FINAL REPORT ON

the creation of three interconnected sectoral simulation models on agriculture, water and energy, customized and parametrized to Cameroon, Uganda and Mozambique

United Nations
Economic Commission for Africa

ACPC
African Climate Policy Centre

WISER
Weather and Climate Information Services for Africa

To order copies of ***Final report on the creation of three interconnected sectoral simulation models on agriculture, water and energy, customized and parametrized to Cameroon, Uganda and Mozambique***, please contact:

Publications Section
Economic Commission for Africa
Menelik II Avenue
P.O. Box 3001
Addis Ababa, Ethiopia

Tel: +251 11 544-9900
Fax: +251 11 551-4416
E-mail: eca-info@un.org
Web: www.uneca.org

© 2021 Economic Commission for Africa
Addis Ababa, Ethiopia
All rights reserved
First printing May 2021

Material in this publication may be freely quoted or reprinted. Acknowledgement is requested, together with a copy of the publication.

The designations employed in this report and the material presented in it do not imply the expression of any opinion whatsoever on the part of the Secretariat of the United Nations Economic Commission for Africa concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

Designed and printed by the ECA Printing and Publishing Unit. ISO 14001:2015 certified.

United Nations
Economic Commission for Africa

ACPC
African Climate Policy Centre

WISER
Weather and Climate Information Services for Africa

FINAL REPORT ON

the creation of three interconnected sectoral simulation models on agriculture, water and energy, customized and parametrized to Cameroon, Uganda and Mozambique

Prepared by Andrea M. Bassi and
Georg Pallaske

21 July 2018

Table of Contents

List of tables

List of Figures

Executive summary

- "Nexus thinking" is an approach that recognizes the critical interdependence of food, energy and water in an increasingly resource-constrained world. Understanding and improving how we manage and use these resources is critical, especially in the face of climate change.

- This project aims to address a specific gap, in that conventional forecasting tools and analyses are often comparatively static (mostly employing linear approaches) and narrowly focus on a sector or a specific set of thematic indicators. The systemic approach employed here considers social, economic and environmental indicators within a sector and links them across sectors to generate dynamic projections that allow policy outcomes to be estimated for all economic actors.

- The work presented in this report entailed the creation of sectoral simulation models for agriculture, energy and water. These models were then connected to one another to carry out a more systemic analysis that represents the nexus approach. Different versions of these models were developed: a template or research version and three customizations at the national level (to Cameroon, Mozambique and Uganda).

- The models are dynamic and represent reality through the use of feedback loops, delays and non-linearity. Specifically, agricultural production depends on the amount of productive agricultural land and the yield per hectare of cropland (both affected by water availability and floods); electricity demand is driven by population and per capita electricity consumption and supply by installed capacity, both thermal and renewable, and the average load factor based on the electricity technology mix (all influenced by floods and droughts in the case of thermal generation); water supply considers precipitation and cross-border inflows, and accounts for the amount of evapotranspiration (reducing the amount of water resources available in the country).

- Three scenarios were simulated: business as usual (BAU), which does not include climate trends; a climate scenario, which uses forecast precipitation variability; and an adaptation scenario, which includes interventions to improve climate resilience.

- In the business-as-usual scenario**,** we see growing population and GDP over time. By 2050, the total population of Mozambique is projected to reach 69.2 million, the population of Uganda 109.4 million people, and the population of Cameroon to increase by 24.4 million to 51.04 million. This will result in higher land use for agriculture, more

Table 1: Climate impacts in the model by type of event

Climate impact	Floods	Droughts
Population affected by extreme events	X	X
Lifetime of agricultural land		X
Productive cropland	X	X
Load factor conventional	X	X
Load factor renewable	X	
Evapotranspiration rate		X
Damage to roads	X	

water consumption and growing energy demand.

- In the climate scenario, the underlying assumptions for population and GDP remain unchanged, but here we introduce a 0.5 per cent increase in precipitation variability (growing over time) compared to the business-as-usual case. Several impacts of climate change are explicitly modelled, as presented in table 1.

- Overall, climate impacts are projected to reduce agricultural GDP by between 12.1 per cent and 16.7 per cent. Furthermore, additional investments in power generation capacity are required to replace capacity that is damaged during flood events.

- The impacts of water scarcity and adverse weather are most visible in Mozambique and reduce agricultural production by an average of about 26 per cent. The reduction in agricultural production compared to the business-as-usual scenario translates into a reduction in value added. Agricultural value added, or GDP, in Mozambique is reduced by approximately 24 per cent on average throughout the simulation period, and reductions for Cameroon and Uganda are 14.2 per cent and 12.4 per cent, respectively.

- Increasing precipitation variability and higher temperatures pose a threat to power generation capacity and impact electricity generation efficiency. The forecast climate impacts lead to total power generation capacity in the climate scenario being slightly higher compared to the baseline. Mozambique is projected to need an additional 25MW of capacity to compensate for climate impacts on power generation, while Uganda and Cameroon will require an additional 4MW and 16MW, respectively.

- The adaptation scenario assumes the implementation of interventions to reduce the vulnerability of climate impacts. To increase the resilience of the agricultural sector, a transition towards organic farming practices is simulated. In the energy sector, the implementation of decentralized renewable energy aims to reduce the vulnerability of power generation capacity to climate impacts. Finally, to increase water security, a transition to drip irrigation is assumed.

- The transition towards organic farming increases the productivity of the agricultural sector considerably. While the amount of total cropland remains the same as in the climate scenario, total annual agricultural production increases on average by 5 per cent. The highest impact is observed for Cameroon, where total agricultural production increases by 3.12 million tons by 2050.

- In addition to beneficial economic impacts, the transition to organic farming increases employment creation in the agricultural sector. The increase in employment in agriculture is projected to be 2.5 per cent for all three countries, which is equivalent to 63,410 additional jobs in Cameroon, 77,770 additional jobs in Uganda and 44,080 additional jobs in Mozambique.

- The transition to renewable energy increases the resilience of the power generation sector in the face of climate change impacts and adverse climate events. Total electricity generation in the adaptation scenario is on average between 1.5 per cent and 2.8 per cent higher than in the climate scenario, which corresponds to a value of up to 245 additional hours (or approximately 10 days) of electricity availability per year.

- The decentralization of the power grid reduces climate-related damage cumulatively by between 38 MW and 500 MW in the three countries. The increase in electricity production and the reduction in physical damage indicate that the electricity generation sector is less vulnerable to the impacts of climate change.

- Projections for the water sector indicate that the introduction of efficient (drip) irrigation has the potential to reduce water consumption significantly and boost productivity. The most significant savings are achieved in Mozambique, where introducing drip irrigation yields average water savings of 27.9 trillion cubic metres per year over a 30-year period. If water savings are used to irrigate additional cropland, the total amount of cropland could be increased by between 12.8 per cent and 14.4 per cent (assuming that the same amount of water is used, when water efficiency increases, the number of hectares irrigated can also increase).

- Several synergies emerge when linking the agriculture, energy and water models.

- The implementation of drip irrigation reduces the pressures on water resources and makes water available for other purposes (e.g. domestic consumption, livestock, industry, etc.), or for additional agricultural production. In other words, it removes a bottleneck for the agricultural sector and increases its resilience. Drip irrigation also significantly reduces the energy requirements for water pumping, which reduces total energy demand.

- The decentralization of power generation capacity benefits employment creation. The generation of power through solar and other small-scale renewable sources would spur the creation of employment to maintain those installations and contribute to improved productivity in rural areas.

- Using a nexus approach allows potential synergies and bottlenecks to be identified that could render a project (or an investment) more or less attractive or economically viable. Positive synergies have been found, with savings emerging in water and energy use that both increase climate resilience and at the same time lead to stronger economic performance for the sectors. Similarly, cross-sectoral impacts emerge for health and livelihoods, where investing in climate adaptation not only improves climate resilience, but also increases social and economic resilience for the local population.

1. Introduction: climate resilience and the nexus

"Nexus thinking" is an approach that recognizes the critical interdependence of food, energy and water in an increasingly resource-constrained world. Understanding and improving how we manage and use these resources is a process full of uncertainty, but it is needed, especially in the face of climate change. There is a critical need to equip both individuals and institutions with research, capacity-building and new tools to plan for a better, climate-resilient future.

This project aims to address a specific gap, in that conventional forecasting tools and analyses are often comparatively static (mainly employing linear approaches) and are narrowly focused on a sector or a specific set of thematic indicators. Here, a systemic approach is employed, which considers social, economic and environmental indicators within a sector and links them across sectors to generate dynamic projections that allow policy outcomes for all economic actors to be estimated.

Many tools are put forward to inform decision-making by estimating the short, medium and longer-term outcomes of investments across social, economic and environmental dimensions (Bassi, Bečić and Lombardi, 2014). But the results produced by these tools are not all that useful for the end users they are designed to support (Rozema and Bond, forthcoming). This is because they lack the capability to present the cross-sectoral impacts of interventions and leave room for (unexpected) side effects.

Current research has already pointed out that there is a need for more appropriate decision-support tools for development bank investors and public decision makers (UNEP, 2014) that include quantified negative environmental externalities for both local communities and national economic priorities, including sectoral development, poverty reduction and job creation (Bassi, Bečić and Lombardi, 2014). This is because most impact assessment tools are designed to evaluate one single dimension of development (i.e. economic, social or environmental), but only their combined use is likely to provide effective support to decision-making. Moreover, many tools and methodologies are developed using frameworks that cannot be easily customized to the local context and this prevents analysts and decision makers using the results of the assessment to inform their specific development priorities (Wallhagen and Glaumann, 2011).

The modelling work presented in this report is designed to support development planning, especially in the context of climate resilience, that aims to leverage investments for greater progress for all. As a result, our approach needs to build on existing work and integrate economic assessments with social and environmental impacts, so that planning exercises at the sectoral level become more effective.

2. Implementing the nexus approach with causal loop diagrams

The main drivers of change on the three sectors analysed (agriculture, energy and water) are summarized in three causal loop diagrams. These diagrams include the main indicators analysed, their interconnections with other relevant variables in the sector and the feedback loops they form.

Causal loop diagrams are the starting point for the development of the mathematical (stock and flow models) described in more depth in section 3. Model results are presented in section 2.

The creation of a causal loop diagram has several purposes: first, it combines the team's ideas, knowledge, and opinions; second, it highlights the boundaries of the analysis; third, it allows all the stakeholders to achieve basic-to-advanced knowledge of the systemic properties of the issues analysed. Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence, something that is normal in complex systems. Since the creation of a causal loop diagram touches upon (and relies on) cross-dimensional knowledge, all the parties involved in the decision-making process and the implementation of an investment need a shared understanding of the factors that generate the problem and those that could lead to a solution in order to implement successful public-private partnerships. The solution should not therefore be imposed on the system, but should emerge from it. In other words, interventions should be designed to make the system start working in our favour, to solve the problem, rather than generate it.

In this context, the role of feedback is crucial. It is often the very system we have created that generates the problem, due to external interference or a faulty design, which shows its limitations as the system grows in size and complexity. In other words, the causes of a problem are often found within the feedback structures of the system. The indicators are not sufficient to identify these causes and explain the events that led to the creation of the problem. Too often, we tend to analyse the current state of a system, or to extend our investigation to a linear chain of causes and effects, that does not link back to itself, thus limiting our understanding of open loops and linear thinking.

Causal loop diagrams include variables and arrows (called causal links), with the latter linking the variables together with a sign (either + or −) on each link, indicating a positive or negative causal relationship (see table 2):

- A causal link from variable A to variable B is positive if a change in A produces a change in B in the same direction.
- A causal link from variable A to variable B is negative if a change in A produces a change in B in the opposite direction.

Table 2: Causal relationships and polarity

Variable A	Variable B	Sign
Sign+		
Sign+		
Sign -		
		-

Circular causal relationships between variables form causal, or feedback, loops. These can be positive or negative. A negative feedback loop tends towards a goal or equilibrium, balancing the forces in the system (Forrester, 1961). A positive feedback loop can be found when an intervention triggers other changes that amplify the effect of that initial intervention, thus reinforcing it (Forrester, 1961). Causal loop diagrams also capture delays and non-linearity.

- "Feedback is a process whereby an initial cause ripples through a chain of causation ultimately to re-affect itself" (Roberts and others, 1983). Feedback (also called feedback loops in systems modelling) can be classified as positive or negative. Positive (or reinforcing) feedback loops amplify change and are typically identified by an 'R' notation, while negative (or balancing) loops counter and reduce change and are identified by a 'B' notation.

- Delays are characterized as "a phenomenon where the effect of one variable on another does not occur immediately" (Forrester, Road Maps: A guide to learning System Dynamics, 2002). A difference between the actual and perceived states of a process can often be important in explaining patterns of behaviour. This implies that it sometimes becomes difficult to attribute certain effects to specific causes, as cause and (perceived) effect are distant in time. For example, when there is an increase in the use of fertilizers, it takes time for nitrogen and phosphorous to reach water bodies and negatively impact the ecological integrity of a bay or river basin.

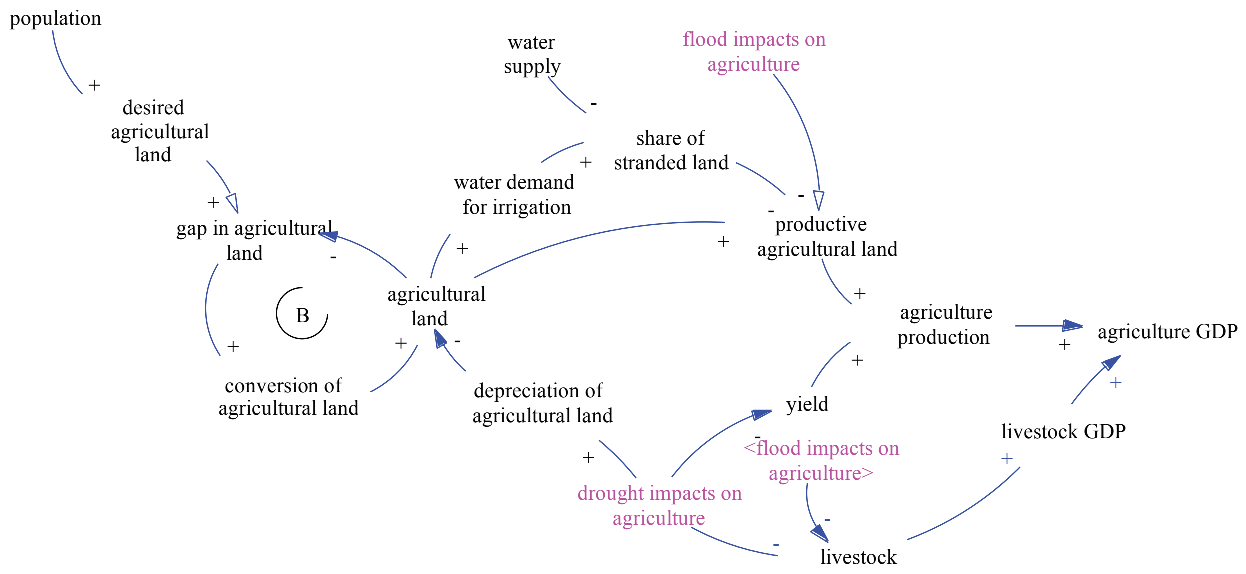
- Non-linear relationships cause feedback loops to vary in strength, depending on the state of the system (Meadows, 1980), and determine how structure defines behaviour. For instance, because agricultural yield is influenced simultaneously by the type of seeds used, nutrients, climate and land use practices, each embedded in a variety of feedback loops, non-linear behaviour emerges from the model.

The strengths and weaknesses of causal loop diagrams are set out in table 3.

Table 3: Strengths and weaknesses of causal loop diagrams

Strengths	Weaknesses
• Facilitate a multi-stakeholder approach to problem solving • Help highlight the causal relationships between the indicators • Support the analysis of system behaviour and its reaction to external interventions	• Effectiveness is strictly linked to the process quality • Wrong or partial causal loop diagrams may lead to ineffective (or even harmful) interventions • Best used if combined with quantitative tools (e.g., simulation models)

Figure 1: Causal loop diagram: Agricultur



2.1 Agriculture

The performance of the agricultural sector is driven by one major balancing feedback loop, as illustrated in figure 1. This balancing loop ensures that demand is met by supply, where possible. The specific case analysed here is the gap between the desired amount of agricultural land, which is driven by population and land productivity (also affected by climate), and the current amount of agricultural land.

