freshwater resources. Challenges of the water for food dimension are the growing usage of fertilizers together with the overexploitation of groundwater, which lead to water contamination by agro-chemicals, soil degradation and desertification. Agricultural usage of water accounts for the biggest share of water usage and irrigated agriculture accounts for 40 percent of the world crop production (cf. Siala et al. 2017). The regional picture in sub-Saharan Africa however looks different, with only 3 percent of cultivated area being irrigated making it the world's least irrigated region (cf. FAO 2011). At the same time, water can not only have an essential role for providing food, but also a devastating one. Through heavy rainfall, floods, etc. crops can be destroyed which effects food security and can likely lead to a food crisis. These and other challenges will be elaborated and their effects on climate migration will be analysed in order to provide an estimation on the affected population as well as on the direction and magnitude of migration.

2. Goals and Objectives

Goal of this thesis is to determine slow-onset events which trigger displacement and to identify scope and scale of climate migration in countries with high dependency on their agricultural production. Implications and effects of population growth, climate change and urbanization on water resources and the agricultural sector will be analysed. The thesis thereby addresses the following research questions:

- What are the challenges faced by the water-food nexus?
- Which areas will be affected the most by the pressure on the water-food nexus and how will climate change influence their agricultural production?
- How will challenges of the water-food nexus influence population movements and whereto will migration flow?
- What political responses to mitigate and counteract these challenges could be expected?

The first research question's objective is to provide a description of the WEF-nexus as well as a general overview on the challenges faced by the nexus due to climate change and population growth. Due to the complexity of the nexus as a whole, a focus will be put on the connection of the water-food nexus.

The second research question has the objective to look deeper into pressures acting on the water-food nexus in a specific, effected region. The geographical analysis aims at identifying high and low sensitive areas and describes in detail why some countries are more at risk than others. The identified challenges of the nexus are investigated jointly with the agricultural production and mean crop yields in a specific region, combined with the available water resources.

The third question's objective is to examine the relation between the water-food nexus and climate migration and to determine magnitude and direction of migration in the specific region.

The fourth question analyses and highlights already existing as well as possible political responses mitigating, counteracting and making use of the described developments.

Countries and economies depending on agriculture are investigated in more detail in the course of this thesis. The most agriculture-dependent countries differ when comparing different sources, but are always located in western sub-Saharan Africa. Even though Africa is already a net importer of agricultural products, the GDP of some sub-Saharan countries still depends for a third to over half on their agricultural output. Sawe (2017) lists Liberia, Somalia and Guinea-Bissau as the countries mostly dependent on agriculture while the World Bank (2019) lists Sierra-Leone, Guinea-Bissau and Chad as the economies where agriculture, forestry and fishing accounts for the biggest percentage of GDP[1]. Western Africa accounts for more than 60 percent of the total value of agricultural output in sub-Saharan Africa and the crop sector's share is significantly higher than the share of livestock (cf. OECD 2016). Additionally, most of the population growth that will take place until 2050 will happen on the African continent. As a result of these circumstances and given the fact that the economic situation of individuals is of high importance for their decision to migrate, a geographical focus will be put on the region where agriculture accounts for the biggest percentage of GDP. Mainly rainfed agriculture, unpredictable and changing precipitation patterns and missing irrigation system provide additional challenges for the future. Climate change projections and demographic development are taken into consideration in order to investigate, whether agricultural development and thereby sustainable livelihoods are at risk in the future which could subsequently lead to climate migration.

[1] Data for Somalia not available in this databank.

3. Materials and Methods

Different methods are used in order to answer the described research questions. Academic books, journals and articles provide the basis for a comprehensive literature review with the aim to identify challenges and interlinkages of the WEF-nexus. This concerns in particular the relation between water and food, which is analysed in more detail. The information is collected either online, in library databases, or on the internet. As demographic development is taken into consideration, prospective challenges of the nexus are analysed in combination with available data on population growth from the World Bank and the UN Population Division (UNPD). In order to estimate the effects that climate change will have on the specific region, a comprehensive literature review is used, comparing and analysing literature from different organizations such as the international organization for migration (IOM), the World Bank, the United Nations, etc. The references to the used literature and data can be found at the end of this thesis.

The impact of identified challenges on a specific area is analysed with a combination of a comprehensive literature review as well as quantitative data from AQUASTAT, CROPWAT and CLIMWAT. The databases are described in more detail in the following subchapters. The described quantitative data is especially used when focusing on a specific geographical area as the identified challenges will be combined with the prospective demand for agricultural products. Statistics and numbers from the International Centre for Migration Policy Development (ICMPD) and IOM (2015) are used for a concrete calculation of affected population and possible magnitude of migration pathways.

A comprehensive literature review is the basis for the analysis of policy instruments already emplaced and possible political responses to challenges. These instruments may vary, depending on whether migration is taking place voluntarily or forced.

3.1. Structure

This thesis covers four main chapters. The introduction and description of goals and objectives provide an overview on the topic while materials and methods describe the used data and indicators. Chapter four provides a description of the term water-energy-food nexus and its importance. The WEF-nexus and its interlinkages are described in detail before a focus is put on the water-food nexus and its global interdependencies.

Taking climate change and demographic development into consideration, challenges of the water-food nexus are identified before the findings of this chapter in regard to the first research question are described.

Chapter five combines challenges of agro-economy and water and puts a focus on a geographical analysis. First, high and low sensitive areas for the determined challenges are identified on a global basis before concentrating on countries whose economies heavily depend on agriculture. Due to the focus on the water-food nexus and the fact that the economic situation of a country is of high importance for the general decision to migrate, attention is aimed at agricultural-dependent economies. Data about this region is combined with quantitative data about water resources, agricultural water management and impacts of climate change on crop yields. A summary in regard to research question number two is provided at the end of this chapter.

The sixth chapter focuses on the effects the water-food nexus on climate migration and identifies whether the economies of the investigated countries are put at risk by the changing conditions and whether this could lead to population movements. Additionally, general reasons for migration are analysed before magnitude and direction of it are estimated and presented as results of this chapter in regard to the third research question.

Chapter seven looks at policies already emplaced to mitigate these challenges or possible political responses to them. Adaptations and adjustments of legal frameworks are necessary in order to guarantee a sustainable management and handling of natural resources. Findings of this chapter in regard to research question number four are discussed subsequently before the findings of all chapters are described jointly.

3.2. Literature Review

The WEF-nexus as well as climate migration, its effects and development is currently much researched. Politicians and scientists emphasize its importance as climate change and resulting population movements constitute a global challenge. In a legal sense, climate migration presents a challenge for international law because it is very broad, the affected subjects are not clearly defined and it can be interpreted in different ways. Often, the definition of the IOM is used, which defines climate migrants as “persons or groups of persons who, predominantly for reasons of sudden or progressive change in the environment that adversely affects their lives or living conditions, are obliged to leave their habitual homes, or choose to do so, either temporarily or permanently, and who move either within their country or abroad" (IOM 2011:33). This definition provides legal challenges and opportunities because it leaves a lot of scope for interpretations and different perceptions (cf. Gemenne et al. 2017). Literature discusses a potential climate-migration nexus which looks more into detail of the relationship between the two as significant influence is found. Several articles look into possibilities and developments in predicting climate change-related migration (cf. McLeman 2013, Cagnacci et al. 2016).

Additionally, it is not clear whether a decrease of agricultural productivity leads to an increase or a decrease of migration. This is due to the fact that not all affected people can afford to seek better living conditions, because they do not have the financial means to do so. This is especially the case for very poor countries. In middle-income countries, a decrease in agricultural productivity likely leads to migration to cities or abroad. It becomes clear that the presence of drivers of migration do not necessarily increase actual migration (cf. Cattaneo and Peri 2016, Black et al. 2011).

Multiple articles discuss, analyse and investigate the relation between climate change, conflicts and security (cf. Abel et al. 2018, Eckstein 2010, Post et al. 2015, Black et al. 2011). This is an aspect however, which will not be discussed in detail in this thesis. Security definitely plays a major role as a reason for general migration and will be shortly discussed in chapter three. Generally, literature is consistent in demonstrating that environmental changes are just one of various reasons for migration which influence people's decision to move and a lot of studies look into the connection between these factors and their significance as well as influence on migration.

Literature exists about the effect of climate change on agriculture as well as on the effect of climate change on migration. The link between agriculture, migration and economic dependency however, needs to be further examined. Recent literature often stresses that further research in the relationship between environmental factors and migration is required and that reliable data on migration streams is required. In a first attempt to evaluate migration policies in Western Africa, the ICMPD and the IOM published a survey in 2015, analysing existing data on policies, practices, and trends in the ECOWAS region.

3.3. FAOSTAT

Data about cultivated crops in the specific countries is obtained from FAOSTAT, where the extent of harvested area is taken as a basis in order to define the region's most important agricultural products. In order to enable comparability of the results, the three crops for which the most arable land is used are defined as the most important ones for the respective countries, taking into account data from 1997 until 2017. Predictions for yield changes of the agricultural products defined as most important in the four countries are analysed in chapter five. FAOSTAT records statistics for 173 agricultural products from diverse categories, such as fruits, vegetable, roots, primary crops, etc. The data used in this database is either official data reported by the respective countries, an FAO estimate or FAO data based on imputation methodology. In the case of unofficial figures, the respective numbers are marked accordingly (cf. FAOSTAT 2019).

3.4. CROPWAT and CLIMWAT

CROPWAT provides information and data about water resources and agricultural water management. It offers the possibility to calculate crop water requirements and irrigation requirements for both existing and new crop and climate data. The program includes standard crop and soil data, which were used in this thesis. Together with data from CLIMWAT, the related climatic database, actual irrigation requirements can be calculated. The database offers agroclimatic information of more than 5,000 international stations. Via the input of monthly, decade and daily input of climatic data, reference evapotranspiration (ETo) can be calculated as well as radiation (MJ/m^2/day). Precipitation in mm per month, temperatures, sun hours and radiation are used to calculate the effective rainfall which describes the portion of rain that can be used by the plant effectively. Soil data was set to medium in order to allow comparability of the results. As a result of runoff and deep percolation, some rain is lost and therefore not available for the crop. Small rainfall amounts are not as useful as bigger amounts, due to the quick evaporation which is an important fact, considering the predicted decrease in mean precipitation in Western Africa (cf. Sylla et al 2016, FAO 2019).

3.5. AQUASTAT

AQUASTAT publishes data on precipitation levels and water resources from countries worldwide. The database is established by the "Food and Agriculture organization" (FAO) and offers global information on water resources and agricultural water management. Several geospatial datasets, tools and over 180 variables and indicators are available which support the regional assessment of water availability and demand (cf. FAO 2019a)

3.6. Terminology

Diverse terms and definitions are used when talking about the application of a cross-sectoral approach in order to discuss and achieve water, energy and food security. The exact notation and the order of mentioned sectors differs when comparing diverse sources. In consideration of the Nexus Resource Platform (2019) which is operated by the Global Nexus Secretariat as part of the Nexus Dialogues Programme as well as the background paper for the Bonn 2011 Nexus Conference (cf. Hoff 2011), the term “Water-Energy-Food (WEF) Nexus” is used in this thesis.

4. The Water-Energy-Food Nexus

The WEF-nexus can be viewed as a response to climate change as well as to social factors such as population growth, urbanization, and globalization which contribute to an increasing demand for resources (cf. Hoff 2011). Underlying the approach of the nexus is the aim to sustainable balance different goals, interests and needs of people and the environment (cf. FAO 2014).

Various diverse nexus-related conferences, initiatives, and projects such as a symposium on the food-energy nexus and ecosystems developed already in the early 1980s. Since the Bonn 2011 Nexus Conference, however, the idea of the WEF-nexus was discussed genuinely. The international conference "The Water Energy and Food Security Nexus – Solutions for the Green Economy" was organized by the German Federal Government as a contribution to the United Nations Conference on Sustainable Development (Rio 20+) (cf. Endo et al. 2015). In the background paper to the conference, Hoff (2011) describes that a nexus approach is needed in order to enable climate mitigation measures to be more "water smart", decrease the energy consumption of adaption measures and to prevent destructing effects on agricultural production. Figure 1 graphically presents the interlinkages of the three sectors and their connection.

The FAO (2014: 3) describes the WEF-nexus as "the complex and inter-related nature of our global resource systems". According to Cai et al. (2018), the interlinkages can be characterized by three forms of interactions: physical, biophysical and chemical, resource input-output, and via institutions, markets, and infrastructure. The boundaries of the resources are different as water is controlled mostly by physical factors and mainly affected by natural variability while food and energy are mostly controlled by human influences and their decisions which determine the outer limits. Due to its dependency, water often acts as the limiting resource and its availability is crucial for the outcome and productivity of a system (cf. Cat et al. 2018).