Agricultural production depends on the amount of productive agricultural land and the yield per hectare of cropland. Productive agricultural land is a function of the amount of cropland and the share of (water-related) stranded land, which depends on water available from rainfall, required irrigation and available water supply.

The climate impacts considered in the agricultural sector are the impacts of floods and droughts on available land, land productivity and livestock.

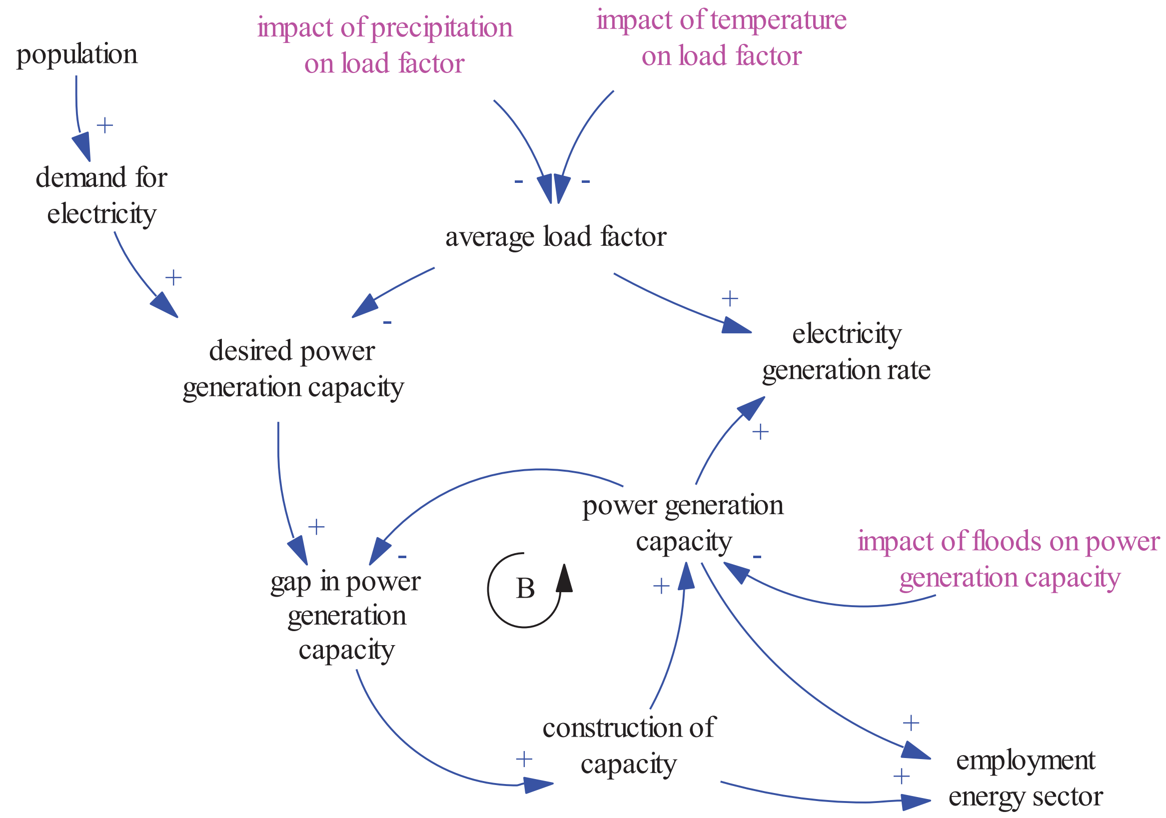
2.2 Energy

The energy sector is driven by one major balancing feedback loop linking demand and supply. This ensures that the amount of electricity demand is met by desired power generation capacity and electricity supply. Figure 2 illustrates the causal loop diagram for the energy sector.

Electricity demand is driven by population and per capita electricity consumption. The electricity generation rate depends on the installed capacity, both thermal and renewable, and the average load factor based on the electricity technology mix. Employment and labour income in the energy sector depend on the amount of installed capacity (operations and maintenance employment) and the installation of new capacity (construction employment).

Climate impacts considered in the energy sector include precipitation and temperature and possible reduction in load factor (i.e. operation of power plants) and efficiency in thermal conversion (i.e. higher temperatures lead to lower efficiency in fuel burning for electricity generation) and the

Figure 2: Causal loop diagram: Energy



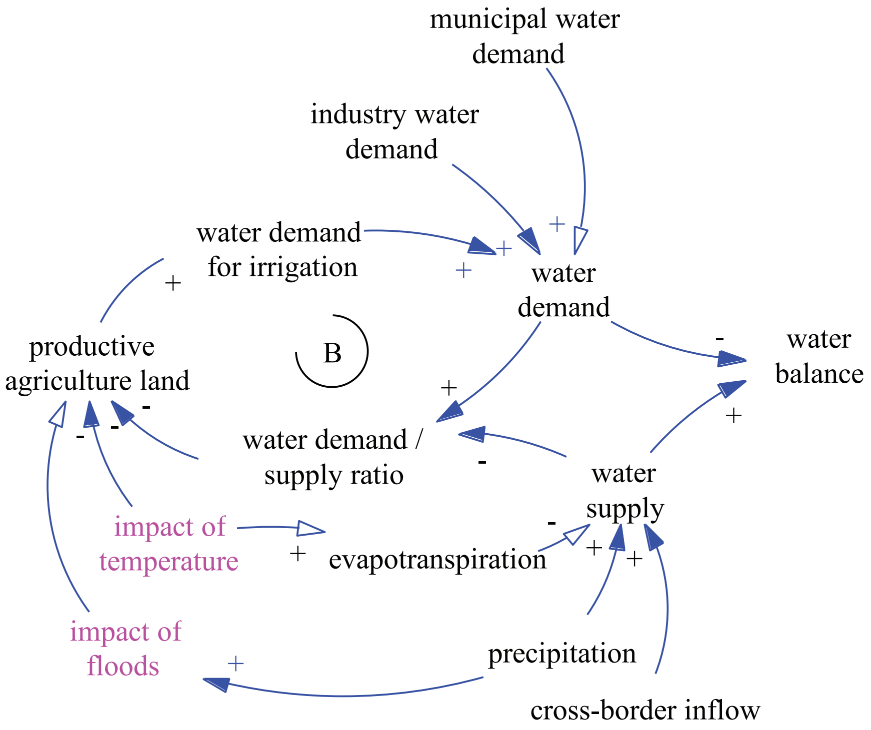
damage to power generation capacity caused by floods.

2.3 Water

The water sector is primarily influenced by one balancing feedback loop, as illustrated in figure 3, also relating to demand and supply. Total water demand consists of municipal water demand, industrial water demand and water demand from agriculture. The available water supply considers precipitation and cross-border inflows and accounts for the amount of evapotranspiration (reducing the amount of water resources available in the country). The water balance indicates whether there is a surplus or scarcity of water at any given point in time.

Climate impacts considered in the water sector are the impact of temperature on evapotranspiration rates, and the impact of floods and droughts on productive agricultural land.

Figure 3: Causal loop diagram: Water



3. Documentation of the model

3.1 Data sources

The data sources used to customize and parametrize the model were selected to minimize the time taken to set up the model tables. The data used as reference modes are attached in a separate file.

The World Development Indicators (World Bank, 2018) serve as the main data source for the calibration of the model and the reference modes used for validation. To simplify model parametrization and for future use, the same data sources were used for all countries.

Agricultural land, cropland, total agricultural production and information on livestock were obtained from the FAOSTAT database (FAO, 2018a). Data on historical precipitation and precipitation trends were obtained from the World Bank Climate Change Knowledge Portal (World Bank, 2018). Information on the efficiency of irrigation technology was obtained from Sauer and others (2010). Crop water requirements were estimated based on Maize FAO CROPWAT Website (FAO, 2018b). Data on electricity generation capacity and power generation (generation = demand) were obtained from The Shift Project (TSP, 2018).

Selected statistics were collected at the country level to fill gaps in international databases.

Cameroon:

Energy capacity and production (Ndongsok and Ruppel, 2017)
Labour income (Glassdoor, 2016)
Roads: (Toma, 2018)

Mozambique:

Roads: (Economies Africaines, 2017)
Salary energy sector: (WageIndicator, 2018)

Uganda:

Salaries, energy sector: (Ayoki, 2012)

3.2 Population module

The population module contains the two stocks: population and GDP. Both stocks change based on an exogenous growth rate that is based on historical trends and future projections. The population stock changes based on the flow population net change and flow values are calculated based on the following equation:

$$\text{population net change} = \text{Population} * \text{population growth rate}$$

The GDP stock changes based on the flow GDP net change, which is calculated using the same approach as the population stock.

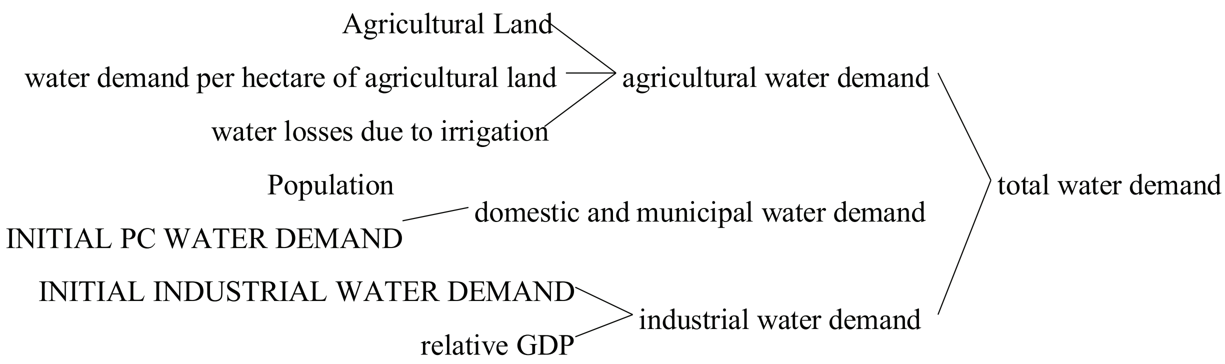
3.3 Water module

The water module provides an overview of water-related variables in the Sustainable Development Goals model, such as demand and supply. It includes a range of indicators that convey information about the sustainability of water use and the amount of water required to satisfy demand.

The water module contains two main segments: water demand and water supply. Total water demand is the sum of domestic and municipal water demand, agricultural water demand and industrial water demand. Figure 4 displays a causes tree showing the factors affecting total water demand and their determinants. Domestic and municipal water demand are calculated by multiplying total population by a per capita water demand value. Water demand from industry depends on the development of total GDP over time and the initial industrial water intensity of the production sector. The following equation illustrates how industrial water demand is calculated:

$$\text{industrial water demand} = \text{relative GDP} * \text{INITIAL INDUSTRIAL WATER DEMAND}$$

Figure 4: Causes tree: Total water demand



Water demand from agriculture depends on the total amount of cropland, average water demand per hectare of cropland and the amount of water applied in excess per hectare based on irrigation system efficiency. Agricultural water demand is calculated as follows:

agricultural water demand =

cropland * (water demand per hectare of agricultural land + water losses due to irrigation)

Total cropland is multiplied by the amount of water required for irrigation per hectare of cropland. The water requirements are the sum of the water demand per hectare of agricultural land and the water lost due to irrigation.

The total water supply, or total renewable water resources, is the sum of water resources internally produced and cross-border inflow. Internally produced water resources represent the domestic water supply available depending on precipitation and evapotranspiration. The causes tree in figure 5 illustrates the variables used to determine the amount of water resources internally produced.

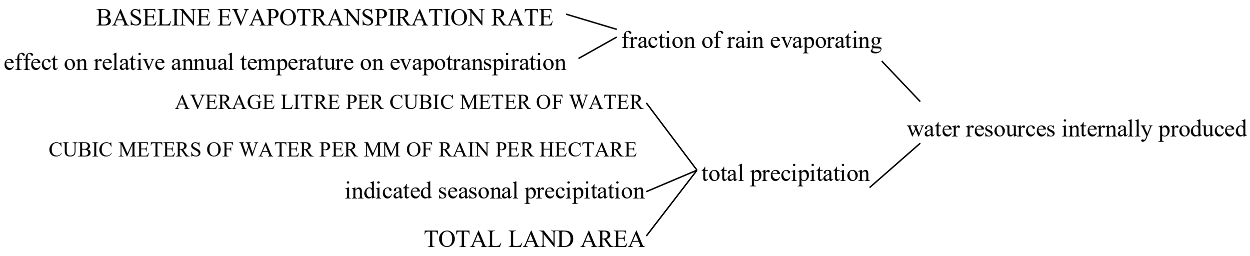
Total precipitation is calculated based on the total land (surface) area of the country, seasonal precipitation, and two conversion factors that are used to convert millimetres of precipitation into litres. The equation for total precipitation is:

Total precipitation =

indicated seasonal precipitation * TOTAL LAND AREA * CUBIC METRES OF WATER PER MM OF RAIN PER HECTARE * AVERAGE LITRE PER CUBIC METRE OF WATER

The fraction of rain evaporating is calculated based on a baseline evapotranspiration rate and the impact of temperature on evapotranspiration. The

Figure 5: Causes tree: Water resources internally produced



latter variable captures the effect that increasing temperature has on evapotranspiration rates.

Indicators relating to the sustainability of water use are based on water demand and water supply. The water balance indicates whether the total amount of available water resources is sufficient to cover total water demand and is calculated by subtracting water demand from water supply. A negative water balance indicates a water shortage. A second indicator relating to the availability of water is the variable water stress, which is calculated by dividing total water demand by total renewable water resources. Indicator values higher than "1" occur if demand exceeds supply.

3.4 Agriculture module

The agriculture module provides information on the amount of agricultural land, cropland, agricultural production and related variables. Water requirements per hectare and irrigation coverage and efficiency are contained in this module. The module is capable of assessing climate change impacts on agricultural production.

3.4.1 Agricultural production

The agriculture module contains the stock Agricultural Land, which changes based on the conversion for agricultural land and the rate at which agricultural land depreciates. The equation for changes in agricultural land is:

Agricultural land$_{t+1}$ =

Agricultural land$_{t0}$ + land conversion for agriculture$_{t0}$ – depreciation rate agricultural land$_{t0}$

The depreciation rate of agricultural land depends on the stock value and the average lifetime of agricultural land and is calculated by dividing the former by the latter. The land conversion rate for agriculture is equal to the desired land conversion for agriculture, which is based on the current and desired amount of agricultural land, the depreciation rate of agricultural land and the time required for land conversion. The following equation illustrates how the desired land conversion for agriculture is calculated:

desired land conversion for agriculture =

(desired agricultural land - agricultural land) /
TIME TO CONVERT LAND FOR AGRICULTURE +
depreciation rate agricultural land

This formulation ensures that the stock of agricultural land is adjusted to its desired value. Desired agricultural land is calculated based on total population and a per capita agricultural land multiplier. The amount of agricultural land contains land that is used for crop production and pasture. The amount of cropland is calculated based on the stock of agricultural land and a fraction of agricultural land that is cropland.