The three resource securities are defined as following by diverse international organizations (cf. Hoff 2011):

- Energy security is defined by the International Energy Agency (cf. IEA 2019) as "uninterrupted availability of energy sources at an affordable price".

- Water security has been defined as "'access to safe drinking water and sanitation" (cf. UN General Assembly 2010). In the nexus approach, availability of water is also important.
- Food security is defined by the FAO as "availability and access to sufficient, safe and nutritious food to meet the dietary needs and food preferences for an active and healthy life" (cf. Hoff 2011). According to the organization, the concept of food security has four dimensions: availability, access, the stability of supply and utilization.

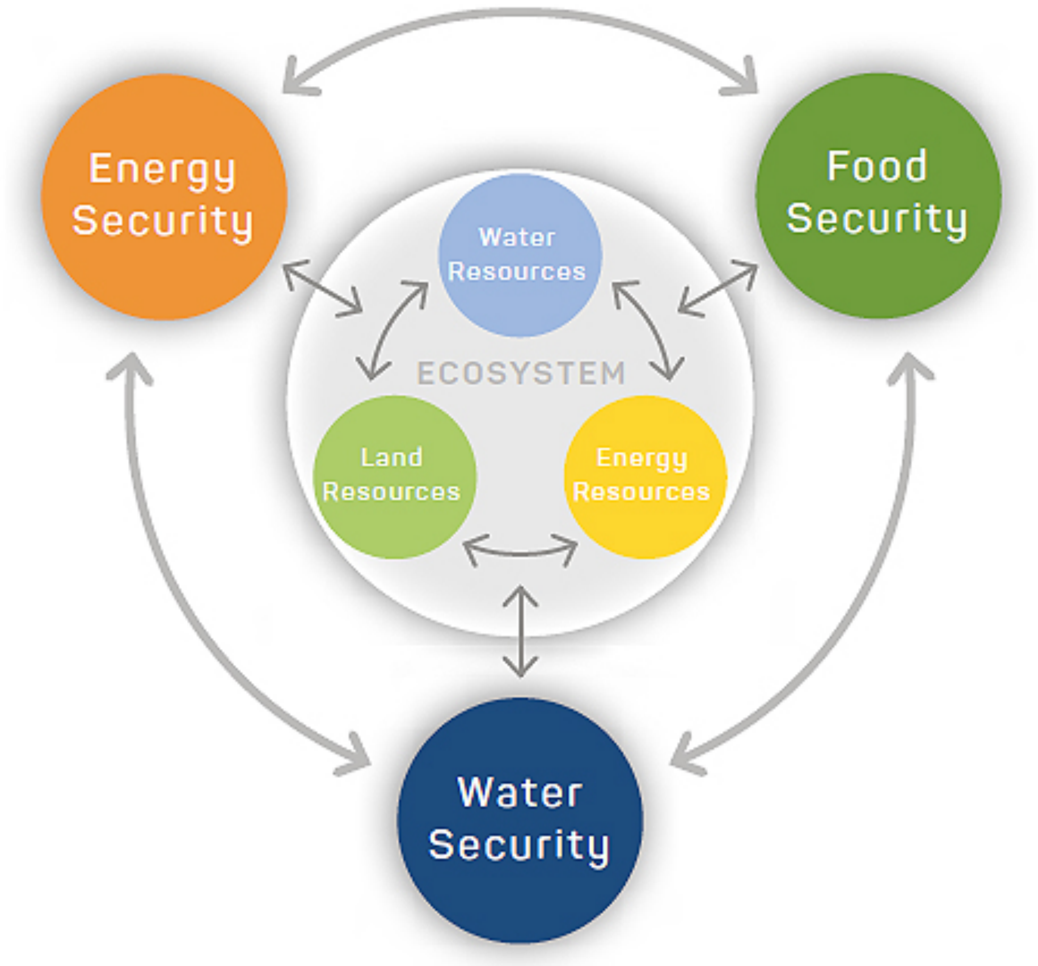

Figure 1: Water-Energy-Food Nexus
Source: Federal Ministry for Economic Cooperation and Development (BMZ) (2016)

Energy, water and food demand and supply are inseparably linked to each other. Energy is needed for the production, procession and transportation of food as well as for the provision of safe drinking water and sanitation. Wastewater treatment, pumping and heating of water for domestic as well as industrial usage and its distribution would not be possible without the generated power to do so. On the other side, water is used extensively in the production of primary energy, power generation and fossil fuel extraction and energy crops impact food supply. The biggest consumer of freshwater resources is agriculture, which accounts for about 70 percent of withdrawals and impacts food supply and land use (cf. Siala et al. 2017). These are just a few examples that demonstrate the dependency of the resources on each other. Their usage is limited by global change, sustainable prosperity and planetary boundaries and the social, as well as economic and environmental dimensions should be considered with the nexus. All of the three resources are influenced by various factors such as institutions, governments, policy and investment who shape and determine their usage and impacts. They are linked to each other and impact people, ecosystems and landscapes.

With the increasing population, demand for all these resources will increase. Until 2050, an increase of food production of 60-70 percent is predicted to be necessary in order to meet global food demands and global energy consumption is projected to grow by up to 50 percent until 2035 (cf. IEA 2010). Therefore the stress on the energy, water and food sector will increase in line with growing population and urbanization (cf. Siala et al. 2017). Achieving energy security without taking into consideration water as well as food security is not possible and vice versa. According to Siala et al. (2017), global energy demand is projected to increase by 30 percent until 2030 and water consumption is to rise by more than 20 percent until the year 2040. Policies and institutions will need to take sufficient and timely measures in order to handle the challenges arising through this development. Food production and supply consumes about 30 percent of total energy globally (cf. FAO 2014). Most of the problems and challenges which are predicted to arise in the future are not only interlinked, but they also affect the same area.

4.1. Water-Food Nexus

Food production is the largest consumer of water and therefore responsible for resource over-exploitation (cf. Hoff 2011). The agricultural sector uses about 70 percent of water withdrawals, while the industrial accounts for 19 and the municipal sector for 12 percent (cf. Siala et al. 2017). While water productivity varies widely among crops, cropping systems, agricultural management methods and climates, a rule of thumb established by the FAO (2009) states that it takes on average one litre of water to produce one calorie of food energy. According to the International Assessment of Agricultural Knowledge,

Science and Technology for Development's Global Report (2009), about 40 percent of the world's food is presently cultivated in artificially irrigated areas.
Globally, these irrigation systems differ widely. While more than two million pumps irrigate about nine million hectares in China, more than 60 percent of all irrigated areas depend at least partly on groundwater in India (cf. Siala et al. 2017). The usage of groundwater irrigation has increased substantially since the 1950s and contributed to the world's food production in the provision of a dependable source of water. At the same time, this has led to a massive overuse of water and falling groundwater levels as a consequence. Due to this development, it becomes necessary to pump water from deeper reservoirs which increases the costs for irrigation. Overexploitation may lead to even greater problems such as contamination of groundwater by nutrients, pesticides and herbicides. This is due to the fact that between 10 and 60 percent of the water used for irrigation flows back and reaches groundwater with higher salt concentrations, thereby contaminating it. Due to the increased usage of fertilizers over the past years, the risks of building up infertile soil has further increased (cf. Siala et al. 2017). Evaporation from reservoirs, canals and soil is an additional factor that needs to be taken into consideration as it accounts for a large amount of water intended to be used for irrigation. By 2050, water demand for irrigation is expected to increase by 10 percent (cf. FAO 2014). In sub-Saharan Africa, irrigation systems are barely emplaced and data about their usage is limited and sparse. According to the World Bank (2007), only 4 percent of the area is equipped for irrigation. Even though the potential for irrigation often exists, maintenance and technical details of the systems provide challenges for the local communities and politicians. Most of the irrigation systems belong to the government due to the high costs of their implementation. Whittles (2018) quotes Tanzania's minister of agriculture, Charles Tizeba, stating that out of 2400 irrigation systems, only 906 are functioning because of lacking financial resources for maintaining the sprinklers and pumps.

Food production is not only affected by changes in the climate, but it is also a major driver for climate change as agriculture contributes 15 percent of global greenhouse gas emissions (cf. Hoff 2011). Climate change may influence food security negatively as the variability of precipitation affects the physical availability of food and usual food supply roots may be disturbed through variability in rainfall patterns and droughts (cf. Siala et al. 2017). Some regions are more vulnerable to these developments than others, an aspect which will be considered in the next chapter. Generally, however, Schlenker and Lobell

(2010) demonstrate that the main reason for food productivity decline is not precipitation changes but increasing temperatures as evapotranspiration demands increase. The effects accompanying increasing temperatures are rarely offset by wetter conditions or a rise in fertilization and CO_2 concentration (cf. Sultan and Gaetani 2016).

Water used for the production of animal-based products is an additional factor. A shift in consumers behaviour and consumption patterns to poultry instead of red meat would e.g. increase water efficiency in the food sector. The combination of a reduction in the meat content of diets and a reduction of per capita production from 3000 to 2000 kcal per day could reduce future annual global water demand for food production (cf. Hoff 2011).

4.2. (Prospective) Challenges

Water is an increasingly stressed resource. Since the 1980s, its usage has increased by about 1 percent each year and its demand is expected to continue increasing until 2050 to 20-30 percent above the current usage level. Driving factors for the past development were population growth, socio-economic development and changing consumption patterns while an increased demand in the industrial and domestic sectors will be of high importance for the progress of the upcoming future (cf. UNESCO 2019). Patterns of withdrawals and consumption, however, depend on the structure of economies as agriculture is the world's largest user of water (cf. Siala et al. 2017). Changes in one sector have effects in other sectors as well. Introducing irrigation patterns may lead to increased agricultural efficiency but at the same time, it increases the water demand and affects soil. Improvements in processing, distribution and retailing provide the opportunity to increase efficiency in the food production chain and can lead to a more efficient usage of resources. Studies show that regions with the highest pressure on land and water resources also face difficulties in achieving food self-sufficiency (cf. Hoff 2011).

Difficulties in predicting the evolution of water demand for the future are diverse. Current average per capita domestic water withdrawal exceeds projections made for 2025 in the early 2000s (cf. Siala et al. 2017) and current water withdrawals follow a higher rate of growth than projected for post-1990 demand (cf. Amarasinghe and Smakhtin 2014). One reason for wrong evaluations are difficulties in finding the most important drivers for different countries and to evaluate their sensitivity for projections. The level of water demand depends on various factors such as the ability to pay, the reliability of the supply as well as climate change and changing temperature patterns. With the growing population, the shift in consumption patterns of consumers becomes more and more important as it defines the limits and possibilities of a system. The increasing demand for biofuels can also play a role in usage and treatment of agricultural area which needs to be taken into account when investigating future developments and possibilities.

Pressure on resources will increase due to the growing world population and urbanization (cf. Siala et al. 2017). By 2050, 68 percent of the world's population is expected to live in urban areas and one-third of the world population will be rural. With the world population growing by approximately 83 million people annually, the population is predicted to increase to 9.3 billion in 2050. Urban population exceeded the rural one for the first time in 2007 and will amount to approximately 6.3 billions in 2050. While presently Africa remains mainly rural with 57 percent living in rural areas, urbanization in Africa and Asia is expected to increase faster than in the rest of the world (cf. Siala et al. 2017). The global population will increase by about 2.4-2.5 billion people until 2050, with most of this growth happening in the two mentioned continents (1.3 billion in Africa and 0.9 billion in Asia) (cf. UN DESA 2018). While services such as electricity and clean drinking water can be provided with a higher efficiency due to these changing living conditions, challenges such as increased usage of resources and waste production arise as well. Sustainable development of resources depends on the successful management of the described urban growth, especially in low-income countries (cf. Siala et al. 2017, UN DESA 2018). With growing energy consumption, also water consumption increases and energy-related water withdrawals are especially high in non-OECD countries which are predicted to rise by 35 percent between 2014 and 2040. The fact that the evolution of water demand for energy depends mainly on the efficiency of the used technology is proven by the point that total water withdrawals fall faster than energy demand in OECD countries (cf. Siala et al. 2017).

In order to fulfil the needs of the growing population, changes in the current patterns of agricultural production will need to take place. The shift to sustainable agriculture represents a major challenge in many economies. According to the FAO (2017), annual world production of crops and livestock will need to increase by 50 percent in order to feed the world population in 2050. In some parts of the world, including sub-Saharan

Africa, agricultural productivity needs to more than double in order to meet increasing demands. Higher yields and cropping intensity are expected to account for the major amount of growth in crop production. Still, the major challenge will be that more people are to be served while at the same time resources are increasingly scarce and contested. One aspect of how water resources can be guaranteed is to establish appropriate legal and institutional frameworks that ensure that the resources are managed and handled sustainable (cf. UNESCO 2015). The usage of water resources, however, is not only affected by legislations that directly affect them, but also by diverse socio-economic developments that are influenced by various factors.

4.3. Summary in Regard to Research Question

Water, food and energy security are influenced by different factors and their boundaries vary. As a matter of fact, water is controlled by physical determinants and its availability is influenced by natural fluctuations which distinguishes it from the other two sectors and further enhances its role as limiting factor. With agriculture being the biggest user of freshwater resources, current agricultural production patterns and their development are of crucial importance when discussing future challenges of the water-food nexus. In the last decades, irrigation systems have been increasingly important and the usage of groundwater irrigation has risen. While the agricultural output can be boosted via the usage of fertilizers, chemicals provide significant challenges to water resources and soil. Climate predictions indicate that the main challenges in the future will not arise due to the fact that water is not available, but due to the fact that rain patterns shift and are increasingly unpredictable. At the same time, food production is expected to be challenged not due to insufficient precipitation but due to a rise in temperature, which increases the evaporation demand of plants. Water and food resources are increasingly stressed with a growing number of population and urbanization, but the industrial and domestic sector will impact the future progress of the resource.

The global trends of urbanisation, population growth and climate change influence all three sectors. Food production, global energy consumption, water demand for irrigation, general water demand, etc. will further increase until 2050. More and more people will demand resources that under certain circumstances are stressed already today. The shift to a sustainable agriculture, higher yields and increased production efficiency is necessary in order to feed the growing world population and to avoid threatening desertification.

5. Agro-economy and Water

Chapter five evaluates the relation between the water-food nexus, agro-economy and water. Even though there has been a lot of development and improvement made regarding energy, water and food security, the outcomes are unequally distributed and vary a lot between different countries and regions (cf. Hoff 2011). The greatest challenges will arise in developing countries and increased cooperation, collaboration and coordination is needed to mitigate the effects and to promote equitable and sustainable growth. With more than 80 percent, Africa and Asia have the highest water withdrawals for the agricultural sector. Europe uses about 25 percent of its water withdrawals for the agricultural sector and North America about 40 percent. Low-income countries need to close energy-, water- and food-security gaps related to low productivity in order to mitigate the challenges described above (cf. Siala et al. 2017).

5.1. High- and Low-sensitive Areas

Climate change affects all areas and regions but has diverse impacts both locally and regionally which are hard to predict.

The Arab region presents the most water-stressed area in the world. While global total renewable water resources per capita and year are 7,453 m^3, only 736m^3 per year are available per person in this region. Due to population growth and climate change, water scarcity has increased and continues to do so which effects agriculture and influences peoples decision to move (cf. World Bank 2008). Due to the increasing drought in this region, more than 50 percent of agricultural products and food are imported (cf. Siala et al. 2017). The GDP dependency on agriculture, forestry, and fishing of the Arab World currently lies at 5.48 percent (cf. World Bank 2019). Disparities in water resources are noted between rural and urban areas as well as different countries, for example between Yemen and Sudan. The region is additionally stressed by the ongoing conflicts which resulted in over 16 million people - 41 percent of internally displaced people (IDPs) worldwide - being situated in the Arab area. Climate change and disasters linked to it accounted for the displacement of over 240,000 people in 2016 (cf. UNESCO 2019). With an annual growth rate of about 3 percent, population growth reached a peak in this region in 1980. Currently, the rate lies at about 1.9 percent (cf. Roudi-Fahimi 2019).

Asia and the Pacific region are facing challenges not only due to the dynamic population growth taking place but also because of its economic progress, urbanization and industrialization (cf. Siala et al. 2017). The ratio of people living in urban areas has more than doubled since 1950. The region is very sensitive for natural disasters and half of the population living in urban regions live in low-lying coastal zones and are therefore especially vulnerable. They are not only at risk to suffer from rising sea levels but also due to storm surges and floods caused by rivers. Sea level rise leads to salinization of low-lying cultivation areas, thereby putting the livelihood of the population at risk (cf. Gemenne et al. 2017). Many people have been displaced due to natural disasters, especially in the People's Republic of China (1,2 million people due to floods in 2017) and in the Philippines (2,5 million people due to typhoons in 2017). Even though strong development took place in the region, there are still a lot of insecurities existing and climate change and natural disasters are worsening water scarcity. According to UNESCO (2019), 29 out of 48 countries in the area qualified as water-insecure because of the low availability of water and unsustainable groundwater withdrawal and other insecurities due to limited land resources and inadequate energy supplies. With two-thirds of the world population living in Asia, population growth provides the biggest challenge for policymakers and institutions. The inhabitants account for 59 percent of global water consumption, notably per capita energy consumption is among the lowest in the world (cf. Siala et al. 2017). Especially in the North China Plain and in Northwest India has the demand for irrigation for agriculture led to severe groundwater stress. The big geographical dimension of this area allows for substantial differences in the countries. Differences exist for example in the ratio of population in urban areas that has access to safely managed drinking water. In Eastern and South-Eastern Asia, this ratio accounts for 89 percent while in Central and Southern Asia only 61 percent of the regarding population has save access. The unequal distribution also applies to irrigation water, impacting the agricultural productivity which accounts for 5.07 percent of GDP in East Asia and the Pacific (cf. UNESCO 2019, World Bank 2019). According to Knox et al. (2012), the income of 75 percent of South Asia's rural poor depends on rainfed agriculture, livestock and forestry.

In Australia, climate change will lead to a reduction in agricultural production and a loss of biodiversity. Rising water temperature and acidification of the ocean leads to a further loss in the biological diversity of the marine ecosystem which puts its use as a sustainable livelihood (for fisheries and tourism) as well as a natural protective barrier, preventing severe weather formation (cf. Gemenne et al. 2017).

In Europe and Central Asia, the agricultural sector accounts for 1.94 percent of the GDP (cf. World Bank 2019). While the situation regarding resource security varies, citizens in Eastern Europe, the Caucasus and Central Asia suffer from unequal access to water and sanitation services. Especially in rural areas, access to safely managed sanitation services remains a challenge. In the regions of Central Asia and the Caucasus, 72 percent of the people without access to basic water services live in rural areas (cf. UNESCO 2019). Europe will be affected by climate change via an increased pattern of heavy rainfall, more frequent heat waves, melting of glaciers and changes in the terrestrial ecosystem. The increasing frequency of heat waver will impose health risks and increase the mortality rate, especially in urban areas. In central and eastern Europe, summer rain is expected to decrease which will most likely lead to water stress and increase the risk of fires in moorland. Northern Europe will face floods in winter more frequently, putting ecosystems at risk and leading to destabilization of soil. The Mediterranean region and Southern Europe will face increasing temperatures leading to droughts and water scarcity, which will result in a decrease in agricultural productivity and increased risks of forest fires (cf. Gemenne et al. 2017).

In North America, agriculture accounts for 1.01 percent of GDP (cf. World Bank 2019). Including South America, the continent will face changes in precipitation patterns such as relocations of rain which then cause floods and spring tides and together with wind cause storm surges. Additionally, heat periods and droughts will increase which will boost wildfire risk. In urban areas, heat waves will increase, again leading to a bigger risk of wildfire. The Andes glaciers will retreat due to climate change, leading to defrosting and removal of the ice cover. This will result in a decrease in annual meltwater and the risk of water scarcity. As the ecosystem faces challenges as well, harvest losses are expected together with a reduction of quality from field crops as well as a dramatic decline in the natural fish stock. These factors combined will lead to uncertainties regarding food security. Especially coasts, coastal areas and towns are at risk due to increasing sea levels. The increasing frequency of hurricanes puts both densely populated areas on the mainland as well as the Caribbean at risk (cf. Gemenne et al. 2017).

In Latin America and the Caribbean, agriculture, forestry and fishing account for 4.651 percent of GDP. Also in this region, differences between the rural and the urban area exist. The difference between the areas is 13 percent for water supply and 22 percent for sanitation service (cf. UNESCO 2019). The availability and security of water, energy and land are additionally under pressure due to climate change and demographic development. Even though a lot of socioeconomic development took place in the past, inequalities still persist. Like in the global picture, agriculture accounts for 70 percent of water used in this region (cf. Siala et al. 2017).

Dependency on agriculture is the highest in sub-Saharan Africa with 32 percent of the GDP. Farming accounts for 65 percent of the area's employment and for 33.6 percent of its exports (cf. Siala et al. 2017). Agriculture, therefore, is essential for the economic situation of this region and for the peoples living conditions. The increasing population combined with land degradation and limited investment in water and rural energy intensify the challenges that the region is currently facing. Sub-Saharan Africa is the only continent where the number of people living without access to electricity is increasing. By 2030, 50 percent of the population are expected to be concerned by this problem (cf. Siala et al. 2017). Periodic and chronic water scarcity provides an additional challenge and irrigation is heavily dependent on groundwater. Agricultural productivity, therefore, is heavily dependent on precipitation and temperature patterns. There are differences in the reduction of poverty between rural and urban areas as well as across sub-regions. As already described, population growth presents a major challenge and needs sufficient planning and legal instruments in order to prevent further development of slums. Sub-Saharan Africa is not only at great risk because of its economic dependency, but also because it is home to the highest percentage of malnourished people worldwide (cf. UNESCO 2019). Moron et al. (2016) estimated trends of mean temperature and warm extremes in West Africa and came to the conclusion that the trends of annual mean maximum and minimum temperature amount to +0.021°C/year and +0.028°C/year. Projections regarding the future rainfall in Western Africa are uncertain but the model correspond regarding the increasing surface temperatures. Heat waves that are unusual under present climate conditions will occur frequently by 2040 (cf. Sultan and Gaetani 2016). Climate change will have a negative effect on food- and water-security and thereby put livelihood at risk. Changes in precipitation patterns will lead to a decrease of, mainly, rainfed agricultural productivity. Negative impacts from droughts, floods and desertification are to be expected. Urbanization being accompanied by population growth will place the most vulnerable population at areas, which face the biggest risk of being affected by natural disasters. This further increases the amount of population being at risk to suffer from natural disasters and climate migration (cf. Gemenne et al. 2017). The climatic challenges of the African continent and climate change hotspots are visualized in Figure 2.

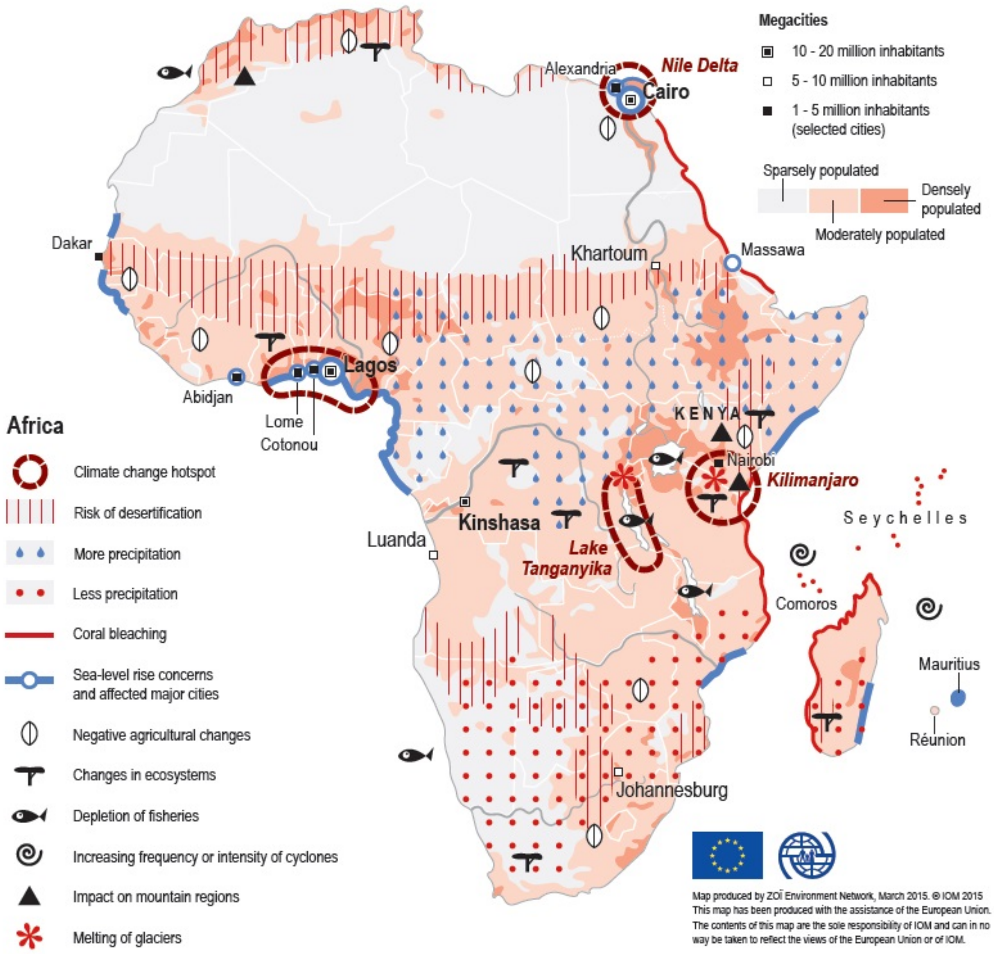

Figure 2: Key climatic risks, impacts and climate change "hotspots" in Africa.
Source: Zoi Environment Network (2015): Regional Maps on Migration, Environment and Climate Change.