Concerning agricultural production, the model distinguishes between productive and affected agricultural land. Productive agricultural land represents agricultural land that is fully productive throughout the year, while affected agricultural land captures agricultural land that is affected by floods or droughts and hence yields lower production quantities. The amount of productive agricultural land is calculated based on the amount of cropland that is neither affected by flood nor drought.

productive agricultural land =

cropland * (1-share of agricultural land affected by drought) * (1-share of agricultural land affected by flood)

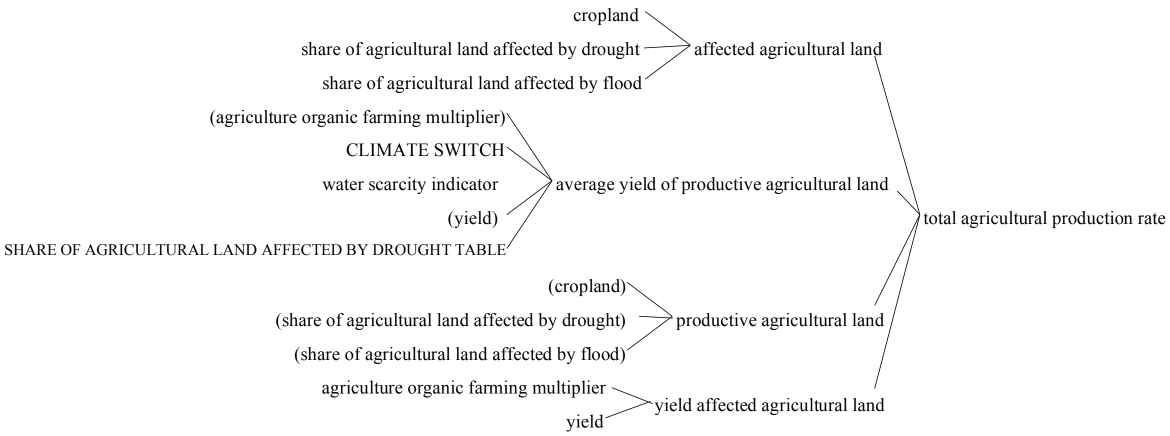
The amount of affected agricultural land represents the land that is affected by floods or droughts, and hence temporarily produces at lower yields.

affected agricultural land =

cropland * share of agricultural land affected by drought + cropland * share of agricultural land affected by flood

The above equation is formulated under the assumption that either a flood or a drought occurs, and not both simultaneously. Together with the respective yield values, productive and affected agricultural land is used to calculate the total agricultural production rate. The variables used for calculating total agricultural production are represented in the causes tree in figure 6.

Figure 6: Causes tree: Total agricultural production rate



The share of agricultural production affected by flood is determined based on the flood indicator and a table function derived from a DESINVENTAR data set. The share of agricultural land affected by drought depends on the water demand/supply ratio. As soon as water demand exceeds water supply by a certain percentage, it is assumed that this translates into a percentage of agricultural land at risk of drought. The following equation is used to determine the share of agricultural land affected by drought:

share of agricultural land affected by drought=

MIN (“water demand-supply/ ratio” – 1, 1)

The water demand/supply ratio is formulated to have a minimum value of “1”. The MIN function ensures that the share of agricultural land affected takes a value between “0” and “1”, equivalent to 0 per cent and 100 per cent of agricultural land affected, respectively.

Agricultural production is calculated as the sum of production from productive and affected agricultural land. A weighted average is used to determine the respective production, which is calculated by multiplying the respective amount of land by the respective yield per hectare.

total agricultural production rate =

affected agricultural land * yield affected agricultural land + productive agricultural land * average yield of productive agricultural land

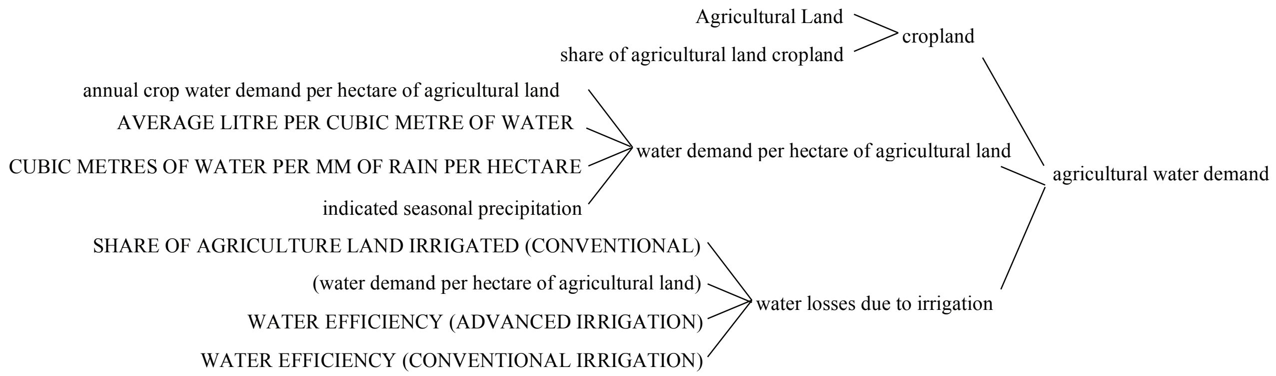
The yield of affected agricultural land is affected by the availability of water and can decline by up to 60 per cent if land is affected by drought. Furthermore, it is assumed that water scarcity reduces the productivity of unaffected agricultural land by up to 30 per cent, depending on the strength of the drought event.

Agricultural GDP is calculated as the sum of value added from livestock and the product of multiplying total agricultural production by a value added per ton of produce.

3.4.2 Agricultural water demand

The amount of cropland further serves to estimate the water demand from agricultural production. The amount of water needed for irrigation depends on the water demand per hectare of agricultural land for every given month and the excess water that is applied (lost) to maintain production due to the efficiency of irrigation systems. The causes tree for agricultural water demand is displayed in figure 7.

Figure 7: Causes tree: Agricultural water demand



The water demand per hectare of agricultural land depends on the type of crop planted and the scheduling of irrigation events, or the annual crop water demand. The variable annual crop water demand is formulated as follows:

annual crop water demand per hectare of agricultural land =

IF THEN ELSE (month counter modulo = 1, 100,
IF THEN ELSE (month counter modulo = 2, 100,
IF THEN ELSE (month counter modulo = 3, 100,
IF THEN ELSE (month counter modulo = 4, 100,
IF THEN ELSE (month counter modulo = 5, 0,
IF THEN ELSE (month counter modulo = 6, 0,
IF THEN ELSE (month counter modulo = 7, 0,
IF THEN ELSE (month counter modulo = 8, 0,
IF THEN ELSE (month counter modulo = 9, 0,
IF THEN ELSE (month counter modulo = 10, 100,
IF THEN ELSE (month counter modulo = 11, 100,
IF THEN ELSE (month counter modulo = 12,
100,0))))))))))))

The month counter modulo function divides each year into 12 time steps and is used to determine the water demand from cropland during each month. In order to determine the net water demand for irrigation per hectare, the monthly crop water demand is compared to monthly precipitation.

Net water demand per hectare of agricultural land=

MAX (annual crop water demand per hectare of agricultural land – indicated seasonal precipitation, 0)
* CUBIC METRES OF WATER PER MM OF RAIN PER HECTARE
* AVERAGE LITRE PER CUBIC METRE OF WATER

If seasonal (monthly) precipitation exceeds crop water demand, there will be no water demand for irrigation. The MAX function hence prevents a negative net water demand. The two additional multipliers are used to convert the unit from millimetres per hectare to litres per hectare.

The second component of agricultural water demand is the water lost due to excess irrigation, or water that could have been used otherwise, but was applied to the fields due to inefficient irrigation systems. Water losses due to irrigation are calculated based on the net water demand per hectare, the share of agricultural land by irrigation scheme and the application efficiency of irrigation systems. A weighted average of additional water demand is assessed based on the following equation:

water losses due to irrigation =

IF THEN ELSE (POLICY SWITCH WATER = 1,

water demand per hectare of agricultural land/”WATER EFFICIENCY (CONVENTIONAL IRRIGATION)”*”share of agricultural land irrigated (conventional) policy”

+water demand per hectare of agricultural land/”WATER EFFICIENCY (ADVANCED IRRIGATION)”*(1-”share of agricultural land irrigated (conventional) policy”),

An IF THEN ELSE function is used to simulate different water use scenarios and to capture the impacts of increasing irrigation efficiency on water losses from agriculture. If the switch has a value of “1”, then the policy is active and the model will calculate a weighted average based on a changing share of agricultural land under efficient irrigation capacity. If the switch has the value "0" then the policy is inactive and a constant share for irrigation technologies is assumed (100 per cent inefficient).

3.4.3 Livestock module

The livestock module provides an overview of the total livestock in the country, value added from livestock production and the loss of livestock from adverse weather events.

The number of animals in the economy is captured through the stock Livestock. The stock changes based on the flow change in livestock and the two flows, loss of livestock due to floods and droughts. The flow change in livestock uses the stock value of Livestock and a growth rate to change the amount of livestock.

change in livestock =

Livestock * growth rate livestock

The loss of livestock due to floods and loss of livestock due to droughts are calculated based on the stock level of livestock and the flood or drought indicator. The fractional impacts of floods and droughts are calibrated based on empirical observations obtained from the DESINVENTAR database. The following equation is representative for both flows, as they are formulated using the same approach.

loss of livestock due to floods=

IF THEN ELSE (CLIMATE SWITCH = 1, Livestock * FLOOD IMPACT ON LIVESTOCK TABLE (flood indicator), 0)

The IF THEN ELSE function is used to provide the option to turn climate impacts on or off, depending on the desired scenario to be simulated. If the switch has a value of "1" then the climate impacts are active. The strength of the impact depends on the table function and the flood indicator, which indicates the strength of the event. If the switch has a value of "0" then the policy is turned off and there will be no loss of livestock due to adverse weather events.

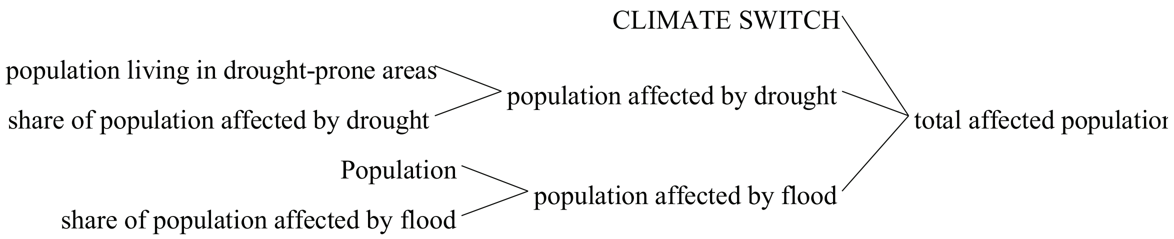
Value added from livestock is calculated based on the stock of livestock and a value added per head of livestock. To estimate the GDP generated by the livestock sector, the number of animals is multiplied by the value added per head of livestock multiplier.

3.5 Food security and population affected module

The model estimates the total population affected by adverse events. The share of population affected by flood and drought depends on the flood and water scarcity indicators and table functions determined based on DESINVENTAR observations. The share of population affected by drought is estimated based on the share of population living in drought-prone areas and the share of population affected by drought. Figure 8 provides an overview of the variables used to calculate total affected population.

The impacts of floods and droughts occur gradually and depend on the strength of the events, indicated by the flood and water scarcity indicators, respectively. Floods are assumed to occur potentially occur throughout the

Figure 8: Causes tree: Total affected population



country and are calculated based on the share of population affected by flood. Droughts affect the population living in drought-prone areas and it is assumed that all people living in such areas are affected starting from precipitation levels of 30 per cent below average. The population affected by drought is calculated as:

Population affected by drought =

Population living in drought-prone areas * share of population affected by drought

The number of people living in drought-prone areas indicates the number of people living in an area at high risk of experiencing water scarcity. It is calculated through the following equation by multiplying total population by a share of people living in drought-prone areas:

Population living in drought-prone areas =

Population * SHARE OF POPULATION LIVING IN DROUGHT-PRONE AREAS

Food security is assessed by comparing the total food demand of the population to the domestic food supply and baseline food imports. Total food demand is calculated by multiplying population by a food demand per capita value. Food supply for human consumption depends on total agricultural production and the share of agricultural production that is not cash crops and is intended for human consumption.

total food production =

total agricultural production rate * SHARE OF AGRICULTURAL PRODUCTION FOR FOOD SUPPLY

Figure 9 displays the variables used to calculate the number of people affected by food scarcity.

Additional food imports indicate that baseline imports and domestic supply are insufficient to satisfy the total demand for food. In other words, additional food imports are required if total food demand is higher than baseline imports and total food supply together.

additional food imports required =

MAX (0, total food demand – BASELINE FOOD IMPORTS – total food supply)

A MAX function is used to ensure that the amount of additional imports either indicates a positive number or zero. The sum of additional food imports and baseline food imports yields the total food imports during a given year.

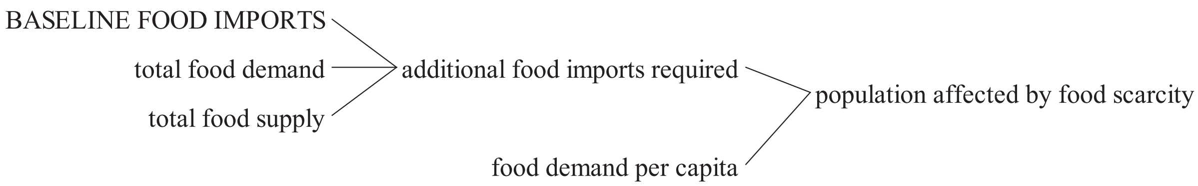
3.6 Electricity generation module

The electricity generation module provides an overview of power generation capacity, electricity generation by source and other variables related to power generation. It contains several indicators providing information on the share of renewable energy, load factor and the cost of power generation.

3.6.1 Capacity, generation and employment

The electricity generation module contains the two stocks of conventional power generation capacity and renewable power generation capacity. This section will use renewable capacity for illustration purposes, as the same approach is used for the adjustment process of both capacity types. The capacity stock increases with the construction rate of renewable capacity and decreases with the depreciation rate of renewable capacity and damage to renewable capacity. The construction

Figure 9: Causes tree: Population affected by food scarcity



rate of renewable capacity depends on the desired power generation capacity, the desired fraction of renewable power generation, capacity construction time and the replacement rate.

construction rate other renewable =

MAX (desired power generation capacity * fraction of power generation capacity renewable - Renewable Power Generation Capacity) / TIME TO CONSTRUCT POWER GENERATION CAPACITY + replacement rate other renewable, 0)

This adjustment process ensures that the stock of renewable capacity adjusts to the desired amount of renewable capacity. Desired power generation capacity multiplied by the desired fraction of renewable capacity indicates the desired amount of renewable capacity, which is then compared to existing capacity. A MAX function is used to ensure that the construction inflow remains positive at all times, as decommissioning of capacity would need to take place via the depreciation flow. Note that the adjustment process for conventional capacity uses the formulation "(1 - fraction of power generation capacity renewable)" for the adjustment process.

Desired power generation capacity depends on the total demand for electricity and the average load factor of existing capacity and the number of hours per year. The demand for electricity is calculated by multiplying population by an electricity demand per capita multiplier. Dividing electricity demand by the average load factor and the number of hours per year yields the desired capacity to satisfy demand.

desired power generation capacity =

electricity demand / weighted average load factor / HOURS PER YEAR

The two outflows of the stock of renewable power generation capacity capture the depreciation of capacity and damage from adverse weather to capacity. The depreciation rate captures the decommissioning of capacity at the end of its lifetime.

Depreciation Rate Other Renewable =

DELAY FIXED (construction rate other renewable, AVERAGE LIFETIME OTHER RENEWABLE, 0)

To capture the amount of capacity decommissioned at the end of its lifetime, a fixed delay function is used. The delay function uses the construction rate as an input and ensures that capacity is decommissioned after the average lifetime of renewable capacity. Damage to renewable capacity from adverse weather events is captured based on the flood indicator and an elasticity value.

renewables damage to capacity =

IF THEN ELSE (CLIMATE SWITCH = 1, Renewable Power Generation Capacity * (flood indicator – 1) ^ ELASTICITY OF POWER GENERATION CAPACITY TO CLIMATE IMPACTS, 0)

An IF THEN ELSE function allows for switching this flow on and off depending on which scenario is simulated. Setting the Climate Switch to the value of "1" (switch active) activates the assumption that a fraction of renewable capacity is damaged during each flood event. The strength of the impact depends on the strength of the flood event.

The model provides information on construction and operations and maintenance (O&M) employment from power generation. Construction employment is calculated based on the construction rate of both capacity types and an employment per MW multiplier. Operations and maintenance employment from power generation is calculated based on the stock of renewable power generation capacity itself.

O&M employment other renewables =

Renewable Power Generation Capacity * "O&M employment per mw of other renewable capacity"

The approach for the calculation of employment is similar for conventional and renewable capacity types but the employment multipliers for the different capacity types are different. The variables used to determine total employment in the energy sector are displayed in Figure 10.