5.2. Impact of Identified Challenges in Specific Areas

Table 1 provides an overview of the global area equipped for irrigation. Irrigation has developed a lot, especially in Asia and it has doubled in the respected timeframe in Africa. Still, irrigated area only amounted to 3.4 percent of total cultivated land in sub-Saharan Africa. Irrigation water withdrawal (in km^3) in sub-Saharan Africa is expected to slightly increase from 105 km^3 to 127 km^3 until 2050 and pressure on water resources due to irrigation are expected to stay at 3 percent until 2050 (cf. OECD 2017). With most agricultural-dependent countries being situated in West Africa, this region will be analysed in more detail with a focus being put on Chad, Liberia, Sierra Leone and Guinea Bissau. These countries' economies and their GDP heavily depend on the agricultural output and food production is needed as supply for the local food demand, with a lot of farmers being small-scale producers, producing food mainly for their own demand and with limited input (cf. FAO 2011, OECD 2016). Climate change is a serious threat to regions that are already food insecure and whose economies depend on agriculture. Climate variability is naturally high in sub-Saharan Africa. This fact combined with the dependency of agriculture on rain for its irrigation leads to vulnerability on the available food production and stability of supplies as well as dependency on global food prices (cf. FAO 2011). Due to the dry climatic conditions, growing population and the focus on rainfed agriculture, water resources are scarce and the countries' yield production is sensitive to challenges of the water-food nexus.

Table 1: Area equipped for irrigation (percentage of cultivated land and part irrigated groundwater)

Continent Region	Equipped area (million ha)		As % of cultivated land		of which groundwater irrigation (2006)	
Year	1961	2006	1961	2006	Area equipped (million ha)	As % of total irrigated area
Africa	**7.4**	**13.6**	**4.4**	**5.4**	**2.5**	**18.5**
Northern Africa	3.9	6.4	17.1	22.7	2.1	32.8
Sub-Saharan Africa	3.5	7.2	2.4	3.2	0.4	5.8
Americas	**22.6**	**48.9**	**6.7**	**12.4**	**21.6**	**44.1**
Northern America	17.4	35.5	6.7	14.0	19.1	54.0
Central America and Caribbean	0.6	1.9	5.5	12.5	0.7	36.3
Southern America	4.7	116	6.8	9.1	1.7	14.9
Asia	**95.6**	**211.8**	**19.6**	**39.1**	**80.6**	**38.0**
Western Asia	9.6	23.6	16.2	36.6	10.8	46.0
Central Asia	7.2	14.7	13.4	37.2	1.1	7.8
South Asia	36.3	85.1	19.1	41.7	48.3	56.7
East Asia	34.5	67.6	29.7	51.0	19.3	28.6
Southeast Asia	8.0	20.8	11.7	22.5	1.0	4.7
Europe	**12.3**	**22.7**	**3.6**	**7.7**	**7.3**	**32.4**
Western and Central Europe	8.7	17.8	5.8	14.2	6.9	38.6
Eastern Europe and Russian Federation	3.6	4.9	1.9	2.9	0.5	10.1
Oceania	**1.1**	**4.0**	**3.2**	**8.7**	**0.9**	**23.9**
Australia and New Zealand	1.1	4.0	3.2	8.8	0.9	24.0
Pacific Islands	0.001	0.004	0.2	0.6	0.0	18.7
World	**139.0**	**300.9**	**10.2**	**19.7**	**112.9**	**37.5**
High-incoe	26.7	54.0	6.9	14.7	26.5	49.1
Middle-income	66.6	137.9	10.5	19.3	36.1	26.1
Low-income	45.8	108.9	13.1	24.5	50.3	46.2
Low-income food deficit	**82.5**	**187.6**	**16.6**	**29.2**	**71.9**	**38.3**
Least-developed	**6.1**	**17.5**	**5.2**	**10.1**	**5.0**	**28.8**

Source: own depiction after: FAO (2011)

Sub-Saharan Africa is particularly vulnerable to the described risks and challenges due to its climate variability and the limited possibility (economically and institutionally) to respond to changing climatic conditions. Most of the regions water resources are used for agriculture and the expected temperature increase imposes a great risk to this sector due to lacking irrigation measures. Due to its dependence on rainfed systems, agriculture in dry tropics focuses on drought-resistant cereals such as maize, millet and sorghum (cf. FAO 2011). Rising temperatures and changes in the precipitation pattern will be especially severe for regions were adaptation technologies and agricultural knowledge are rare (cf. Sultan and Gaetani 2016, Knox et al. 2012). Changing climatic conditions in West Africa, characterized by an extensive warming as well as an increased frequency of climate extremes and the recovery of the monsoonal precipitation, are signs of a rapid climate change occurring in the region. Concrete predictions regarding the future climate development are hard to make and uncertainties exist, especially regarding summer precipitation. The occurring ambivalence in climate predictions affects the predictability of yield loss in West Africa. Nevertheless, robust evidence for this scenario emerges when comparing diverse studies, driven by an increase in temperature. Concentrating on a specific region, Roudier et al. (2011) came to the conclusion that mean yield reduction in West Africa will amount to -13 percent and Knox et al. (2012) identified a reduction of 8 percent in all Africa.

Climate conditions in West Africa depend heavily on the West African monsoon (WAM) system, with more than 70 percent of annual precipitation occurring between May, when the monsoon develops, and October, when it elapses. This key element to the region is influenced strongly by the emergence of the Atlantic cold tongue and the Saharan heat low. The Atlantic cold tongue is described as “a cold pool which characterizes the equatorial eastern Atlantic Ocean from boreal spring to early summer“ (Sultan and Gaetani 2016: 3) and its fluctuation influences the monsoon onset as well as the rainfall distribution and intensity over the Guinean coast. Driven by the global ocean sea surface temperature, precipitation recovered partially at the turn of the twenty-first century after a long period of drought during the 70s-80s. Beside its dependency on the WAM, the West African climate depends on vegetation-associated land surface processes which have the highest impact in this region. Less rainfall at the beginning of the growing season due to changes in the precipitation brought by the monsoon can affect crop growth (cf. Sultan et al. 2014, Sultan and Gaetani 2016).

In Guinea-Bissau, agriculture contributes 62.6 percent of GDP, 12.2 percent for the industry sector and 25.5 percent for the service sector (cf. Republic of Guinea-Bissau, 2011). 83.3 percent of the population was employed in the agricultural sector in 2018 according to the FAO (2019b). Agricultural land accounts for 58 percent of land area and average annual precipitation accounted to 1,577 millimetres in 2014 (according to Aquastat 2019). Two crops dominate the agricultural output: cashew nuts and rice, followed by groundnuts. The country does rely heavily on the export of cashew nuts, a product that is sensitive for price fluctuations and weather conditions. According to the World Bank, two-thirds of the population are exposed to terms-of-trade shocks due to the reliance on this agricultural product for economic livelihood (cf. World Bank 2018). More than half the households in Guinea-Bissau are active in cashew farming. The cashew monoculture depends heavily on smallholder production, according to Havik et al. (2018) and 90 percent of revenues achieved by exporting and 10 percent of the GDP accounts to cashews. In Guinea-Bissau, 22,560 ha were equipped for irrigation in 1996 from which only 8,562 ha were equipped for full control irrigation and actually irrigated. Irrigation is practiced during the dry season from June to October according to the FAO (2019b).

In Liberia, 28 percent of the land area is used as agricultural land and average annual precipitation accounts for 2,391 millimetres in 2014 (according to Aquastat 2019). Due to the significant rainfall, irrigation measures are barely used. According to the National Adaptation Programme of Action of Liberia (cf. Republic of Liberia 2008), agriculture employs about 70 percent of the population while it accounts for about 37 percent of GDP as reported by the World Bank (2019). According to the FAO, agricultural output is dominated by rice and rubber, followed by cassava. Irrigation takes place during the dry season, between November and April (cf. FAO 2019b).

In Sierra-Leone, average annual precipitation accounted for 2,526 millimetres in 2014 according to Aquastat (2019) and 60,6 percent of the population was employed in the agricultural sector. 55 percent of the land area was used for agriculture in the period 2014-16. 60.28 percent of the GDP depends on agriculture (World Bank 2019). Agricultural output is dominated by rice, cassava and pulses. In Sierra Leone, the total area equipped for irrigation amounted to only 29,360 ha in 1992 according to the FAO (2019b). Irrigated agriculture is poorly developed and only 1,000 ha were actually irrigated in the same year. During the dry season, from December to April, temporary crops are irrigated according to the FAO.

In Chad, agricultural land accounted for 40 percent of land area in 2014 and average annual precipitation for 322 millimetre in the same year (cf. Aquastat 2019). According to the World Bank (2019), 81.6 percent of total employment worked in the agricultural sector in 2018. In 2016, GDP dependency on agriculture accounted for 49.12 percent. The biggest share of the harvested area is used for millet, followed by sorghum and groundnuts (cf. FAO 2019b). Extreme wet rainfall is predicted to increase by 10-25 percent in southern Chad (cf. Sultan and Gaetani 2016).

5.2.1. Effect of Climate Change on Crop Yield

Due to the fact that agriculture uses about 70 percent of water withdrawals (cf. Siala et al. 2017), it is the most important aspect of the water-food nexus. Growth in population combined with climate change will increase the required food production and thereby the request and usage of water resources. Various studies looked at the effect that climate change has on crop yield which is important for determining the prospective agricultural production necessary to meet the expected future demand.

According to Sultan and Gaetani (2016), statistical crop models can be divided into two categories: models trained on historical yield (taking into consideration simplified measurements such as growing season average temperature and precipitation) and process-based crop models (simulating the main processes of crop growth and development). The latter requires extensive data on the cultivar, management, soil conditions, calibration and validation data but is therefore able to take into consideration the impacts of climate, CO_2 concentrations and other effects and limitations. For a large part of Africa however, the required data is often not available. Furthermore, global research is often concentrated on crop sorts other than the ones most common in Africa (sorghum, cassava, millet). The uncertainties in regional climate change projections and lacking data result in a large range of crop yield projections. Estimations are further hampered by uncertainties regarding the adaption of agriculture to climatic conditions and the unknown response of crops to changes in the environment (cf. Sultan and Gaetani 2016). The variety of results obtained is reflected by various studies, investigating results from numerous crop models. Examining the outcome of 16 publications, Roudier et al. (2011) evaluated that responses of crop yield may vary from -50 percent to +90 percent. In a review by Müller et al. (2010), agricultural production levels range even from -100 percent to +168 percent (cf. Sultan and Gaetani 2016).

The negative impact on crop productivity resulting from climate change is an effect brought about by the increasing temperatures whose rise is projected to be larger relative to precipitation change in climate models. Increased temperature leads to a reduction in the crop cycle duration and bigger evapotranspiration demand, thereby increasing water stress. Drier or moist conditions and enhanced CO_2 concentrations can additionally impact the effect of increased mean temperatures. Due to the vast proportion of rainfed agriculture, a high relation between crop yield and climate variability exists. As a consequence, the regions food production and therefore its food security, as well as economic performance, is put at risk (cf. Roudier et al. 2011, Schlenker and Lobell 2010, Sultan and Gaetani 2016). Carbon fertilization can additionally influence the impact in crop productivity, but differences between crop sorts exist as some are more dependent on and affected by CO_2 fertilization than others. The predicted impact that climate change has on crop yields varies depending on whether CO_2 is accounted for or not and prognoses are more pessimistic for the latter option. However, the growth of C4 plants which are important for Western Africa (such as sorghum, maize and millet) can't be stimulated by the usage of such fertilizers (cf. Roudier et al. 2011). Even though the production of other crop types can be increased with the usage of CO_2 fertilization and crop water productivity can be increased by enhancing photosynthesis, negative effects such as a decrease of the protein content need to be taken into consideration when its application is discussed. Taking into consideration various factors, Roudier et al. (2011) reach the conclusion that dry cereals cultivated in Sudano-Sahelian countries[2] will be more affected (-18 percent) by climate change than crops cultivated in Guinean countries[3] (-13 percent). The variables accounted for in this study are the CO_2 fertilization effect, the intensity of the warming scenario, the yield modelling category, the crop type and the area. Cereals are especially

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[2] Including Niger, Mali, Burkina Faso, Senegal and Gambia

[3] Including Benin, Togo, Nigeria, Ghana, Liberia, Sierra Leone, Cameroon, Guinea, Guinea Bissau, Ivory Coast

important for food security as they remain the primary source of energy for people living in sub-Saharan Africa (cf. OECD 2016).