Figure 10: Causes tree: Total employment energy sector

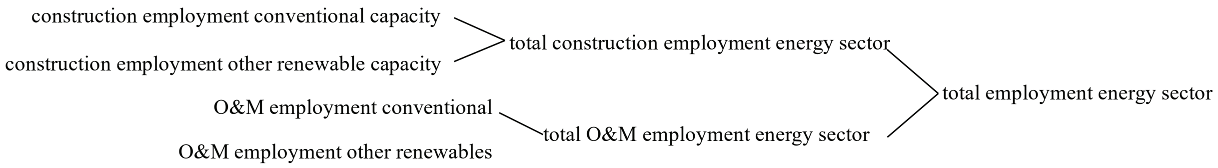


Figure 11: Causes tree: Total electricity generation rate

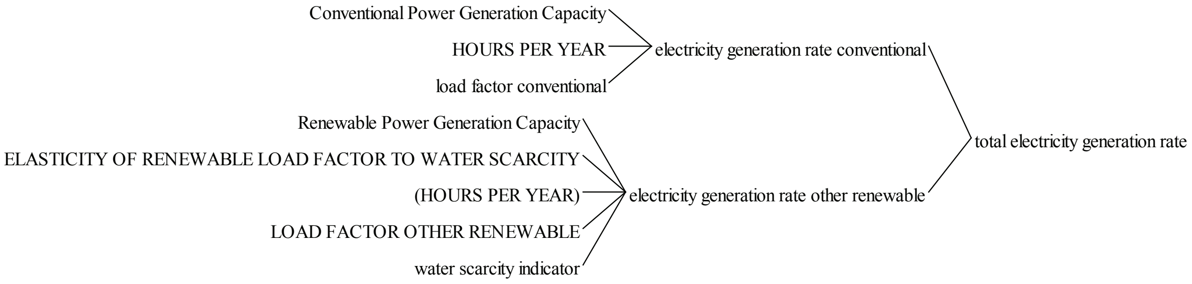
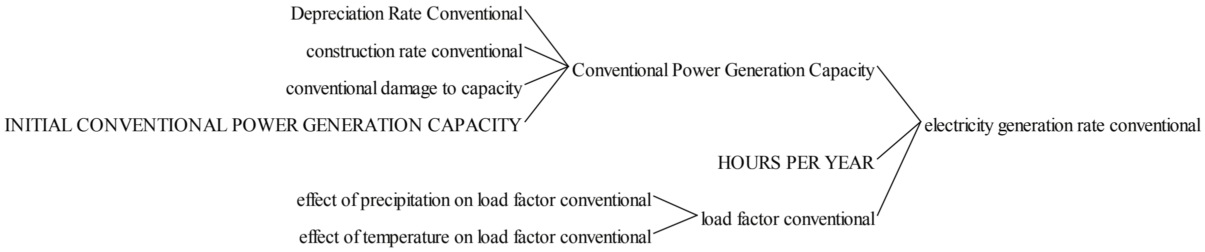


Figure 12: Causes tree: Conventional electricity generation



The sum of construction employment from renewable capacity sources and construction employment from renewable capacity yields the total construction employment of the energy sector. Similarly, the sum of operations and maintenance employment from conventional and renewable capacity yields the total operations and maintenance employment in the energy sector.

Labour income from the energy sector is calculated by multiplying the employment by capacity type by an average salary in the energy sector.

Figure 11 provides an overview of the variables used for the calculation of the total electricity generation rate. The total electricity generated is the sum of electricity generated from renewable and conventional sources.

The electricity generation rate from conventional power generation capacity depends on the amount of installed capacity and the load factor of conventional capacity

electricity generation rate conventional =

conventional power generation capacity * HOURS PER YEAR * load factor conventional

The load factor of conventional capacity is affected by precipitation and temperature, as illustrated in figure 12. The effect of precipitation captures the availability of water for cooling purposes and assumes a reduction in load factor if precipitation values are well below average. Temperature impacts on load factor capture the fact that conventional power plants need to stop production during extremely high temperatures, which in turn reduces the overall load factor of capacity.

The electricity generation rate from renewable power generation capacity is calculated using the same approach as for conventional electricity generation.

electricity generation rate other renewable =

renewable power generation capacity * HOURS PER YEAR * load factor other renewable

Due to a predominance of hydropower in the selected countries, renewable power generation is affected by water scarcity, as illustrated in figure 13. The effect of water scarcity captures the reduction of hydropower effectiveness during dry periods during which water levels in rivers and storage basins are low.

The total electricity generation rate is used in the calculation of the variables and indicators displayed in figure 14. The shares of electricity generated by conventional and renewable sources is calculated by dividing the respective generation rates by total electricity generation. In addition, the total amount of electricity produced compared to the total demand for electricity yields the amount of electricity that needs to be imported to satisfy total demand. Total electricity generation is used to define the initial electricity generation rate at the beginning of the simulation. The relative electricity generation rate is calculated by dividing the current electricity generation rate by the initial value, which provides information about the relative increase in electricity generation since the beginning of the simulation.

Figure 13: Causes tree: Renewable electricity generation

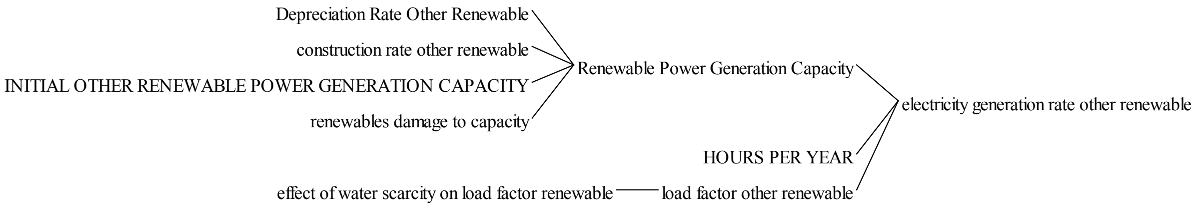


Figure 14: Uses tree: Total electricity generation rate

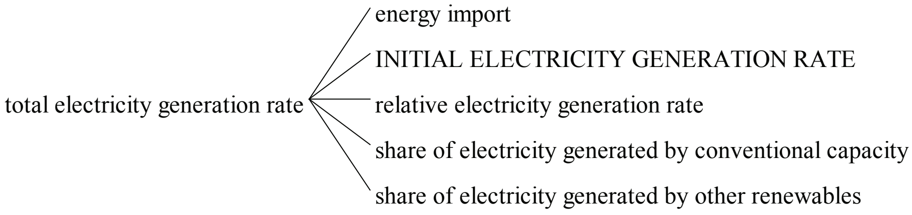
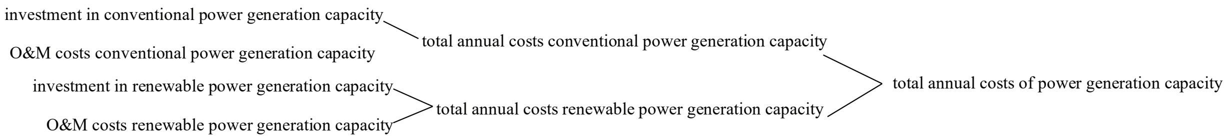


Figure 15: Causes tree: Total annual costs of power generation capacity



3.6.2 Costs of generation and electricity generation price

The total annual costs of power generation are the sum of total annual costs of conventional power generation capacity and total annual costs of renewable power generation capacity.

total annual costs of power generation capacity =

total annual costs conventional power generation capacity + total annual costs renewable power generation capacity

The total annual costs for renewable and conventional capacity is the sum of investment and operation costs for the respective capacity, as illustrated in figure 15.

The price of electricity is calculated as a weighted average between the electricity generation price from conventional and renewable energy sources.

weighted average electricity generation price =

electricity generation price conventional * share of electricity generated by conventional capacity + electricity generation price other renewable * share of electricity generated by other renewables

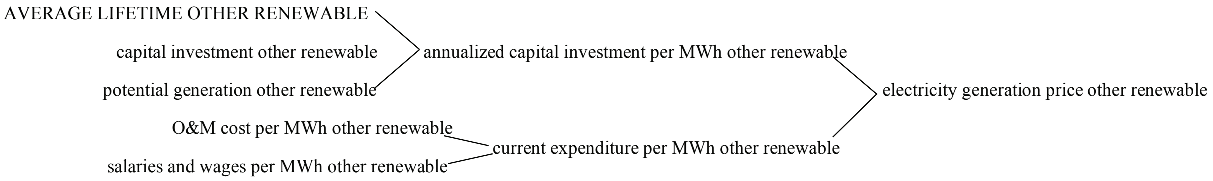
The calculation of the electricity generation price for renewable energy sources will be used for illustration purposes since the same approach is used to calculate the electricity generation price for conventional and renewable capacity. The price of electricity is calculated as the levelized cost of electricity and hence consists of annualized capital investments per MWh and the current operations and maintenance expenditure per MWh of renewable capacity.

electricity generation price other renewable =

annualized capital investment per MWh other renewable + current expenditure per MWh other renewable

The capital investment of renewables is annualized by dividing the total capital investment in renewables by the average lifetime of renewable capacity and then divided by total potential generation to obtain a value per MWh. The current expenditure per MWh of renewable electricity is the sum of operations and maintenance costs and salaries and wages per MWh of renewable electricity. These values are obtained by dividing current operations and maintenance expenditure and current salaries and wages, respectively, by the current electricity generation from renewable capacity. Figure 16 provides an overview of the variables used for the calculation of the electricity price for renewable energy.

Figure 16: Causes tree: Electricity generation price renewable generation



4. Overview of results

4.1 Business-as-usual scenario

4.1.1. Assumptions

Population and GDP are the main external drivers for the simulation of the model. After 2016, GDP growth is assumed to remain constant to simplify model validation and improve the comparability of results across countries. Population uses existing projections from the United Nations World Population Prospects. Table 4 presents the assumptions for both drivers from 2016 onward.

Based on the above assumptions, the total population of Mozambique is projected to reach 69.2 million by 2050, a net increase of 40.3 million people compared to 2016. The population of Uganda is projected to reach 109.4 million, a net increase of 67.5 million people, while the population of Cameroon is projected to increase by 24.4 million people to 51.04 million inhabitants by 2050. Population trends for the three countries are illustrated in figure 17 on the left. The graph on the right compares the population of Cameroon to World Bank Data (World Bank, 2018) up to 2016. This is presented for validation purposes, and shows that the historical simulation of the model closely matches data.

Mozambique shows strong economic growth, with GDP projected to quadruple by 2050. Projections indicate that the GDP of Cameroon will more than triple between 2018 and 2050. The total GDP of Uganda is projected to increase by 153.8 per cent and hence to more than double compared to 2018. The development of GDP of the three countries over time is summarized in table 5.

Table 4: Assumptions for key variables in the model

Variable	Country	Value 2016 (%)	Value 2050 (%)	Source
GDP growth rate	Mozambique	4.5	4.5	Assumption
	Uganda	3.0	3.0	
	Cameroon	4.2	4.2	
Population growth rate	Mozambique	2.82	2.12	(UNDESA, 2018)
	Uganda	3.32	2.26	
	Cameroon	2.63	1.18	

Figure 17: Population trends

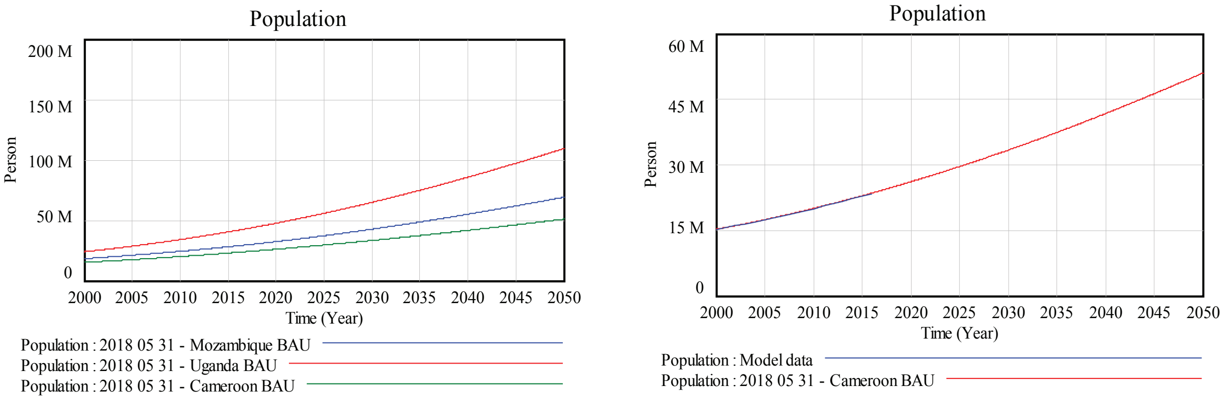


Table 5: Total GDP

Total GDP (business as usual)	Unit	2018	2020	2025	2030	2040	2050
Mozambique	bn MC	532.1	582.1	728.7	912.2	1 429.3	2 149.4
% change to 2018	%	0.0	9.4	36.9	71.4	168.6	304.0
Uganda	bn U Sh	60 210	63,928	74,260	86,262	116 398	152 806
% change to 2018	%	0.0	6.2	23.3	43.3	93.3	153.8
Cameroon	bn CFAF	16 767	18 218	22 333	27 232	39 846	55 269
% change to 2018	%	0.0	8.7	33.2	62.4	137.6	229.6

4.1.2. Agriculture

Driven by population growth, the amount of cropland increases by 46.5 per cent, 48.7 per cent and 31.1 per cent for Mozambique, Uganda and Cameroon, respectively. By 2050, the increase for Uganda is projected at 3.46 million hectares, followed by Mozambique at 3.24 million hectares and Cameroon at 2.2 million hectares. According to the projections, by 2050 the total amount of cropland in Uganda, Mozambique and Cameroon will be 10.59 million, 10.2 million and 9.38 million hectares, respectively. In the business-as-usual scenario, it is assumed that all cropland is productive throughout the year (i.e. there is no seasonality or reduction of yield during dry seasons). The development of cropland for the three countries is displayed in figure 18 on the left. The graph on the right compares the development of cropland in Cameroon to historical data for validation purposes.

Total agricultural production in Cameroon is projected to increase by 31.1 per cent (consistent with the forecast change in agricultural land), from 47.7 million tons in 2018 to 63.9 million tons in 2050, which represents a net increase of 26.8 million tons. In the absence of climate impacts (analysed in the next scenarios), land productivity is assumed to remain constant in the future. The average production rate between 2018 and 2050 is projected at 57.7 million tons per year. During the same period, total production in Uganda and Mozambique is projected to increase by 48.7 per cent and 46.5 per cent to 32.4 million tons and 26.2 million tons, respectively. By 2050, the projected increase is equivalent to additional annual production of 10.6 million tons in Uganda and 8.3 million tons in Mozambique. Figure 19 illustrates projected agricultural production for all three countries in the business-as-usual scenario and compares the total agricultural production rate of Cameroon to historical agricultural production for validation purposes.

Figure 18: Total cropland, business-as-usual scenario

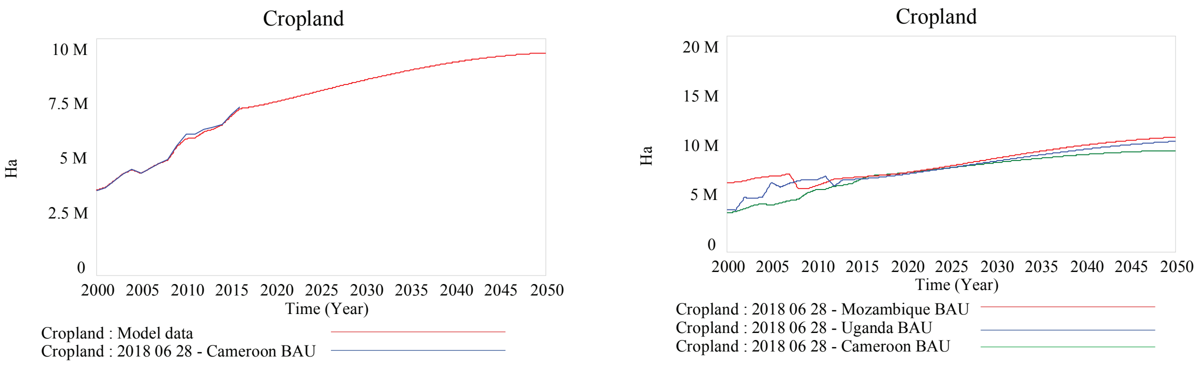


Figure 19: Total agricultural production rate, business-as-usual scenario

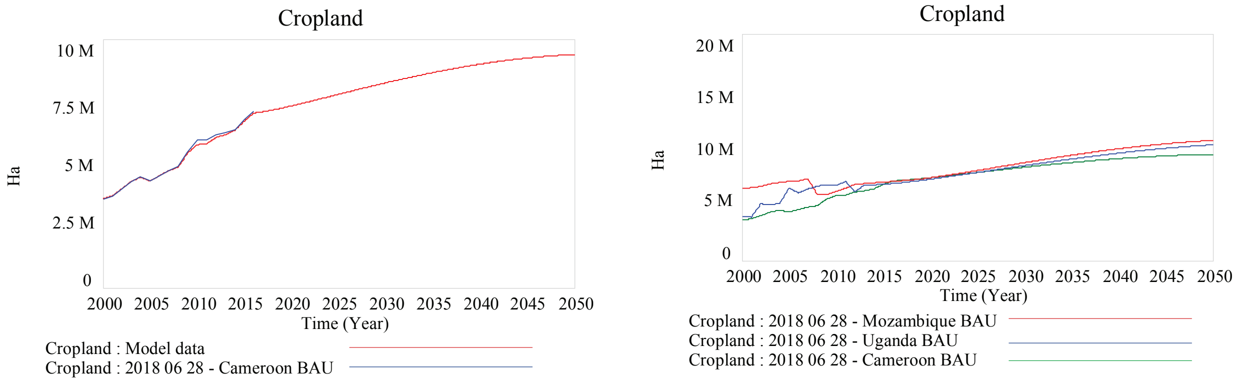


Figure 20: Water demand for irrigation

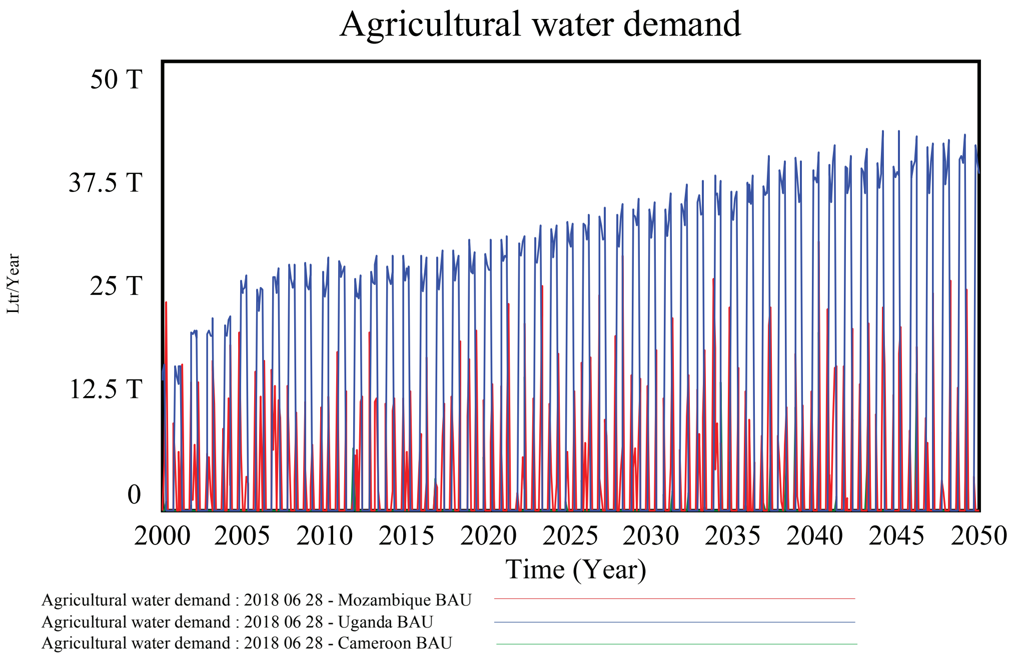
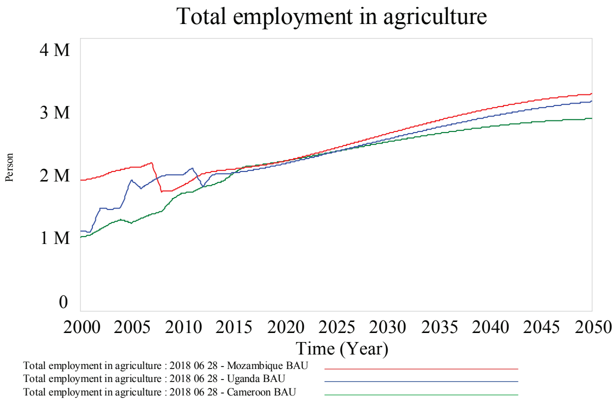


Figure 21: Total employment in agriculture, business-as-usual scenario



The expansion of agricultural land leads to an increase in water demand for irrigation (i.e. water demand for crops, minus rainfall). This is especially critical for Mozambique, where water is already scarce during the dry season. Figure 20 illustrates water demand for irrigation for the three countries and highlights the strong shortage of water that Mozambique is already facing.

Employment in agriculture is projected to increase by 30 per cent in Cameroon, 45 per cent in Mozambique and 47 per cent in Uganda by 2050, a net creation of 667,500, 973,600 and 1.04 million jobs for Cameroon, Mozambique and Uganda, respectively. In Uganda, the agricultural sector is projected to provide employment for 3.17 million people, followed by Mozambique with 3.07 million people and Cameroon with 2.81

Table 6: Agricultural GDP, business-as-usual scenario

Agricultural GDP	Unit	2018	2020	2025	2030	2040	2050
Mozambique BAU	bn MT	111.5	114.7	123.7	132.9	149.7	160.7
% change from 2018	%	0.0	2.9	11.0	19.2	34.3	44.1
Uganda BAU	bn U Sh	14 809	15 256	16 652	18 147	20 936	22 852
% change from 2018	%	0.0	3.0	12.4	22.5	41.4	54.3
Cameroon BAU	bn CFAF	2 559	2 613	2 760	2 904	3 142	3 267
% change from 2018	%	0.0	2.1	7.8	13.5	22.8	27.7

million people employed. Agricultural employment for Cameroon, Mozambique and Uganda is depicted in figure 21.

The increase in agricultural production translates into an increase of agricultural GDP (table 6). The contribution of the agricultural sector in Uganda increases by 54 per cent from 14.8 trillion Ugandan shillings (U Sh) in 2018 to U Sh 22.9 trillion in 2050, representing a net increase of U Sh 8.16 trillion. During the same period, agricultural GDP in Mozambique is projected to increase by 111.5 billion meticais (MT) from MT 49 billion in 2018 to MT 160.7 billion in 2050, an increase of 44.1 per cent. The agricultural GDP of Cameroon is projected to increases by 708 billion CFA francs (CFAF) from CFAF 2.56 trillion in 2018 to CFAF 3.27 trillion in 2050.

In Uganda, the value added from livestock in 2050 is projected to be 85 per cent higher than in 2018 and to increase its contribution to agricultural GDP from 17.4 per cent to approximately 21 per cent. By 2050, the livestock sectors in Mozambique and Cameroon are projected to increase economic output by 36 per cent and 17 per cent, respectively, which is equivalent to an increase of MT 5.05 billion and CFAF 85.8 billion. The contribution of the livestock sector to total agricultural GDP decreases in both Cameroon and Mozambique. Between 2018 and 2050, the contribution of livestock value added to agricultural GDP declines from 20 per cent to 18.4 per cent in Cameroon and from 12.5 to 11.8 per cent in Mozambique.

4.1.3. Water

In the baseline scenario, a continuation of observed precipitation trends between 2000 and 2015 is assumed. The baseline precipitation for the three countries is displayed in figure 22. For Uganda and Mozambique, an increase in precipitation is projected, while the baseline precipitation for Cameroon declines over time. The changes in precipitation lead to an increasing trend for internally produced water resources in Uganda, and a clear decline in Cameroon. In the case of Mozambique, the change in baseline precipitation is too small to be visible. The water resources internally produced are illustrated in figure 22 on the right.

Both population growth and the expansion of agricultural land put additional pressure on water resources. Especially in Mozambique, the expansion of agriculture more than doubles the water deficit during the dry season, which

Figure 22: Baseline precipitation (left) and water resources internally produced (right)

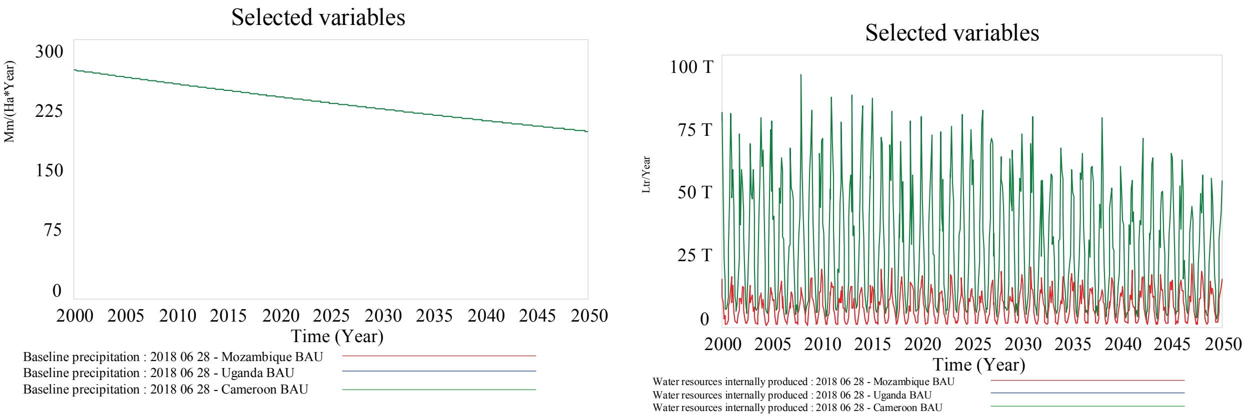
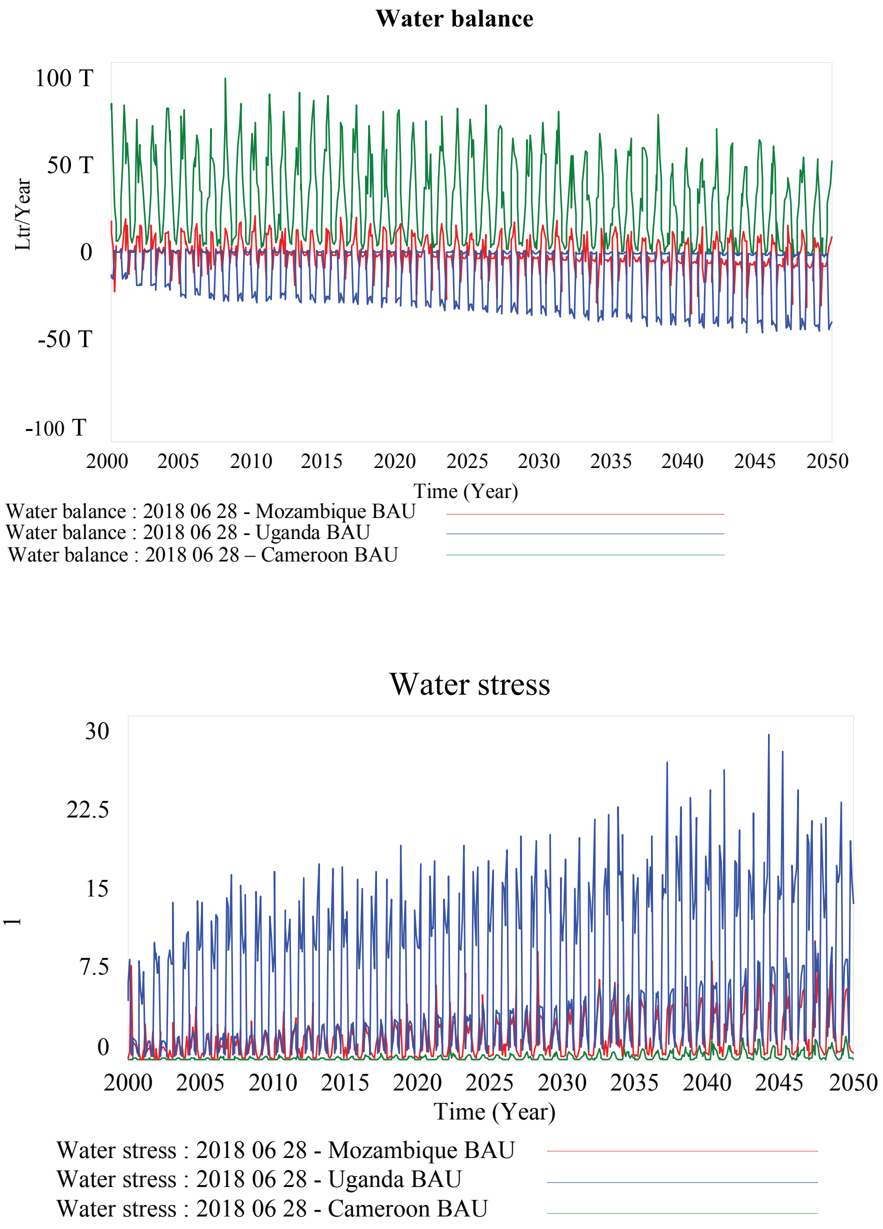


Figure 23: Water balance and water stress, business-as-usual scenario



significantly increases the risk of land becoming stranded during the dry season. The expansion of land increases the demand for water beyond the available supply, which is unsustainable, and leads to increasing water stress over time in all three countries. The water balance and water stress indicators for all three countries are depicted in figure 23.

4.1.4. Energy

Additional power generation capacity is required to ensure energy security and to satisfy the increasing demand from population and the economy. Projections indicate that the electricity generation capacity needs to more than double in all three countries to provide the required electricity supply by 2040 and 2050. Table 7 provides an overview of the capacity requirements by country over time and indicates the increase compared to 2018.

Assuming that electricity demand per capita remains constant after 2015, electricity generation increases by 74 per cent in Uganda, 111 per cent in Mozambique and 276 per cent in Cameroon by 2050. Electricity generation in Uganda, Mozambique and Cameroon is projected to reach 310 million MWh, 754 million MWh and 279 million MWh, respectively. In figure 24, the graph on the left shows the development of total electricity generation over time for the three

Table 7: Power generation capacity, business-as-usual scenario

Power generation capacity	Unit	2018	2020	2025	2030	2040	2050
Mozambique BAU	MW	3 408.9	3 766.8	4 325.7	4 944.1	5 617.6	6 339.0
% change from 2018	%	0.0	10.5	26.9	45.0	64.8	86.0
Uganda BAU	MW	833	933	1 089	1 261	1 450	1 652
% change from 2018	%	0.0	12.0	30.7	51.4	74.0	98.2
Cameroon BAU	MW	1 173	1 281	1 448	1 628	1 821	2 025
% change from 2018	%	0.0	9.3	23.5	38.8	55.3	72.7

Figure 24: Electricity generation rate, business-as-usual scenario

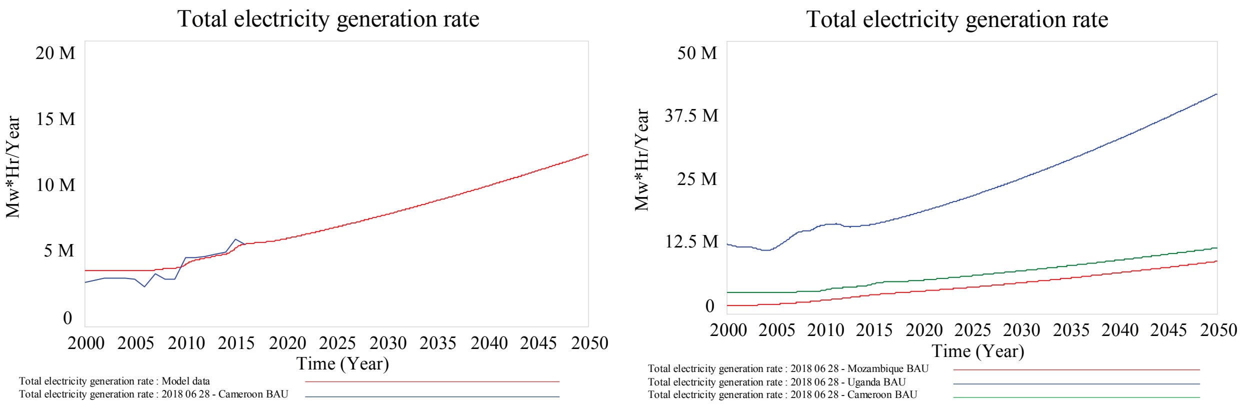


Figure 25: Total employment in the energy sector, business-as-usual scenario

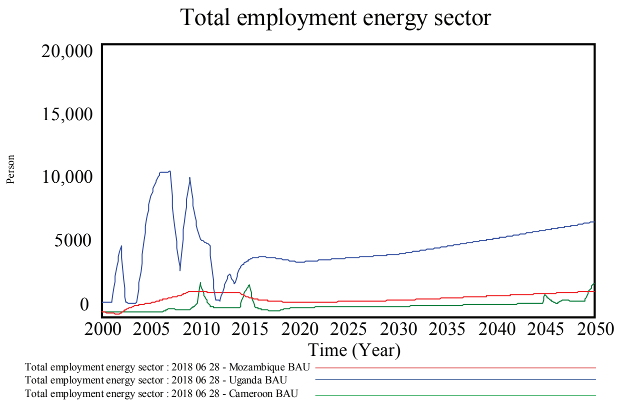


Table 8: Annual cost of power generation, business-as-usual scenario

Annual cost of power generation	Unit	2018	2020	2025	2030	2040	2050
Mozambique BAU	mn MT	677.4	721.6	830.3	948.6	1 198.7	1 431.4
% change from 2018	%	0.0	6.5	22.6	40.0	77.0	111.3
Uganda BAU	mn U Sh	177.5	181.1	197.7	213.3	256.9	309.7
% change from 2018	%	0.0	2.1	11.4	20.2	44.7	74.5
Cameroon BAU	mn CFAF	101.1	133.1	153.7	170.9	206.4	380.0
% change from 2018	%	0.0	31.6	52.0	69.0	104.1	275.7

countries, while the graph on the right presents model outputs for annual electricity generation in Cameroon compared to the historical reference mode for validation purposes.