Differences in their response to changing climatic conditions between crops exist. Jarvis et al. (2012) estimated that beans will be affected by the negative impacts of -16 percent ±8.8 via climate change impacts. Cultivation of maize, under future climate conditions, is expected to suffer yield losses (cf. Sultan and Gaetani 2016). According to Schlenker and Lobell (2010), the mean estimate of aggregate production changes for maize accounts for -22 percent. As stated in their paper, the mean estimate of aggregate production changes for groundnut accounts for -18 percent. Taking CO_2 fertilization into account, positive effects are found for the cultivation of groundnut with an increase of mean yields and reduced risks of crop failure in West Africa (cf. Sultan and Gaetani 2016).

Jarvis et al. (2012) used the EcoCrop model to demonstrate that cassava reacted very well to predicted climatic conditions in West Africa. According to their data analysis, cassava is the least sensitive crop in regard to a changed 2030 climate with projected changes in its production of -3.7 percent to +17.5 percent. It may also be used as a substitute for sorghum in areas, where the latter suffers crop losses. According to Schlenker and Lobell (2010), cassava is the only crop (compared to maize, sorghum, millet and groundnut) where there isn't a 95 percent probability that damages will exceed 7 percent.

Climate change has a negative impact on sorghum yields in West Africa but differences between diverse sorts exist. Lowest negative impacts are predicted for "modern cultivars with a short and nearly fixed growth cycle" (Sultan et al. 2014: 11). Jarvis et al. (2012) estimated that negative impacts of -2.66 percent ±6.45 are to be expected by sorghum via climate change impacts. Via CO2 fertilization, negative climate impacts can be reduced and sorghum yields can be increased by 10 percent as shown by a simulation of Sultan et al. (2014) with the biggest benefits in dry regions. According to Schlenker and Lobell (2010), the mean estimate of aggregate production changes for millet and sorghum both accounts for -17 percent. Millet and sorghum are dominated by traditional cultivars which are very sensitive to photoperiod. This sensitivity can constitute a benefit as it allows for flowering at the end of the rainy season and incomplete grain filling could, therefore, be avoided. Additionally, photoperiod-sensitive cultivars would not be as affected by temperature increases because of their reduced crop duration (Sultan and Gaetani 2016).

Even though Liu et al. (2008) predict an increase in yield of millet due to climate change, available per capita calories will decrease in the future for most African countries due to population growth.

A decrease in agricultural productivity will have several effects. It will affect food security as well as the economic income. According to the OECD (2016), Western Africa accounts for 60 percent of the agricultural output in sub-Saharan Africa. 45 percent of the total crop production is attributed to the five most important crops, with maize being the most important one. More than half of the workforce in sub-Saharan Africa is employed in the agricultural sector, and over time, this number has increased. The sector is the most important one for the West African economy. It is hard to predict the exact effect that climate change will have in Western Africa, but consensus exists regarding two predictions: variability in agricultural production will increase and crop productivity will possibly decline. Already now, the frequency of droughts in sub-Saharan Africa is bigger than in other regions of the world. Even though the value of the agricultural output has increased over time, the region remains the one with the biggest problems regarding food security (cf. OECD 2016). While there is uncertainty on the exact influence of climate change in Africa, it is certain that the country is one of the most vulnerable regions to climate variability. The impact of an increase in maximum temperature and a decrease in annual precipitation on the agricultural production of millet will be analysed in more detail in the next step.

5.2.2. CROPWAT Simulation

According to Sylla et al. (2016), continuous and stronger warmings (1.5-6.5 °C) are projected for the region while the development of precipitation is highly uncertain (between -30 and +30 percent). Especially the length of the rainy and the growing season are projected to decrease. This information is used for CROPWAT simulations. Here, the effects of a maximum temperature increase on the irrigation requirements of millet are evaluated. As the biggest country of Western Africa, Chad is chosen as area. According to the FAO (2017), the production of millet and sorghum decreased by 9 and 5 percent in 2017, compared to 2016 and national cereal production was estimated 2 percent below the five-year average of the country.

With data from CLIMWAT, big differences in the precipitation patterns within the country become evident. While precipitation per year accounts for 1080.1mm in the south of the country (station Moundou), only 11.7mm per year are measured by the station in Faya in the north of the country and 371mm of rain are measured in Ati, located in the centre of the country. Irrigation requirements for millet differ accordingly - according to CROPWAT, actual irrigation requirements amount to 223,3mm in Ati, 699mm in Faya and 3,9mm in Moundou. When the maximum temperature is increased by 1°C, actual irrigation requirements increase to 228.1mm in Ati, 4,00mm in Moundou and 712,5mm in Faya. According to these results, the additional average irrigation requirements increase by about 2.5 percent.

Impacts of a decrease of 10 percent in annual precipitation were measured as well. Considering the decrease, the effect on actual irrigation requirements, in fact, did not show any differences for all three stations in the country. This supports the result obtained by the study of Schlenker and Lobell (2010) as well as from Sultan and Gaetani (2016), demonstrating that the main reason for food productivity decline are not precipitation changes but increasing temperatures as evapotranspiration demands increase.

According to this Aquastat, long-term average annual precipitation in depth (mm/year) accounted for 322mm in Chad in 2014. Data on irrigation systems are sparsely available. According to Aquastat (2019), the irrigation potential in Chad amounts to 335,000 ha in 2013. Data on the area actually equipped for irrigation is even more scarce. In Chad, total area equipped amounted to 30,270 ha in 2002 from which only 26,200 (86.55 percent) were actually irrigated (cf. FAO 2019b). Cereals are irrigated from June to October, corresponding to the raining season, except wheat. Vegetables, however, are cropped and irrigated from December to April.

In Chad, millet is sowed from May until July, grows in August and is harvested in September and October (cf. FAO 2018). Accordingly, irrigation is required from June until October with differences between different regions of the country. Studies predict that dry spell periods are projected to lengthen, increasing the need for irrigation. In 2017, the total harvested area for millet in Chad amounted to altogether 1,165,459 ha, according to the FAO database. Depending on where the crop is grown, irrigation requirements vary according to the precipitation pattern as demonstrated above. Due to missing information, it is hard to estimate actual numbers on irrigation equipment. Based on the data available, however, technical and maintaining issues are evident and increased irrigation predicted to be difficult. Food is scarcest between June and September, but total affected population may vary depending on the harvest outcome and market prices (cf. US aid 219).

Agricultural water withdrawal in Chad, according to Aquastat, accounts for 0.6722 (10^9 m^3/year). The calculated irrigation requirement for millet (based on the total harvested area and irrigation requirements of 4mm in the south of the country, where most millet is grown) amount to 46.6 x 10^6 m^3/year and therefore account for about 0.7 percent of water withdrawal, taking into consideration a 1°C increase in maximum temperatures. This equals an increase of 2.5 percent of water withdrawals needed for irrigation in order to produce the same level of millet compared to temperatures before the modelling. Assuming that the usage of irrigation systems does not increase nor is expanded and additional water resources are not available, increased temperatures would, therefore, reduce yield production for 2.5 percent because fewer areas can be cultivated with the same amount of water. According to population growth and future predictions however, food production in sub-Saharan Africa needs to double in order to meet the growing demands.

According to the FAO database, millet yield was estimated to amount for 5,665 hg/ha in 2017. A reduction of 29,137 ha of the harvested area would, therefore, sum up to a decrease in 165.06 x 10^6 hg in total. Since millet is mainly used for domestic consumption and not exported, it is an important staple and a decrease in its production affects food security.

Irrigation potential in ha is actually much higher than the amount of ha currently being irrigated. The same holds for total renewable surface water currently available. According to AQUASTAT, total renewable surface water is estimated to be 44.2 (10^9 m^3/year). If assumed that only 30 percent of renewable water is available for human use and the percentage of water used for agriculture (provided by AQUASTAT) accounts for 76.42, then total renewable surface water available for agriculture thereby is estimated to be 10.1 (10^9 m^3/year) and therefore much bigger than the sum actually available.

5.2.3. Impact on Food Security

As shown in the previous chapter, crop yield production is predicted to decrease in the future. This outlook combined with the need to increase irrigation, does not only influence the economic situation of farmers but also the food security of the region. It is hard for the food production to maintain the growth rate needed to meet the food demands of the growing population. Availability of food in Western Africa is therefore predicted to decrease on average 500 calories per person resulting in up to 40 percent of cereal demand that will have to be covered by imports (cf. Kotir 2011). This issue will be further affected by the decreasing productivity, politics, conflicts, financial markets (illustrated by the example of cashew nuts' price fluctuations), health aspects, poor infrastructure, etc.

Globally, the major amount of additional food that is needed in the future is predicted to be produced via an increase in productivity, rather than an expansion of cultivated land. Looking at the comparison of annual average crop yields (tonnes/ha), it becomes evident that great potential to increase their harvest exists for low-income countries. While maize yield there accounted for 1.54 tonnes/ha on average, the same crop sort accounted for 8.99 tonnes/ha in high-income countries, and the global average amount to 4.87 tonnes/ha (cf. FAO 2017). With heightening their productivity, it is likely that low-income countries can account for a much bigger share of requested food demand with local production. In the past however, yield production growth in sub-Saharan Africa has mainly been achieved by expansion of the cultivated land. Until 2025, total agricultural production is expected to rise by 2.6 percent with an increasing share being attributed to improved productivity. Food demand however, are projected to increase by more than 3 percent per year until 2015. Imports will, therefore, remain an important factor in ensuring that the regions food demands are met. Whether or not yield gaps can be closed in the future, remains a challenge (cf. OECD 2016). According to Rosa et al. (2018), investments and increased usage of irrigation could increase food production by about 40 percent, allowing to feed additional 450 million people and significantly decrease imports. The chances of rainfed agriculture being highly productive however is reduced by growing rainfall variability, increasing risks and unpredictability (cf. FAO 2017).

In Chad, the situation is additionally worsened by ongoing conflicts and closure of the border with Libya in the north of the country. Household incomes have fallen due to the conflict resulting in limited food consumption (cf. Famine early warning systems network

2019). Even though the country's economy depends on its agricultural production, more food is imported than exported already. Taken into consideration yield reduction projected by the existing literature, a mean decline of 13 percent as well as greater year-to-year yield variability is estimated for Western Africa which would even increase required imports and effects the income variability, listed as a driver for migration (cf. Roudier et al. 2011). Most of the harvested area in Chad is used for millet, sorghum and groundnuts, all of them being used mainly for consumption inside the country. A decrease in their production will, therefore, impact local food security and increase the need for imports.

5.3. Summary in Regard to Research Question

Chapter four presented the various challenges of the water-food nexus. Chapter five elaborated that, while climate change will provide a global challenge, pressures such as a growing population, urbanisation and elaborated temperatures will especially effect Africa and Asia. Due to the fact that the economies mostly dependent on agriculture are situated in sub-Saharan Africa, this region is analysed in more detail with a focus on four specific countries: Chad, Guinea Bissau, Liberia and Sierra Leone. These countries agro-economies have adopted to the climate, focussing on cereals and crops resistant to dry conditions, namely maize, millet and sorghum. In order to investigate the effect that climate change will possible have on them, the existing literature is analysed in combination with a CROPWAT simulation. Significant, projected yield reductions are the result of various studies, however, the amount of predicted reduction varies. Reductions of 8 percent in all Africa are predicted by Knox et al. (2012), while mean yield reductions in Western Africa are projected to amount to 13 percent by Roudier et al. (2011). Essential for these reductions are increasing evaporation demands of plants due to an increase in temperature. The CROPWAT simulation came to the conclusion that an increase in maximum temperature of 1°C leads to an increase of additional irrigation requirements by about 2.5 percent. The predicted reduction in yields affects both food security and the economy of the countries and the gap between production increase and growing food demand will need to be covered by imports.