The installation of additional capacity provides employment from construction, as well as from operation and maintenance. The energy sector in Mozambique leads employment creation, with 1,910 additional jobs by 2050. Those of Cameroon and Uganda provide 370 and 540 new jobs, respectively.

Capital investments and increasing operation and maintenance costs from installed capacity lead to higher annual costs of power generation by 2050. These are summarized in table 8.

4.2 Climate scenario

4.2.1. Assumptions

The assumptions for population and GDP remain unchanged in the climate scenario, but the climate scenario introduces a 0.5 per cent increase in precipitation variability (growing over time) compared to the baseline. This indicates that rainfall patterns will become more volatile in the future, as illustrated in figure 26 for the example of Cameroon.

Table 9: Climate impacts in the model by type of event

Climate impact	Floods	Droughts
Population affected by extreme events	X	X
Lifetime of agricultural land		X
Productive cropland	X	X
Load factor conventional	X	X
Load factor renewable	X	
Evapotranspiration rate		X
Damage to roads	X	

In addition to the assumptions made for the business-as-usual scenario, the climate scenario assumes impacts of adverse weather, as presented in table 9.

The inclusion of adverse climate events shows impacts on the population, especially for that

Figure 26: Growth rate in precipitation variability (left) and relative seasonal precipitation (right), climate scenario

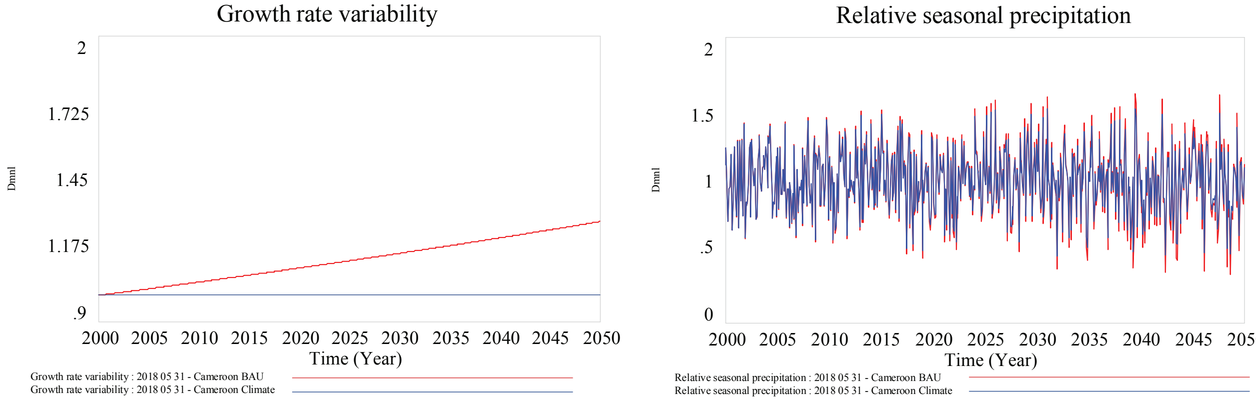


Table 10: Population affected by adverse climate events (5-year annual averages)

Population affected	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique BAU	million	0.31	0.33	0.47	0.72	0.55	0.92	0.64
% change of total	%	1.0	1.0	1.2	1.6	1.1	1.6	1.0
Uganda BAU	million	0.38	0.56	0.66	1.46	0.96	1.35	1.07
% change of total	%	0.8	1.1	1.1	2.1	1.2	1.5	1.0
Cameroon BAU	million	0.37	0.30	0.30	0.61	0.69	0.86	0.73
% change of total	%	1.4	1.1	1.0	1.7	1.7	2.0	1.5

portion that lives in areas affected by climate events. Table 10 shows the total number of people affected (on average) every year as the average share of population affected, which ranges between 0.8 per cent and 2.1 per cent of total population.

4.2.2. Agriculture

While the amount of cropland remains unchanged compared to the business-as-usual scenario, productive cropland and agricultural production in the climate scenario are affected by adverse weather and water shortages. Figure 27 compares total cropland in the business-as-usual scenario (left) to productive cropland in the climate scenario (right). The differences (especially seasonal) are very significant in the case of Mozambique due to severe water shortages during the dry season, when most of the land is not irrigated.

The impacts of adverse weather and water shortages reduce agricultural production throughout the year depending on the frequency and magnitude of adverse climate events. Total agricultural production in the business-as-usual and climate scenarios are compared in figure 28.

The impacts of water scarcity and adverse weather are most visible in Mozambique, reducing agricultural production on average by approximately 26 per cent. The impact of climate and water scarcity on total agricultural production rates in Cameroon and Uganda range between 1.9 per cent and 3.9 per cent and 0.5 per cent and 2.1 per cent, respectively. The average production rates for the business-as-usual and climate scenarios are summarized in table 11.

Figure 27: Productive cropland (left) and productive agriculture land (right), business-as-usual and climate scenarios

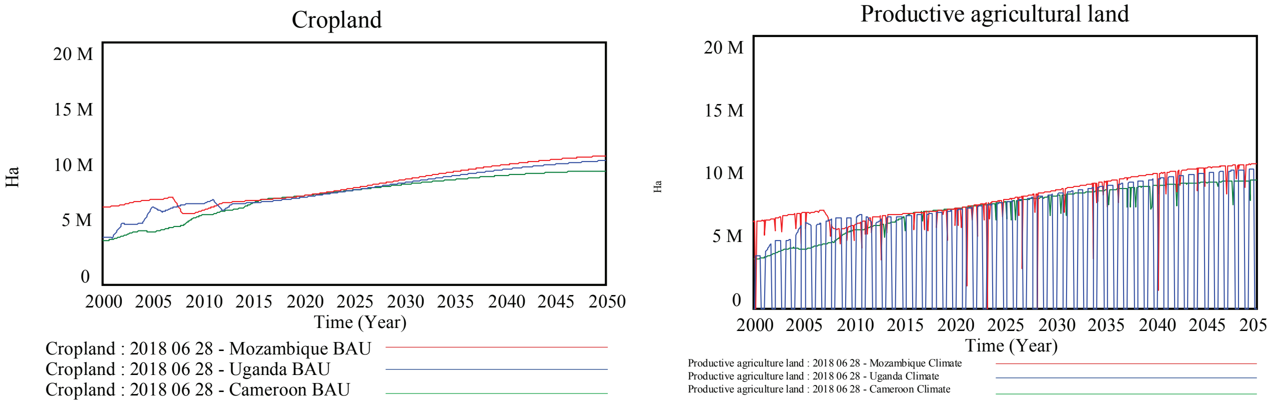


Figure 28: Total agricultural production, business-as-usual (left) and climate scenarios (right)

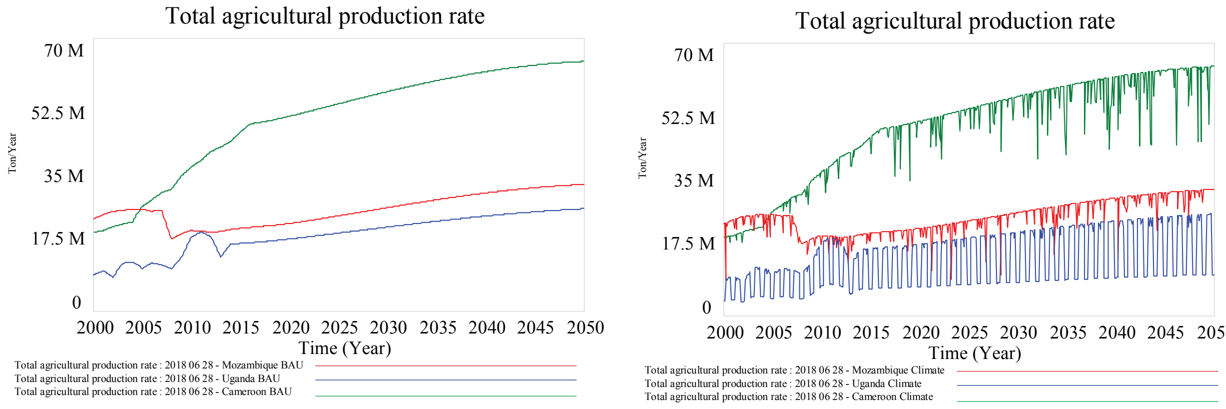


Table 11: Agricultural production, business-as-usual and climate scenarios

Agricultural production	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique Climate	mn tons / year	1.12	1.18	1.28	1.37	1.47	1.54	1.60
Mozambique BAU	mn tons / year	1.51	1.59	1.72	1.85	1.97	2.07	2.15
Climate vs BAU	%	-25.8	-25.7	-25.6	-26.0	-25.3	-25.8	-25.5
Uganda Climate	mn tons / year	1.82	1.90	2.08	2.25	2.42	2.56	2.65
Uganda BAU	mn tons / year	1.84	1.94	2.11	2.29	2.44	2.57	2.67
Climate vs BAU	%	-1.0	-2.1	-1.5	-1.6	-0.8	-0.7	-0.5
Cameroon Climate	mn tons / year	3.99	4.20	4.46	4.64	4.82	4.96	5.09
Cameroon BAU	mn tons / year	4.11	4.28	4.55	4.80	5.02	5.18	5.29
Climate vs BAU	%	-2.76	-1.86	-2.04	-3.30	-3.82	-4.24	-3.90

Table 12: Water demand for irrigation, business-as-usual and climate scenarios

Water demand for irrigation	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique Climate	mn m3	11 469.74	12 228.40	13 329.00	14 125.89	15 110.27	15 775.31	16 297.97
Mozambique BAU	mn m3	11 479.25	12 225.81	13 308.43	14 123.20	15 088.72	15 769.09	16 301.32
Climate vs BAU	%	-0.1%	0.0%	0.2%	0.0%	0.1%	0.0%	0.0%
Uganda Climate	mn m3	3 356.94	3 354.79	4 317.73	4 091.49	3 242.99	4 562.01	3 266.99
Uganda BAU	mn m3	3 254.78	3 247.54	3 968.52	3 771.12	3 013.77	4 038.17	3 083.42
Climate vs BAU	%	3.1%	3.3%	8.8%	8.5%	7.6%	13.0%	6.0%
Cameroon Climate	mn m3	534.67	461.86	259.26	843.20	952.68	1 020.24	1 250.14
Cameroon BAU	mn m3	437.23	358.71	145.17	425.83	644.27	825.90	1 007.72
Climate vs BAU	%	22.3%	28.8%	78.6%	98.0%	47.9%	23.5%	24.1%

The increase in climate variability strongly impacts water demand for irrigation in Cameroon and increases water requirements for agricultural production by 22 per cent and up to 100 per cent. This implies that increasing variability might double water demand for irrigation in some years. Climate impacts on the Ugandan agricultural sector are less marked, with additional water requirements between 3.1 per cent and 13 per cent. Mozambique is projected to experience additional water requirements of only 0.2 per cent during the peak season. This may seem counterintuitive, but it is because most of Mozambique's cropland already suffers water scarcity throughout the year. The development of water demand for irrigation over time is summarized in table 12.

Figure 29 illustrates employment in the agricultural sector in the climate scenario compared to the business-as-usual scenario. As a consequence of reduced productive land, full-time employment in agriculture is projected to be lower in the climate scenario. In Mozambique, approximately 42 per cent of agricultural employment is threatened (or will become seasonal) through water scarcity and climate impacts, which leaves around 1.26 million jobs at risk by 2050. The impact on employment in the agricultural sectors of Cameroon and Uganda are in the range of 0.5 per cent to 2.6 per cent and 0.3 per cent to 2.7 per cent, respectively.

Figure 29: Total employment in agriculture, business-as-usual (left) and climate scenario (right)

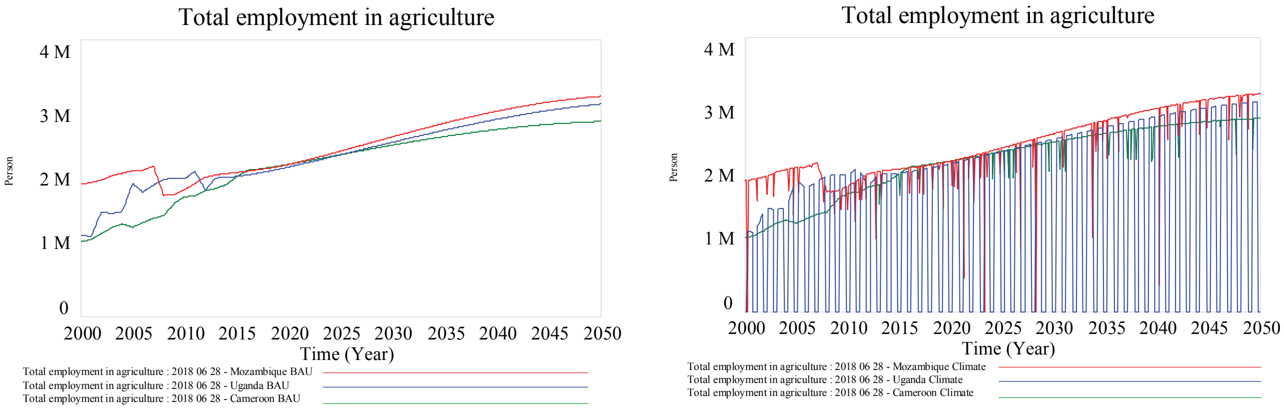


Table 13: Agricultural GDP, business-as-usual and climate scenarios

Agriculture GDP	Unit	2018	2020	2025	2030	2040	2050
Mozambique Climate	bn MT	84.66	87.95	94.89	101.23	111.23	120.95
Mozambique BAU	bn MT	111.47	114.73	123.73	132.91	149.70	160.66
Climate vs BAU	%	-24.0	-23.3	-23.3	-23.8	-25.7	-24.7
Uganda Climate	bn U Sh	13 970.07	14 353.52	15 871.60	17 107.79	18 339.91	20 658.28
Uganda BAU	bn U Sh	14 808.81	15 255.66	16 652.21	18 147.35	20 935.51	22 852.44
Climate vs BAU	%	-5.7	-5.9	-4.7	-5.7	-12.4	-9.6
Cameroon Climate	bn CFAF	2 464.57	2 524.08	2 614.70	2 748.34	2 784.98	2 803.36
Cameroon BAU	bn CFAF	2 559.26	2 612.64	2 760.03	2 903.77	3 141.51	3267.16
Climate vs BAU	%	-3.7	-3.4	-5.3	-5.4	-11.3	-14.2

The reduction in agricultural production in the business-as-usual scenario translates into a reduction in value added. Agricultural value added, or GDP, in Mozambique is reduced by approximately 24 per cent on average throughout the simulation time, while the reductions for Cameroon and Uganda are up to 14.2 per cent and 12.4 per cent, respectively. Despite experiencing the smallest impact in relative terms, the cumulative reduction in agricultural GDP is highest in Cameroon, with CFAF 8.38 trillion ($14.9 billion) compared to the baseline. The cumulative reduction for Uganda totals U Sh 37.17 trillion ($9.9 billion) by 2050, while reductions in Mozambique are projected to total MT 367.8 billion ($6.2 billion).

Table 13 provides an overview of the development of agriculture GDP between 2018 and 2050 for the business-as-usual and climate scenarios.

4.2.3. Water

In addition to population growth and the expansion of agricultural land, the increasing variability and higher evapotranspiration rates put additional pressure on water resources and increase the uncertainty of water supply. Table 14 provides an overview of the projections of the water balance for the three countries.

A decline (or growing deficit) in the water balance over time is observed for all three countries, which indicates that demand increases faster than supply. Due to the significant expansion of agricultural land in Uganda, projections indicate a negative water balance after 2025 and hence increasing exploitation of existing groundwater stocks. The average reduction in the water balance in Uganda totals 5 billion m3 per year between 2018 and 2050. The average water balance in Cameroon is projected to decrease by 6.6 billion m3 by 2050, equivalent to a 27.9 per cent reduction compared to 2018. In Mozambique, the water balance is projected to further decrease by 68.8 per cent from an average shortage of 5.98 trillion m3 in 2018 to an average annual shortage of 10.1 billion m3.

Table 14: Water balance, climate scenario

Water balance	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique Climate	mn m3	-10 978.7	-11 856.1	-13 157.8	-14 149.2	-15 371.7	-16 349.0	-17 205.1
% change to 2018	%	0.0	8.0	19.8	28.9	40.0	48.9	56.7
Uganda Climate	mn m3	448	-259	-2 174	-2 177	-2 389	-4 369	-4 258
% change to 2018	%	0.0	-157.7	-585.1	-585.9	-633.1	-1074.9	-1050.1
Cameroon Climate	mn m3	25 946	28 218	28 186	24 417	23 170	20 346	19036
% change to 2018	%	0.0	8.8	8.6	-5.9	-10.7	-21.6	-26.6

4.2.4. Energy

Increasing precipitation variability and higher temperatures pose a threat to power generation capacity and impact electricity generation efficiency. The forecast climate impacts lead to total power generation capacity in the climate scenario being slightly higher compared to the baseline. Mozambique is projected to need an additional 25MW of capacity to compensate for climate impacts on power generation, while Uganda and Cameroon require an additional 4MW and 16MW, respectively. In addition to higher capacity requirements, damage to power generation capacity significantly increases the costs of the energy sector. Compared to the baseline, Cameroon requires an additional cumulative investment of CFAF 10.49 trillion in power generation capacity by 2050, followed by Uganda and Mozambique, with cumulative additional required investments of USh 47.66 trillion and MT 221.1 billion.

The climate impacts forecast are projected to reduce the average efficiency of power generation capacity by between 1 per cent and 3.3 per cent across all three countries. Impacts can vary depending on the frequency and magnitude of adverse climate events and the technologies used to generate electricity. Figure 30 compares electricity generation rates in the business-as-usual and climate scenarios for all three countries. The spikes in electricity generation occur as a consequence of capacity damage during flood events. The model assumes that damaged capacity is replaced, and that capacity construction takes place to satisfy expected demand.

Table 16 shows average electricity generation rates between 2018 and 2050 in five-year intervals.

Table 15: Impacts on power generation capacity

Table 15 provides an overview of damage to capacity, total economic damage and annualized damage over a period of 30 years.

Country	Cumulative damage to capacity	Total economic damage	Economic damage over 30 years
	MW	bn LCU	bn LCU / Year
Mozambique	387	34.4	1.15
Uganda	1 315	7 409.7	246.99
Cameroon	3 826	3 228.4	107.61

Abbreviation: LCU, local currency unit.

Figure 30: Electricity generation, business-as-usual (left) and climate scenario (right)

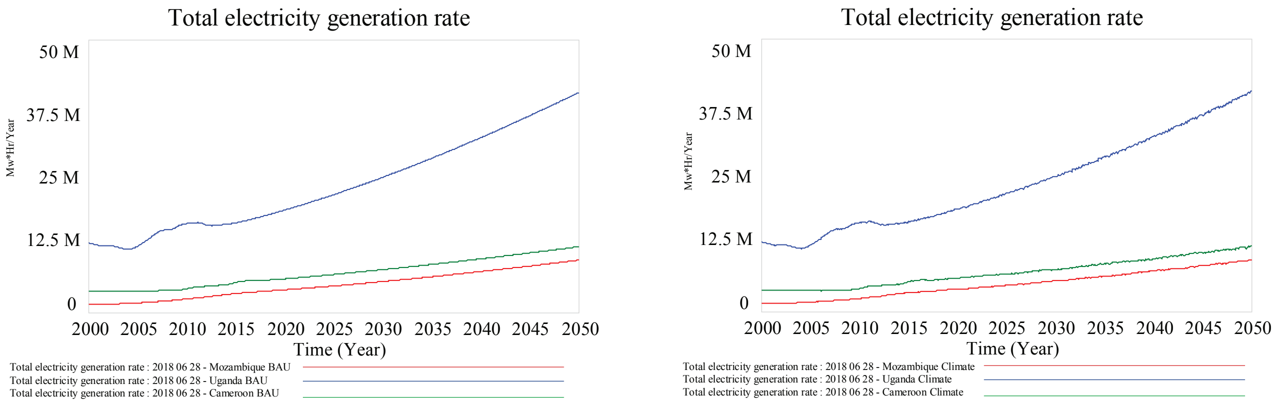
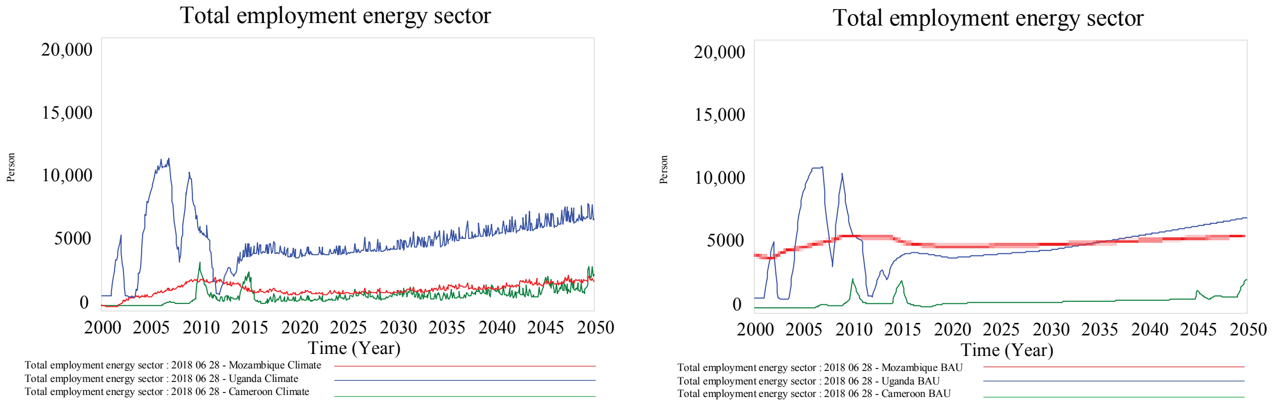


Table 16: Electricity generation, business-as-usual and climate scenarios

Electricity generation	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique Climate	TWh	18.19	20.08	23.10	26.40	30.05	33.97	38.09
Mozambique BAU	TWh	18.19	20.09	23.09	26.42	30.06	33.96	38.10
Climate vs BAU	%	0.0	-0.1	0.0	-0.1	0.0	0.0	0.0
Uganda Climate	TWh	3.94	4.40	5.17	6.00	6.90	7.87	8.89
Uganda BAU	TWh	3.99	4.47	5.23	6.07	6.98	7.97	9.02
Climate vs BAU	%	-1.4	-1.6	-1.1	-1.2	-1.2	-1.3	-1.5
Cameroon Climate	TWh	5.94	6.48	7.26	8.17	9.16	10.23	11.31
Cameroon BAU	TWh	6.00	6.52	7.37	8.29	9.28	10.34	11.44
Climate vs BAU	%	-1.0	-0.6	-1.6	-1.4	-1.4	-1.0	-1.2

Figure 31: Total employment in the energy sector, business-as-usual (left) and climate scenario (right)



Total employment in the energy sector increases because of the need to replace damaged capacity. The increase in employment stems from construction only. On average, employment in the energy sectors of Mozambique, Cameroon and Uganda increases by 26.2 per cent, 67.1 per cent and 17.9 per cent, respectively (1,250, 230 and 600 additional jobs, respectively, between 2018 and 2050). The employment provided by the energy sector for both scenarios is depicted in figure 31. The spikes in electricity employment represent period of reconstruction of capacity damaged by floods.

4.2.5. Summary of results

The results of the analysis have shown that including climate impacts in simulations has significant impacts on the performance and costs

Table 17: Integrated assessment of costs and benefits

Category Value added	Unit	Mozambique	Uganda	Cameroon
Agriculturale GDP	mn USD	-6 201.54	-9 897.41	-14 899.45
Climate vs BAU	%	-12.1%	-13.7%	-16.7%
Livestock GDP	mn USD	-43.55	-201.55	-369.85
Climate vs BAU	%	-21.9%	-43.0%	-70.7%
Investments and costs				
Electricity				
Investments	mn USD	3 728.23	12 688.93	18 652.83
Conventional	mn USD	667.83	1 680.25	5 877.30
Renewable	mn USD	3 060.41	11 008.68	12 775.53
Avoided costs				
O&M cost power generation	mn USD	-27.18	18.79	25.37
Conventional	mn USD	-5.47	6.44	17.79
Renewable	mn USD	-21.71	12.35	7.58
Added benefits				
Labour income energy	mn USD	2 694.84	21.59	12.26
Net benefits	mn USD	-7 262.1	-22 546.0	-33 514.6
Exchange rate	LCU / USD	59.3	3 756.0	562.5

Abbreviations: LCU, local currency unit; USD, United States dollars.

of the agricultural, water and energy sectors. Policy interventions to adapt to climate change and mitigate these additional costs have not been tested yet, but the results already show the potential for cost mitigation and for restoring baseline economic performance.

Table 17 provides a summary of the cumulative economic impacts (by 2050) of introducing climate change trends in the simulation of the three sectors analysed.

Climate impacts are projected to reduce agricultural GDP by between 12.1 per cent and 16.7 per cent. Furthermore, additional investments in power generation capacity are required to replace capacity that is damaged during flood events. Because more labour is required to replace power generation capacity, total labour income is projected to increase through additional employment.

Table 2 provides an overview of the physical impacts of climate events by sector.

Table 2: Physical impacts, climate scenario

Sector	Unit	Mozambique	Uganda	Cameroon
Agriculture				
Total production	mn tons	-8.9	-25.9	-51.2
Additional water demand	mn m3	270.1	114 615.1	87 114.7
Energy				
Power generation capacity	MW	1 684.5	6 404.4	9 089.7
Electricity production	mn MWh	-0.1	-2.5	-3.3
Water				
Water resources internally produced	mn m3	-72 249	-377 674	-1 596 445
Water balance	mn m3	90 595	64 219	3 698 844

Table 19: Annualized impacts over 30 years, climate scenario

Sector	Unit	Mozambique	Uganda	Cameroon
Agriculture				
Total production	mn tons / year	-0.30	-0.86	-1.71
Agricultural GDP	mn USD / year	-206.72	-329.91	-496.65
Crop production GDP	mn USD / year	-205.27	-323.20	-484.32
Livestock GDP	mn USD / year	-1.45	-6.72	-12.33
Additional water demand	mn m3 / year	90.02	3 820.50	2 903.82
Energy				
Capital investment	mn USD / year	124.27	422.96	621.76
O&M expenditure	mn USD / year	-0.91	0.63	0.85
Electricity production	mn MWh / year	0.00	-0.08	-0.11
Power generation capacity	MW	56.15	213.48	302.99
Labour income energy	bn LCU* / year	89.83	0.72	0.41
Water				
Water resources internally produced	mn m3 / year	-2 408.3	-12 589.1	-53 214.8
Water balance	mn m3 / year	3 019.8	2 140.6	123 294.8

Adaptation scenario

The table above presents annualized values of climate-related impacts across all sectors. The cumulative values are annualized over 30 years. The results of the agricultural sector will serve for illustration purposes. The key impacts observed in the agricultural sector are that total production decreases, while total water demand increases. The cumulative reduction in agricultural production indicated in table 18 translates into an average annual production of 300,000 tons for Mozambique, 860,000 tons for Uganda and 1.71 million tons for Cameroon over 30 years. While production declines, total annual water consumption increases on average by between 90 million m3 per year in Mozambique and 3.82 billion m3 of water per year in Uganda. Overall, the reduction in production and climate-related loss of livestock leads to a reduction in total agricultural value added.

4.3 Adaptation scenario

4.3.1. Assumptions

The adaptation scenario assumes the implementation of interventions to reduce the

Table 20: Assumptions, adaptation scenario

Sector	Value 2018 (%)	Value 2025 (%)
Agriculture (all countries)		
Share of organic farming	0	25
Additional productivity organic farming	10	
Additional value-added organic farming	10	
Additional labour organic farming	10	
Energy		
Share of renewable energy		
Cameroon	70.0	85.0
Uganda	90.0	100.0
Mozambique	82.6	97.6
Water		
Share of drip irrigation	0	30
Efficiency conventional irrigation	25	
Efficiency drip irrigation	82	

vulnerability of climate impacts. These interventions are simulated using the climate scenario (i.e. the climate scenario is used as baseline), and the results are therefore compared to the climate scenario to determine net investments and related outcomes. This implies that the adaptation scenario uses the same assumptions presented in section 2.3.1.

To increase the resilience of the agricultural sector, a transition towards organic farming practices is simulated. In the energy sector, the implementation of decentralized renewable energy aims to reduce the vulnerability of power generation capacity to climate impacts. To increase water security, a transition to drip irrigation is assumed. Table 20 summarizes the assumptions by sector and intervention.

Policy interventions are implemented between 2018 and 2025. A linear increase between 2018 and 2025 is assumed until the stated target is reached.

4.3.2. Agriculture

The transition to organic farming increases the productivity of the agricultural sector considerably. While the amount of total cropland remains the same as in the climate scenario, total annual agricultural production increases on average by 5 per cent. The highest impact is observed for Cameroon, where total agricultural production increases by 3.12 million tons by 2050. The increase for Uganda and Mozambique is projected at 1.59 million tons and 0.86 million tons by 2050, respectively. Total agricultural production for the adaptation and climate scenarios is illustrated in figure 32.