Investments in water are essential for enabling an increase in agricultural performance, but the already scarce resource will be demanded more and more by a growing number of population. Water resources are increasingly requested by urban areas due to the growing amount of people living there and the competition between agriculture and urbanised areas is likely to increase in the future. Estimating the effect that climate change has on water resources is difficult as the development of precipitation patterns is hard to predict and project. Fluctuation in rainfall patterns will possibly increase, with a decrease in mean precipitation and an increase in extreme precipitation (cf. Sylla et al. 2016, Kotir 2011). In order to achieve the necessary increase in agricultural efficiency, the increased usage of irrigation methods will be of crucial importance.

6. Water-Food Nexus and Climate Migration

The following chapter evaluates the relation between the water-food nexus, agro-economy and (climate) migration. Slow-onset events are difficult to determine as a reason for migration because of their connection with additional changes in the social and economic surroundings (increasing the attraction of the urban area via increased economic opportunities, declining wage levels, etc.). However, there is evidence for environmental factors being at the root of these developments, resulting in migration (cf. Barnett and Webber 2010).

As discussed above, literature provides significant results on the sensitivity of crop yields to climate change and increasing temperatures affect yields, leading to a decrease in average agricultural yield production in West Africa (cf. Schlenker and Lobell 2010, Knox et al. 2012). Due to the regions high dependency on agriculture (economically and for their own food production), reductions in crop yields will have an impact on peoples life. Because of the big economic dependency, the affected population will need to look for job alternatives in order to maintain their living conditions and migration presents a possibility to do so. People will likely move to urban areas, if their possibilities are not restricted by financial means. Evidence (cf. Cattaneo and Peri 2016, Black et al. 2011) exists, that an increase in temperature will lead to increased migration especially in middle-income economies, whereas poor countries and the low-income population do not have the means to migrate and the affected population, therefore, stays at their original location. This can have a dampening effect on migration in the investigated countries. Additionally, Zickgraf et al. (2016) provide evidence that migration decreases during severe drought years as the financial resources needed for migration cannot be raised.

Environmental factors have always been a cause of migration although it is often hard to isolate them from social, political and economic factors. Climate change effects already existing drivers for migration, especially economic, environmental and political drivers. Environmental changes have the biggest impact on the macro-level, which describes influences that can’t be influenced by individuals themselves (cf. Kumari Regaud et al. 2018). Migration due to changes in the environment can be positive for the population as well as negative, as it can allow the affected community to react to changing conditions via increased mobility and temporary migration and to take advantage of economic opportunities (cf. IOM 2018, Cattaneo and Peri 2016). One example for a community taking advantage of this is the Economic Community of West African States (ECOWAS), which will be discussed in the next chapter.

When examining the relationship between agriculture and climate migration, Cai et al. (2016) reach the conclusion that an increase in temperature has a significant positive effect on migration, however statistically significant only for agriculture-dependent countries. Therefore, both reduced crop yields and increased migration are correlated with higher temperatures. The study also proves that the GDP of agriculture-dependent economies is significantly more negatively affected by an increase in temperatures than the GDP of non-agricultural countries. The authors of the mentioned study reach the conclusion that each 1°C increase in temperature leads to a 5 percent increase in migration in agriculture-dependent countries. In countries where the GDP is not as dependent on agriculture, there is only a 0.4 percent increase in migration per degree increase in temperature. The migration flow itself is largely determined by an already existing network. Family members living abroad and friends and people of the same origin living in a different country may determine where migration leads to and act as pull factors. Cai et al. (2016) further reach the conclusion that increasing temperature tends to intensify migration at already established migration routes but doesn't affect migration to countries that weren't seen as an envisaged destination before. This results in presenting challenges to already migrant-receiving countries such as Chad, Côte d'Ivoire, Burkina Faso, ….

The authors find that extreme heat above 30°C significantly reduces the GDP of agriculture-dependent countries but it doesn't have this effect in countries that are not as dependent. Evidence on the relationship between temperature and income is also provided by Barrios et al. (2010) and Dell et al. (2009) who show that weather anomalies significantly impact the GDP per capita. This finding is supported by Marchiori et al. (2012) who show that due to the effect of weather anomalies, wages decrease and this dependence negatively affects the GDP of affected countries. Economical aspects can be important drivers for migration, as analysed in the next step.

6.1. General Reasons for Migration

Black et al. (2011) define five main categories for drivers of migration: environmental, political, social, economic and demographic. The environmental aspect includes the

exposure to natural hazards and ecosystem services. Political factors include discrimination, governance and insecurity. Social influences contain education and family obligations. Economic factors include employment opportunities, income and prices. And demographic factors include the population size, its structure and density. Climate change can have an indirect effect on migration as it affects the mentioned drivers and maybe even increase conflict probability, an effect which is often discussed in literature (cf. Abel et al. 2018, Eckstein 2010, Post et al. 2015, Black et al. 2011).
Environmental, social, political and economic factors are interlinked and present the root causes of migration. Due to the variety of factors involved in the decision of migration, studies can result in misleading conclusions if not all factors are taken into consideration. Push and pull factors are important aspects that need to be considered. Push factors refer to the circumstances at the original location, reasons why someone migrates, whereas pull factors refer to the factors at the envisaged destination, making the area attractive as final location. The push-pull theory explains why migration often leads to large urban areas as a bigger amount of economic opportunities exists compared to rural areas (cf. Kumari Regaud et al. 2018). Several impacts affect the decision of migration and several forms of it exist. Migration can take place voluntarily or forced, one can move within the country or abroad, it can be temporary or eternal. All these factors need to be taken into account when talking about migration (cf. Gemenne et al. 2017).

Personal factors that affect the decision to migrate include age, sex, educational level, wealth, marital status, attachment to a certain place, access to financial capital, existing institutions, etc. (cf. Black et al. 2011, Kniveton et al. 2012). Migration is impeded by various factors, such as the costs of moving, legal and administrative barriers, religion and culture in the envisaged destination, access to means of transportation, etc. (cf. Black et al. 2011). Most of these factors are independent of the environmental situation. However, the political and institutional framework may change due to a change of the environmental conditions (cf. Black et al. 2011). Although several drivers for migration exist, two main reasons and drivers are identified which are of economic nature: first, the income level difference between the origin location and second, the envisaged destination and the income variability in the origin area. Environmental risks not only reduce the income but also affect the reliability of it, which may becomes an additional driver for migration or even hinders migration in reducing individuals ability to move to a different location (cf. Black et al 2011). Both of these economic drivers are affected by climate change, especially in countries with a high dependency on agriculture (cf. Bie Lilleør and Van den Broeck 2011, Cai et al. 2016). Marchiori et al. (2012) analyse the effects of weather anomalies on migration in sub-Saharan Africa and their model estimates that environmental changes will lead to lower rural wages due to their effect on agricultural productivity. Agriculture is especially important for rural areas as it is a relevant source for income and employment. As a result of lower rural wages, weather anomalies will then increase the movement from workers from rural to urban areas. Weather anomalies thereby significantly affect the mentioned reasons for migration and can additionally be seen as key effects of urbanization and the attraction of urban areas in the home country may weaken international migration. The example of the trend of urbanization due to changes in environmental conditions is especially important for sub-Saharan Africa, as no evidence for the same effect exists for the rest of the world according to Barrios et al. (2006).

6.2. Magnitude and Direction of Migration in Western Africa

As several studies show, migration in Western Africa takes place especially internally within a country or within the region (cf. Cattaneo and Peri 2016). Cattaneo and Peri (2016) examine the outcome of a warming climate on migration and conclude that only non-OECD countries face higher migration rates due to increased temperatures, but migration to OECD countries does not increase. Given the fact that migration takes place mainly because of changes in the push factors (decrease of income and worsening of wage predictability), affected people will look for better economic opportunities in similar economies in consideration of their given constraints. The authors furthermore elaborate that migration of middle-income countries takes place especially to close locations (<1000km) while poor countries experience a decrease in migration. Poor countries are defined as countries where the income per capita is lower than 1,500$ per person which includes many countries in sub-Saharan Africa, such as Guinea-Bissau and Liberia. For the countries investigated this would mean that migration in Chad and Sierra Leone is more likely to take place than for Guinea-Bissau and Liberia.

As stated above, increased migration will likely take place at already established migration routes. Additionally, urbanization increases when agricultural production decreases, leading to the growth of the urban population. In sub-Saharan Africa, migration represents a bit less than one-third of urban population growth (cf. Kumari

Regaud et al. 2018). Increased urbanization will lead to additional challenges and requires improved logistical measures, for example for the treatment of wastewater, sanitation facilities and infrastructure, further increasing the challenges of the water-food nexus. Urbanization is accompanied by a shift in consumption and dietary patterns and in urban areas, demand for processed and prepared food increases together with the request for fruits and vegetables while the share of pulses and cereals decreases. Non-agricultural activities related to the food sector (such as processing, logistics and retail) are developing and estimated to grow further. These activities are important for new employment possibilities in rural as well as urban areas and can influence the transformation of economies into less agriculture-dependent countries (cf. OECD 2016).

Figure 3 shows the major migration flows in the region and their direction (excluding Chad). According to Awumbila et al. (2014), while all countries in Western Africa are both sending as well as receiving migrants, the countries receiving the most migrants are Ghana, Côte d'Ivoire, Nigeria, Guinea and the Gambia.

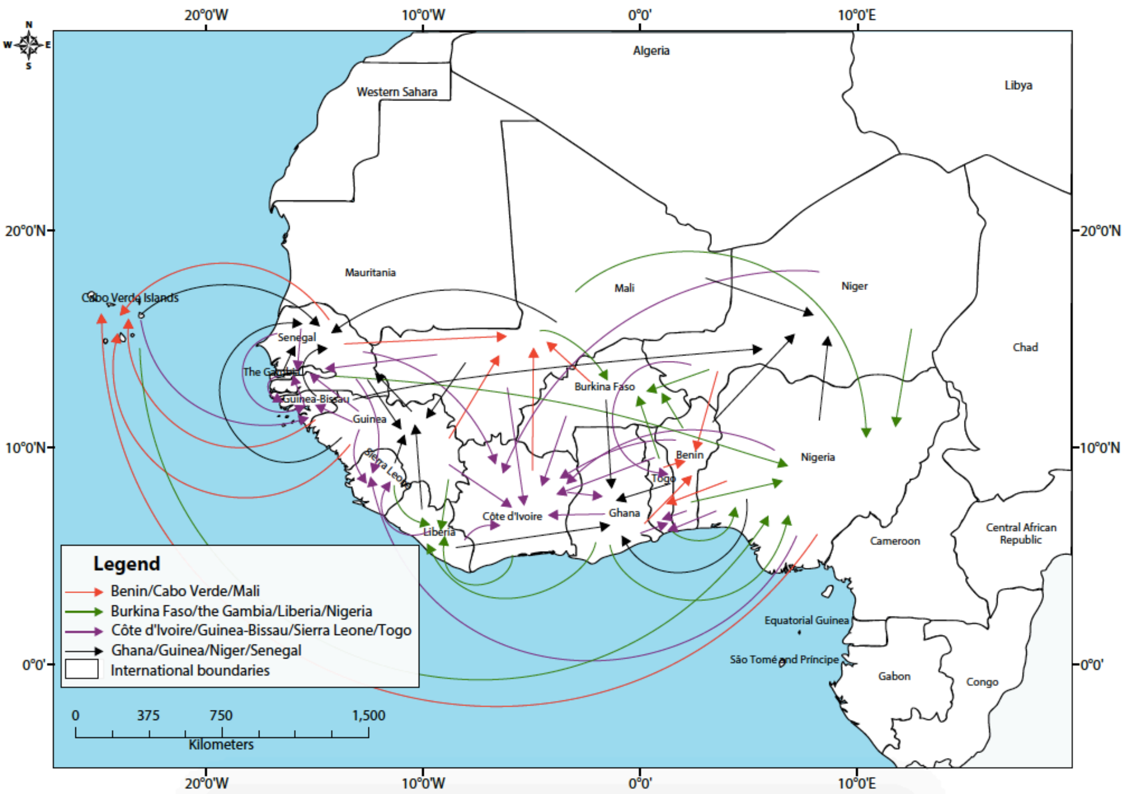

Figure 3: Major migration flows in the ECOWAS region.
Source: Awumbila et al. (2014).

Intraregional labour migration in the ECOWAS region takes place especially from the north to the south and to mineral-rich and plantation-rich countries. Internal migration often occurs when people seek on-farm employment during the harvest season. Periodical migration, therefore, takes place internally, depending on the harvest and whether or not there is a shortfall in cereal production. According to the famine early warning systems network (2019), there is a peak in non-agricultural labour demand from February to April, a peak in labour demand for land preparation from April to June and a peak labour demand for weeding from July until September. This, so-called circular migration, is an important characteristic of the region as it takes place internally according to the requested labour demand and supply. According to Kumari Regaud et al. (2018), internal migration worldwide in 2009 (estimated at 740 million people) was three times bigger than international migration and it is likely that the number is even higher today. It is hard to estimate a concrete number of internal migrants and they may depend on the number of administrative units existing in a country with migration being higher in regions with more territorial administrative authorities. Intraregional movements in the ECOWAS region are estimated at 7,5 million persons (cf. Awumbila et al. 2014). An increase in migration of 5 percent (as estimated by Cai et al. 2016 due to an increase of 1°C) would lead to 375,000 more migrants in the region.

Table 2 shows the projected percentage distribution of the population in selected countries and per age group, visualising the big share of young population. According to the OECD (2016), about 17 million people are entering the labour force annually over the next decade in sub-Saharan Africa and two-thirds at most will work in the non-agricultural sector. The fact that the share of the population in working-age is bigger than the share of the non-working-age population shows that big economic potential is present in all these countries.

Table 2: Percentage distribution of the population in selected age groups

	2015				2050				2100			
Country	0-14	15-59	60+	80+	0-14	15-59	60+	80+	0-14	15-59	60+	80+
World	26.1	61.7	12.3	1.7	21.3	57.2	21.5	4.5	17.7	54.0	28.3	8.4
Chad	47.7	48.3	4.0	0.3	36.4	58.2	5.4	0.4	22.7	60.7	16.5	2.2
Guinea-Bissau	40.8	53.9	5.3	0.3	31.2	60.5	8.3	0.5	21.5	60.8	17.7	2.1
Liberia	42.3	52.9	4.8	0.3	32.0	60.0	8.0	0.5	21.4	59.9	18.7	2.7
Sierra-Leone	42.4	53.2	4.4	0.2	29.3	63.1	7.7	0.4	19.4	61.0	19.6	2.1

Source: DESA, 2015

Taking into consideration the fact that the share including the working population is the biggest and even increasing until 2050, one can estimate that the share of the population considering migration is growing if economic possibilities in their country of origin do not increase. Additionally, migration studies suggest that migration takes place especially among young people. As can be seen in Table 2, the share of young people in the examined countries is bigger than the global average (cf. Kumari Regaud et al. 2018). Table 3 provides estimates (medium variant) on the number of population living in chosen countries.

Table 3: Total population by country 1950, 2015, 2030, 2050, 2100

	Population (thousands)				
	1950	2015	2030	2050	2100
Chad	2 502	14 037	21 946	35 131	68 927
Guinea-Bissau	535	1 844	2 541	3 564	5 489
Liberia	930	4 503	6 414	9 436	15 977
Sierra-Leone	1 944	6 453	8 598	11 392	14 489

Source: DESA, 2015

In its report, Kumari Regaud et al. (2018) present three different scenarios for migration. The estimated amount of migrants depends on whether the “pessimistic”, the “more inclusive development” or the “more climate-friendly” model is used. High greenhouse gas emissions, the worst expected outcome, leads to an estimate of 55-86 million migrants in sub-Saharan Africa. A more optimistic approach, including improved development pathways, leads to an estimate of 40-65 million migrants. The best possible development, considering lower global emissions, leads to an estimate of 15-35 million migrants in the area. In areas with better or worse climatic conditions, climate “in-migration” or “out-migration” takes place and hotspots develop. “In-migration” will likely lead to cities, cooler highlands and areas with favourable climatic conditions while “out-migration” will take place in dry of flooded areas, that do not provide good livelihood conditions. The two types of hotspots will develop and increase in size especially between 2030 and 2050 (cf. Kumari Regaud et al. 2018).

Depending on the type of scenario, the projected amount of climate migrants in West Africa differs. The estimated average amount of internal climate migrant by 2050 when considering the pessimistic scenario accounts for 54,4 million people, with a minimum of 44,8 million and a maximum of 64 million migrants. 38,5 million people are expected to become internal climate migrants when considering the more inclusive development with a minimum of 32 million and a maximum of 45 million people. 17,9 million climate migrants are estimated when considering the most climate-friendly scenario, with a minimum of 11,1 million and a maximum of 24,8 million people (cf. Kumari Regaud et al. 2018). The authors examined several global regions and sub-regions and came to the conclusion that the most internal climate migrants are expected for West Africa due to the expected high impact of climate change in the region.

The long-term development of migration is hard to predict due to several factors. First of all, most studies concentrate on a short timeframe and long-term investigations barely exist. Second, as discussed in this thesis, the exact impact and extent of climatic change in the region is still not clear and hard to predict. Variations in precipitation and growing periods impede predictions and forecasts.

6.3. Current Situation and Outlook of Migration for Specific Countries

Especially the eastern western and southern parts of Chad are hosting internally displaced people. According to the IOM, the country currently hosts about 440,000 refugees and nearly 130,000 internally displaced persons (cf. IOM 2019). Additionally, a significant amount of people may move away from coastal zones to inland Africa (cf. Marchiori et al. 2012). Local resources are increasingly stressed due to the influx of refugees, leading to increased food insecurity (cf. US aid 2019). Migration to and from Chad takes places especially due to unstable political situation in neighbouring countries and the country itself. It is hard to separate environmental from political factors as they are inseparably linked. The prospective number of migrants will depend a lot on the political situation and on solving ongoing conflicts.

Data about immigration in Guinea-Bissau is rare. According to the ICMPD and IOM (2015), two studies were undertaken in the country in 2009 and 2013. While the first study recorded only 1,316 foreign immigrants in the country, the second study recorded around 55,000 foreigners in a regular situation and 250,000 in an irregular situation. The numbers are hard to validate, but they suggest that Guinea-Bissau acts as an important destination in the region. Most people leaving the country emigrate to the neighboured state Senegal, where they work in groundnut and rubber plantations. In total, according to the study of the ICMPD and IOM, about 180,000 migrants went abroad during a five year time period. Portugal is a popular country of destination, followed by Senegal and Cape Verde. The top source countries of migration are Senegal, Guinea, other southern countries and the Gambia. An increase of outmigration of 5 percent as result of an increase in temperature would lead to about 9,000 more people emigrating.

The two main source countries of migration to Liberia are Guinea and Ghana, while the top destination countries are Guinea and Côte d'Ivoire. Increasing political and economic stability will likely increase immigration in the next years. General estimates from national authorities assess 500,000 national residing abroad. However, data sources are not identified and the estimate should be taken with caution. Foreign residents living in Liberia were estimate at about 68,000 in 2008. 5 percent more people leaving the country would lead to about 25,000 more emigrants, but as already stated, the number has to be regarded cautiously (cf. ICMPD and IOM 2015).

According to data from 2004, 97 percent of foreigners in Sierra Leone originated from West African countries, mainly Guinea and Liberia and accounted for about 89,800 people (cf. ICMPD and IOM 2015), with most of them being employed in the mining sector. Top destination countries for emigration are Guinea and the United Kingdom. About 100,000 migrants immigrated to Sierra Leone, and about 180,000 people left the country (cf. ICMPD and IOM 2015). An increase of migration of 5 percent would end up in about 9,000 more people leaving the country.

6.4. Summary in Regard to Research Question

There is a significant correlation between an increase in temperature and an increase in migration and temperatures above 30° significantly reduce the GDP of agricultural-dependent countries (cf. Cat et al. 2016). This is of high relevance for the examined countries, as their economies rely on agriculture. Nevertheless, the effect may decrease in low-income countries, as people do not have the financial means to migrate (cf. Cattaneo and Peri 2016). Even though the results and trends found in diverse studies and articles all support the argument that migration in Western Africa will take place mainly due to changes in the mean temperature and precipitation pattern, low income of the population may damp the effect. The fact that moving from a rural to an urban area in the same country is less costly, increases the importance of internal migration even though the economic benefit may is smaller compared to migration to a different country. As urbanization increases, cities such as Monrovia (Liberia), Bissau (Guinea-Bissau), Freetown (Sierra Leone), Kenema (Sierra Leone), N'Djamena (Chad), Moundou (Chad) and Sarh (Chad) will experience a growing number of inhabitants.

Taking into consideration the possibility given by the Economic Community of West African States (ECOWAS) region, a lot of factors have been considered and measures provided to support people in their search for better economic opportunities. Here, migration is seen as adaption strategy to climate change with both benefits and challenges. As a possible measure to mitigate climate change, it is important to enable migration as a potential response to changing conditions and to enable the population to adapt to changing environmental circumstances.

If people can afford it, migration is predicted to take place intraregional, leading to close locations (<1000km). In the given example, migration flows would increase especially among the Guinean countries, reaching from Ghana up to Mauretania. In Figure 4, the estimated radius of 1000km was used in order to visualize the reach that migration is predicted to have. In Chad, migration can lead from Kongo in the south up to Liberia in the north. Countries in the west such as Guinea, Sierra Leone, Senegal and Côte d'Ivoire would be affected the most especially where migration routes are already established. As migration is predicted to take place from north to the south, the mentioned countries are once more favourable destinations for immigrants.

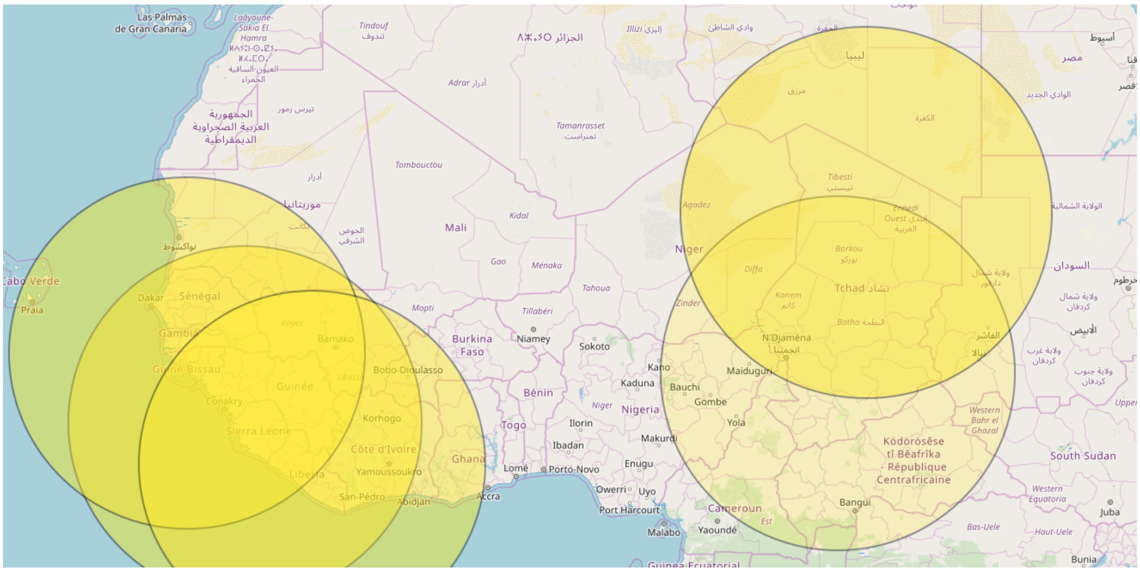

Figure 4: Scope of migration in selected countries.
Source: own depiction

Periodical fluctuations in the amount of immigrants exist due to the importance of circular migration in the region. The dimension of migration, however, is hard to estimate. An increase of 5 percent (based on estimation by Cai et al. 2016) would lead to 375,000 more migrants in the region, while Kumari Regaud et al. (2018) estimate that under the worst climatic scenario, migration could lead to 45-64 million migrant in Western Africa. Under the most climate-friendly scenario, about 11-25 million migrants are estimated. An increase of 5 percent due to elevated temperatures would result in additional 555,000-1,25 million migrants. As described, the future development does not only depend on climatic conditions, but also political aspects and legal institutions. In the given example, resolving conflicts is especially important for Chad, currently hosting about 4400,000 refugees. The description of destination and source countries for Guinea Bissau (emigrants leaving to Senegal, immigrants coming from Senegal, Guinea and Gambia), Liberia (emigrants leaving to Guinea and Côte d'Ivoire, immigrants coming from Guinea and Ghana) and Sierra Leone (emigrants leaving to Guinea, immigrants coming from Guinea and Liberia) demonstrate the importance of intraregional migration.

7. Policy Instruments

Aiming at producing crops that are less dependent on weather anomalies can have a significant impact on the agricultural output, food security, the wage level and thereby impact incentives for migration. The same is true for the improved and enhanced usage of irrigation methods. Agricultural development, however, is often obstructed by an unstable political and institutional framework. Consistency in political measures and focusing on the long-term development is a key factor in defining the sectors future development (cf. OECD 2016). Causes rather than symptoms of migration need to be placed in the centre of political methods.

7.1. Policies and Institutions Emplaced

The Economic Community of West African States (ECOWAS) governments tries to benefit from peoples movements in providing possibilities for labour migration within the region. In fact, in 2006, 84 percent of migration from West Africa was directed towards another country in the region, making clear that West African movement is mainly intraregional (cf. Awumbila et al. 2014). These movements, visualized in Figure 3, are seven times greater than international migration. The protocol establishing ECOWAS provides the opportunity for the population of the Community to enter, reside, and establish businesses in Member States (ICMPD and IOM 2015). It thus is an important tool in providing the opportunity for circular migration which is important for the region.

By the establishment of the Comprehensive Africa Agriculture Development Programme (CAADP), agriculture was recognized as an important factor to improve nutrition and increase food security. The programme provides a framework for agricultural transformation and identifies possible development methods (cf. UN 2019).

In 2001, the Conference of the Parties (COP) established the least developed countries (LDC) work programme which includes national adaptation programmes of action (NAPAs). This process is supported by the United Nations Development Programme (UNDP) and should help countries in addressing arising challenges due to climate change and to identify their needs for a successful adaptation to climate change. Additionally, a Least Developed Countries Fund (LDCF) was established to provide financial support for the implementation of NAPAs and an LDC Expert Group (LEG) with the objective to provide knowledge and support to the LDCs (cf. UNFCCC 2019). In 2008, Guinea Bissau submitted its report, focussing on the implications and negative impacts of droughts and salination of soil on migration. Additionally, measures against the emigration are proposed. Migration flows that are observed are movements of farmers from the south of Guinea Bissau to the North part of the Republic of Guinea and from the highlands to the lowlands (small valleys), especially in the East, the Northeast and some parts of the South (cf. Republic of Guinea Bissau, 2011). The NAPAs of all four examined countries have identified the need to enhance, expand and/or develop irrigation systems for agriculture. As stated in chapter four, financial means often damp the implementation or maintenance of irrigation systems. The promotion of low-cost watering systems, therefore, needs to be seen as an objective for potential adaptation measures.

Already, countries struggle in providing enough food for the growing demand due to a change in dietary patterns and population growth. Lacking growth in food production results in an increase of wheat, rice and poultry imports. Farmers have little incentives to invest in their agricultural methods if they do not sell their food due to cheaper imports being sold on the local markets. Political measures such as import tariffs were applied in order to protect local producers. Especially intra-regional trade is a desirable development for many countries in the region. In 2015, the tripartite free trade areas was established between the Common Market for Eastern and Southern Asia (COMESA), the East African Community (EAC), ECOWAS and the Southern African Development Community (SADC) with the aim to further reduce tariffs and positively influence trade in the region (cf. OECD 2016). In order to ensure that development such as increased irrigation methods take place, support and protection of local farmers is needed. There have been fertilizer subsidy programmes emplaces in various African countries but often the costs of these programmes are often bigger than the benefits which is why their applications are disputed (cf. OECD 2016).

The Lake Chad Basin Sustainable Development Program, PRODEBALT, established in 2007, aims for the "rehabilitation and conservation of the productive capacities of Lake Chad basin ecosystems" (OECD 2017: 205). The adaption of the system to challenges brought by climate change and its effects on the population depending on the water resources are goals of the program.

The mentioned programs and institutions are just a number of examples, proving that the region is trying to counteract the adverse effects that climate change and scarce water resources have on agriculture. These methods try to get the most out of the agricultural potential and regional characteristics such as circular migration.

7.2. Possible Political Responses to Challenges

According to Cai et al. (2016), policies addressing climate migration are especially efficient if focusing on agriculture-dependent countries and the people employed in this sector. As reported by Kumari Rigaud et al. (2018), the number of people being forced to migrate due to environmental distress can still be reduced. Action in the following three areas is predicted to be especially effective in doing so:

1. Cut greenhouse gases:
   By reducing emissions now, stress can be taken from ecosystems and peoples livelihoods. At the present, the possibility still exists to provide opportunities and chances for people to remain at their country of origin and to improve their living conditions. Without a reduction in emissions, the reports' pessimistic scenario is more likely to become reality.
2. Embed climate migration in development planning:
   So far, climate migration is only sparely accounted for in long-term planning and policies. The earlier the scenario is dealt with, the better can its preparation take place and its effects can be accounted for in institutional and legislative frameworks.
3. Investment in order to improve the understanding of internal climate migration:
   Financial means are needed in order to monitor migration movements and to establish measures enabling the collection of data on climate migration. The availability of data can determine whether or not it is possible to successfully handle migration streams and can give indications for new streams that are slowly developing.

Encouraging off-farm work, urbanization and structural upgrading are mentioned as additional possibilities to mitigate climate migration. Shifts in the demographic, economic, and social context may change the relationship between future climate and migration (cf. Cat et al. 2016). Increased irrigation and improved seeds are possible measures in order to mitigate the effects of climate change on agriculture (cf. Henderson et al. 2017). Especially due to a predicted shortening in the growing-phase of crops, the efficiency of agricultural seeds needs to be increased. Investment in crops more resistant to weather anomalies is a policy recommendation supported by various authors (cf. Marchiori et al. 2012, Schlenker and Lobell 2010, Knox et al. 2012). The application of techniques for improving soil fertility is an additional method mentioned to increase agricultural productivity. The usage of mineral fertilizers, when applied cautiously and balanced, together with additional techniques that improve soil health are effective in restoring and enhancing soil fertility. Financial support may be necessary as fertilizers are often not available to farmers due to high costs and their limited financial capacities (cf. OECD 2017).

Strategic investment in the agricultural sector and the sectors involved in food processing would be a benefit for the economic development of West African countries. Improvement in rainfall agriculture requests the minimization of unproductive water evaporation, increasing "soil organic matter content" and to decrease any other soil disruptions in order to increase the water actually available for plants (OECD 2017). All investigated countries have a much higher irrigation potential than the area that is actually irrigated. Due to lacking stability in the political and institutional framework, however, growth and improvement in this economic area are often prevented. Supporting farmers with financial means or via cooperatives with the aim to establish irrigation equipment can sustainable improve food production. Currently, the majority of irrigation equipment is owned by the government but lacking financial resources dampen its actual application.

Hotspots of in-migration will likely emerge but these locations are not pre-defined. With appropriate planning and measures taken early, the establishment of these hotspots can be influenced and shaped by politicians, institutions and international organizations (cf. Kumari Rigaud et al. 2018).

Investments in climate-smart infrastructure, diversification of economic activities generating income and specific financial support for vulnerable groups have high potential to increase the adaptive capacity to changes in the environment. Especially people living in rural areas should be educated and empowered in order to reduce the number of people being forced to migrate. The mentioned measures need to be implemented especially until 2050 because climate migration is expected to increase in the second half of the century when climate impacts become more present. Unless significant political and institutional measures are emplaced, migration is expected to increase in that time period. Still, migration can be seen as an adaption strategy out of poverty and thereby substantially contribute to the development of Western Africa (cf. Kumari Regaud et al. 2018).

7.3. Summary in Regard to Research Question

Challenges of the water-food nexus are influenced by political decisions made in the respective sector. Existing political frameworks constitute good approaches in order to benefit from local (climatic) conditions and cultural circumstances. Organizations supporting intraregional trade and local producers are additional, high relevant, instruments. Circular migration is, without doubt, an important tool in the region and its importance was acknowledged and supported by the establishment of the ECOWAS. Still, adoptions are necessary in order to ensure that a substantial part of the growing demand in agricultural product can be covered by regional products and local producers. Additionally, the mobility of the affected population needs to be ensured. Increasing efficiency and expanding irrigation methods as well as strategic investments in the agricultural sector and other sectors linked to it is required for a successful economic development of the region.

The regions prospective development is marked by challenges, affecting each of the analysed country and their agro-economies. In view of the common challenge, it can be expected that the regional governments will increasingly work together and collaborate, as they are doing partly already. Their political and institutional frameworks can still determine and shape hotspots of (in-)migration. In order to do so, however, additional information on migration streams and its dimensions are needed which requires an increased collection of data.

8. Synopsis

The overall aim of this analysis was to investigate the effect that challenges in the water-food nexus have on climate migration. This question is answered by a cross-sectoral analysis, combining information from databases and various existing studies, the state of the art and simulations carried out based on existing and available data. Information is combined with the advantage to enable cross-sectoral projections and evaluate their connection to each other. While each of the four research questions was shortly answered at the end of the respective chapter, their linkage and relation to each other are essential for this thesis.

The connection between the water-food nexus, climate change, agro-economies and resulting climate migration is complex. Water and food security are a major concern in the respective countries, being limited both by natural variability as well as lacking institutional and technical resources. In the majority of discussed cases, the projected increase in temperature is responsible for a decrease in crop yields, leading to food insecurities and challenges for the countries' economies. With economic factors being essential for the decision to migrate, the concerned population is encouraged to emigrate in order to improve their living conditions. With increasing reliance on imports in order to satisfy existing food demands, the already existing economic dependency as well as systematic uncertainties are likely to increase. In order to reduce poverty in the region and enable sustainable development, however, increase independency and economic development are crucial.

The most obvious finding of this thesis is that climate migration will be crucially affected by challenges of the water-food nexus. Migration due to changing environmental conditions is predicted to take place in the considered countries and its direction can be projected based on the existing literature and current migration streams. It will mainly take place intraregional, from rural to urban areas and from rural to other rural areas, with the preferred destinations being dependent on the agricultural cycle and crop yields in the respective harvest year. Urbanization will continue to provide a challenge and the amount of people living in urban areas will further increase in the future. Capitals and cities of the respective countries (Chad, Guinea-Bissau, Liberia and Sierra Leone) will increasingly be challenged to ensure safe and reliable providence of water resources while at the same time agriculture will be dependent on irrigation methods to a greater extent. Predictions regarding seasonal fluctuations and precipitation levels are more and more difficult to make, leading to more migration to profitable regions which are difficult to determine in advance. Current agricultural patterns are adjusted to the local dry and hot conditions with few irrigation systems being emplaced. However, the increased use of irrigation methods will be crucial in order to boost production efficiency which in turn is required to meet the growing food demand. This thesis provides a cross-sectoral analysis of how the described phenomenon are related to and interact with each other. The diverse factors should not be investigated separately, however, correlations need to be interpreted with caution. The challenges of the water-food nexus affecting agricultural production and resulting in climate migration are influenced by a variety of factors, with only a few of them being elaborated in this thesis. The connection between migration and climate change was analysed in previous papers already, however the connection to the water-food nexus as well as the prospective development of agro-economies provides an advanced approach being conducted in this thesis.

The results of this study indicate that there are several characteristics for migration occurring in the selected region. Population movements take place mainly within the same area and are mainly temporal as they fluctuate with the season and the respective agricultural procedure and production. The dependency on agriculture makes the area highly sensible for climate change and in combination with low income levels, people may be trapped in their living situation. Enabling mobility in order to respond to changing environmental conditions therefore is crucial as adaptation strategy. With strategic investments and political instruments, measures can still be taken in order to enable sustainable living conditions. Considering the economic potential given by the big amount of working-age population, the importance of employment opportunities offsides the agricultural sector will further increase and the seek for employment opportunities away from agriculture will encourage more and more people to move to urban areas. The investigated countries would benefit from a decreasing dependency on agricultural products in order to be less vulnerable to climate change. According to current numbers and studies, between 375,000 and 1,25 million more migrants are to be expected in the area under the most climate-friendly scenario. These numbers can still change, when mitigation measures are taken in the near future and more attention is given to climate migration. Especially capitals and cities such as Monrovia (Liberia), Bissau (Guinea-

Bissau), Freetown (Sierra Leone), Kenema (Sierra Leone), N'Djamena (Chad), Moundou (Chad) and Sarh (Chad) are expected to significantly increase in population size. This outlook should be incorporated into measures of urban planning in order to guarantee resource security in the future. Even if employment possibilities can arise in urban areas, the region will continuously be dependent on agriculture. Investments in irrigation methods and technology as well as high efficient crop sorts therefore are of crucial importance in order to enable successful agricultural production. Cassava was mentioned as possible substitute for other, more vulnerable, crop sorts. These kind of projections and agricultural research enable farmers to improve their planning and adjust to changing climatic conditions. Additionally, attention should be given to sectors related to the food processing as they provide big potential for new employment areas. The existing irrigation potential needs to be used in order to guarantee food security and economic opportunities in the future. Furthermore, political stability is of major importance for migration streams. Successfully managing projected migration flows requires data, which currently if often not available. Investments in the monitoring and documentation of population movements are required in favour of appropriate response measures to be taken. In order to manage and administer climate migration in the future, the underlying causes such as lacking economic opportunities, insufficient agricultural equipment and unpredictable weather circumstances need to be placed in the centre of politics and legal frameworks.

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