Figure 32: Total agricultural production, adaptation vs climate scenarios

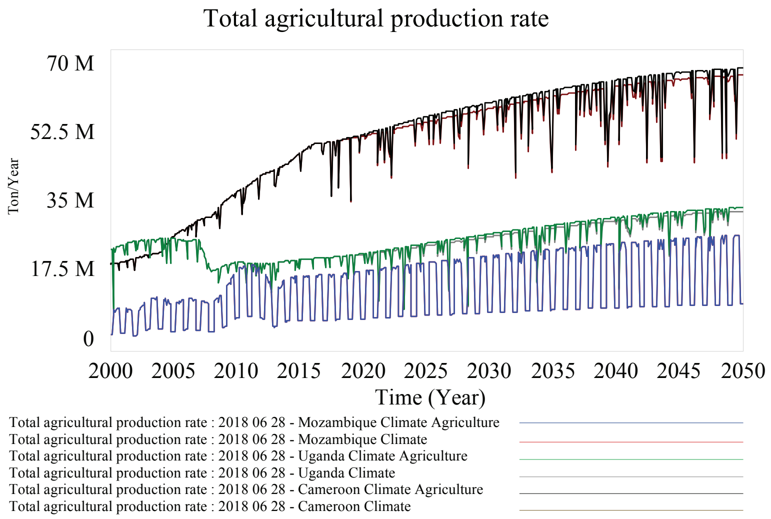


Table 21: Agricultural production, adaptation vs climate scenarios

Agricultural production	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045
Mozambique Adaptation	mn tons / year	1.12	1.21	1.34	1.42	1.53	1.60
Mozambique Climate	mn tons / year	1.12	1.18	1.28	1.36	1.47	1.53
Adaptation vs Climate	%	0.6	2.9	4.5	4.5	4.5	4.5
Uganda Adaptation	mn tons / year	1.80	1.92	2.16	2.31	2.52	2.61
Uganda Climate	mn tons / year	1.79	1.86	2.05	2.20	2.40	2.49
Adaptation vs Climate	%	0.7	3.2	5.0	5.0	5.1	5.0
Cameroon Adaptation	mn tons / year	4.02	4.35	4.69	4.89	5.09	5.26
Cameroon Climate	mn tons / year	4.00	4.21	4.47	4.65	4.84	5.00
Adaptation vs Climate	%	0.70	3.24	5.05	5.06	5.05	5.06

Table 22: Agricultural GDP, adaptation and climate scenarios

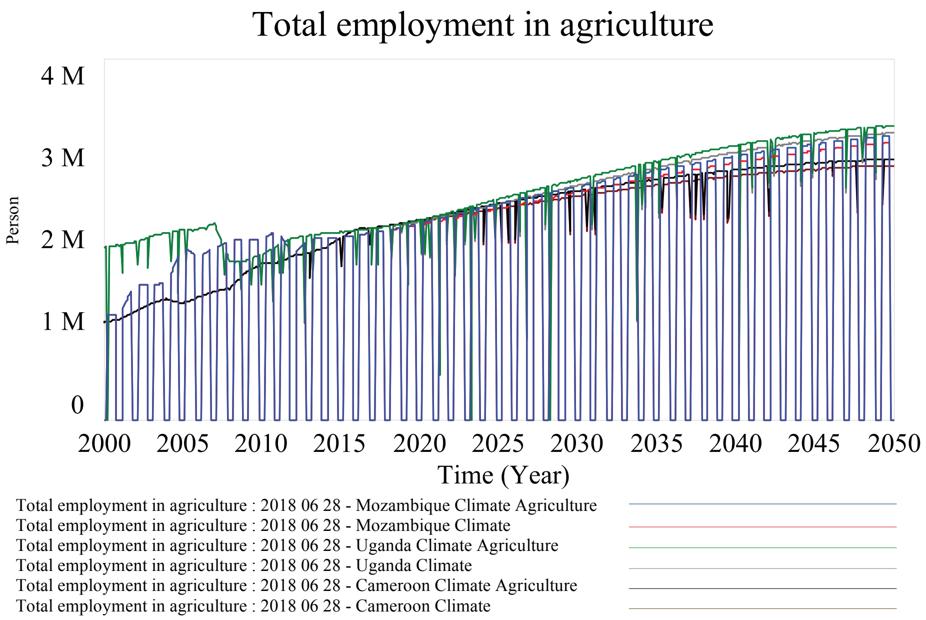
Agricultural GDP	Unit	2018	2020	2025	2030	2040	2050
Mozambique Adaptation	bn MT	84.91	89.29	99.01	105.66	116.13	126.31
Mozambique Climate	bn MT	84.66	87.95	94.89	101.23	111.23	120.95
Adaptation vs Climate	%	0.3	1.5	4.3	4.4	4.4	4.4
Uganda Adaptation	bn U Sh	14 009.23	14 569.83	16 558.18	17 853.01	19 144.57	21 572.26
Uganda Climate	bn U Sh	13 970.07	14 353.52	15 871.60	17 107.79	18 339.91	20 658.28
Adaptation vs Climate	%	0.3	1.5	4.3	4.4	4.4	4.4
Cameroon Adaptation	bn CFAF	2 471.40	2 561.11	2 725.47	2 866.30	2 910.05	2 934.75
Cameroon Climate	bn CFAF	2 464.57	2 524.08	2 614.70	2 748.34	2 784.98	2803.36
Adaptation vs Climate	%	0.3	1.5	4.2	4.3	4.5	4.7

Table 21 summarizes the development of agricultural production in the adaptation scenario and the climate scenario, in five-year intervals.

The increase in agricultural production leads to an increase in agricultural GDP of 4.5 per cent in Mozambique, 5.0 per cent in Uganda and 5.06 per cent in Cameroon. Cumulatively, the increase in the agricultural GDP of Cameroon totals CFAF 3.44 trillion between 2018 and 2050, equivalent to an increase of CFAF 114.7 billion over 30 years. The cumulative additional GDP for Uganda and Mozambique during the same period is U Sh 13.74 trillion and MT 133 billion, respectively. In the long run, the application of organic farming practices increases agricultural GDP by between 4.4 per cent and 4.7 per cent.[1] Table 22 provides an overview of agricultural GDP in the climate and adaptation scenarios, and indicates the percentage change observed between the two scenarios.

In addition to beneficial economic impacts, the transition to organic farming increases employment creation in the agricultural sector. The increase in agricultural employment for all three countries is projected to be 2.5 per cent, which is equivalent to 63,410 additional jobs in Cameroon, 77,770 additional jobs in Uganda and 44,080 additional jobs in Mozambique. The development of agricultural GDP and employment is illustrated in figure 33.

Figure 33: Agricultural employment, adaptation vs climate scenarios



---

[1] The increase in production is slightly higher than the increase in GDP. This is because the envisioned interventions only apply to crop production and not to livestock.

Table 23: Net benefits of organic farming

Investments	Unit	Mozambique	Uganda	Cameroon
Organic farming	bn LCU*	386	25 282	3 515
Added benefits				
Agricultural GDP	bn LCU	133	13 735	3 440
Total net benefits	bn LCU	-253	-11 547	-74

**LCU* = local currency unit.

Table 24: Break-even conditions for organic farming, adaptation scenario

Policy measure	Unit	Mozambique	Uganda	Cameroon
Required cost per ha	USD / Ha / Year	34.5	54.3	97.9
Required premium price	%	29.0	18.4	10.2

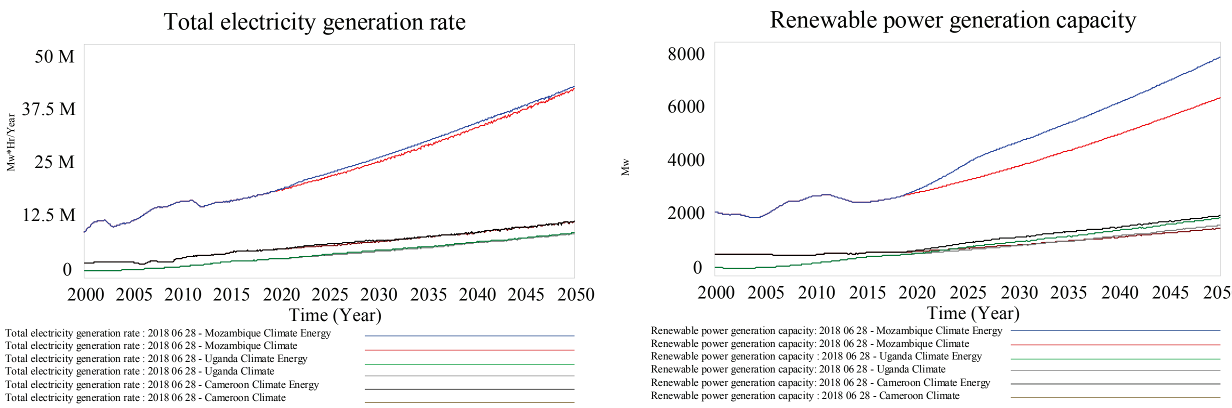
Between 2018 and 2050, the transition to organic farming requires investments of CFAF 3.52 trillion in Cameroon, U Sh 25.28 trillion in Uganda and MT 386 billion in Mozambique. Table 23 illustrates the required investments and the additional value added realized through the transition towards organic farming.

Projections indicate that the additional value added per hectare is currently insufficient to cover the additional investments, despite higher productivity and the increase in value added per ton of output.[2] Options to cover the additional costs would be a reduction in investment per hectare or a higher price premium for export products. Table 24 provides an overview of the break-even costs and price premium for organic agriculture.

4.3.3. Energy

The transition towards renewable energy increases the resilience of the power generation sector in the face of climate change impacts and adverse climate events. Between 2018 and 2050, the increase in resilience leads to cumulative additional power generation of 24.9 million MWh in Mozambique, followed by Cameroon and Uganda, with 4.1 and 3.5 million MWh, respectively. Figure 34 (left) illustrates the development of renewable capacity in the adaptation and the climate scenarios. The graph on the right compares the electricity generation rate for both scenarios. Total electricity generation in the adaptation scenario is on average between 1.5 per cent and 2.8 per cent higher than in the climate scenario, which corresponds to a value up

Figure 34: Renewable capacity (left) and electricity generation (right), adaptation vs climate scenarios



---

[2] The assumed investment costs per hectare of organic agriculture is $100 per hectare per year.

Figure 35: Energy sector employment, adaptation and climate scenarios

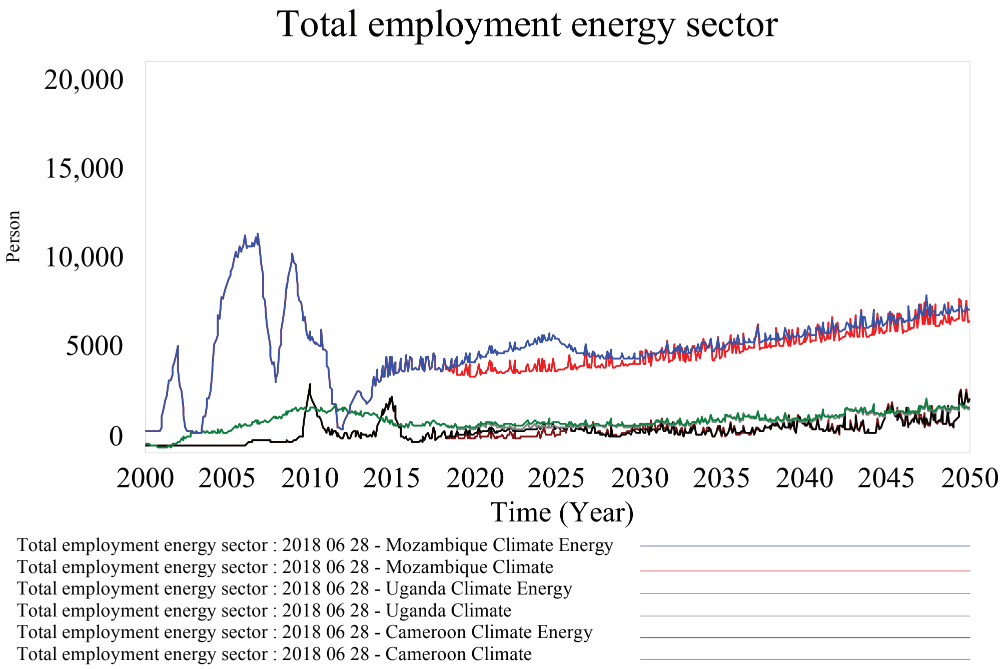


Table 25: Net benefits to the energy sector, adaptation scenario

Investments	Unit	Mozambique	Uganda	Cameroon
Renewable capacity	mn USD	75 153	9 119	15 768
Investment	mn USD	73 693	9 008	15 298
Operation and maintenance cost	mn USD	1 460	111	470
Avoided cost				
Conventional capacity	mn USD	27 594	4 440	8 778
Investment	mn USD	26 298	4 309	8279
Operation and maintenance cost	mn USD	1 297	131	498
Added benefits				
GDP from access to energy	mn USD	17 115	20 775	25 393
Labour income	mn USD	20 986	5.1	1.4
Total Net benefits	mn USD	-9 458	16 100	18 404

to 245 additional hours (or approximately 10 days) of electricity availability per year.

The transition to renewable energy generates temporary higher employment in the energy sector, mainly driven by the construction of new power capacity. In the long run, employment in Mozambique and Uganda increases by 4.6 per cent and 2.5 per cent, respectively, while employment in the energy sector in Cameroon is projected to decrease by 0.7 per cent.

Despite improved economic productivity as a result of increased access to electricity, the transition to renewable energy needs to be balanced by the current stock of installed capacity to avoid idle capacity and the need to use thermal power capacity sub-optimally. Table 25 provides an overview of the investments, avoided costs and added benefits in the energy sector. While the transition requires additional investments in capacity in all three countries, net economic benefits are only realized in the cases of Uganda and Cameroon. In the case of Mozambique, the 15 per cent increase in renewable capacity creates overcapacity, which results in a net loss of $9.46 billion between 2018 and 2050. This indicates that overambitious investments in renewable energy run the risk of not being economically viable in the long run. The model was simulated with this assumption to assess its validity and to evaluate the diversity of country contexts.

Table 26: Climate impacts on power generation capacity, adaptation vs climate scenarios

	Adaptation scenario		Climate scenario		Difference	
Total damage to capacity	MW	mn USD	MW	mn USD	MW	mn USD
Mozambique	1 254	2 931	1 292	2 815	-38	116
Uganda	6 812	13 825	7 025	13 777	-213	48
Cameroon	7 622	16 636	8 122	16 353	-500	282

Table 27: Water demand for irrigation, adaptation vs climate scenarios

Water demand for irrigation	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045	2045-2050
Mozambique Adaptation	mn m3	11 219.15	10 931.26	11 105.33	11 769.28	12 589.44	13 143.52	13 578.99
Mozambique Climate	mn m3	11 469.74	12 228.40	13 329.00	14 125.89	15 110.27	15 775.31	16 297.97
Adaptation vs Climate	%	-2.2	-10.6	-16.7	-16.7	-16.7	-16.7	-16.7
Uganda Adaptation	mn m3	3 281.86	3 006.64	3 597.41	3 408.91	2 701.96	3 800.94	2 721.96
Uganda Climate	mn m3	3 356.94	3 354.79	4 317.73	4 091.49	3 242.99	4 562.01	3 266.99
Adaptation vs Climate	%	-2.2	-10.4	-16.7	-16.7	-16.7	-16.7	-16.7
Cameroon Adaptation	mn m3	520.43	419.11	216.01	702.53	793.74	850.04	1 041.58
Cameroon Climate	mn m3	534.67	461.86	259.26	843.20	952.68	1 020.24	1 250.14
Adaptation vs Climate	%	-2.7	-9.3	-16.7	-16.7	-16.7	-16.7	-16.7

The physical and economic damage resulting from adverse weather in the adaptation and climate scenarios area compared in table 26. The decentralization of the power grid reduces climate-related damage cumulatively by between 38 MW and 500 MW in all three countries. The increase in electricity production and the reduction in physical damage indicate that the electricity generation sector is less vulnerable to the impacts of climate change. However, despite the reduction in damage to physical capacity, the cumulative economic value of damage increases by between 0.4 per cent and 4 per cent compared to the climate scenario due to the higher capacity costs of renewable capacity. This is equivalent to an average increase of between $1.5 million and $8.8 million per year between 2018 and 2050.

4.3.4. Water

Projections for the water sector indicate that the introduction of efficient (drip) irrigation has the potential to reduce water consumption and boost productivity significantly. The most significant savings are achieved in Mozambique, where introducing drip irrigation yields average water savings of 27.9 trillion cubic metres per year over a 30-year period. During the same period, the projected water savings obtained in Uganda and Cameroon average 7.26 and 1.54 trillion cubic metres, respectively. If water savings were used to irrigate additional cropland, the total amount of cropland could be increased by between 12.8 per cent and 14.4 per cent (assuming that the same amount of water is used, when water efficiency increases the number of hectares irrigated can also increase). Table 27 compares water demand for irrigation in the adaptation and climate scenarios. In the long run, water demand for irrigation could be reduced by 16.7 per cent.

Introducing drip irrigation would require additional cumulative investments between $6 billion and $6.67 billion between 2018 and 2040 (see table 28). The development of water demand from agriculture in the adaptation and climate scenarios is illustrated in figure 36. It is difficult to assess the value of these water savings, since water efficiency could be driven by the need to ensure minimum environmental flows, provide more water for population and livestock or to increase the productivity of agricultural land.

Figure 36: Agricultural water demand, adaptation vs climate scenarios

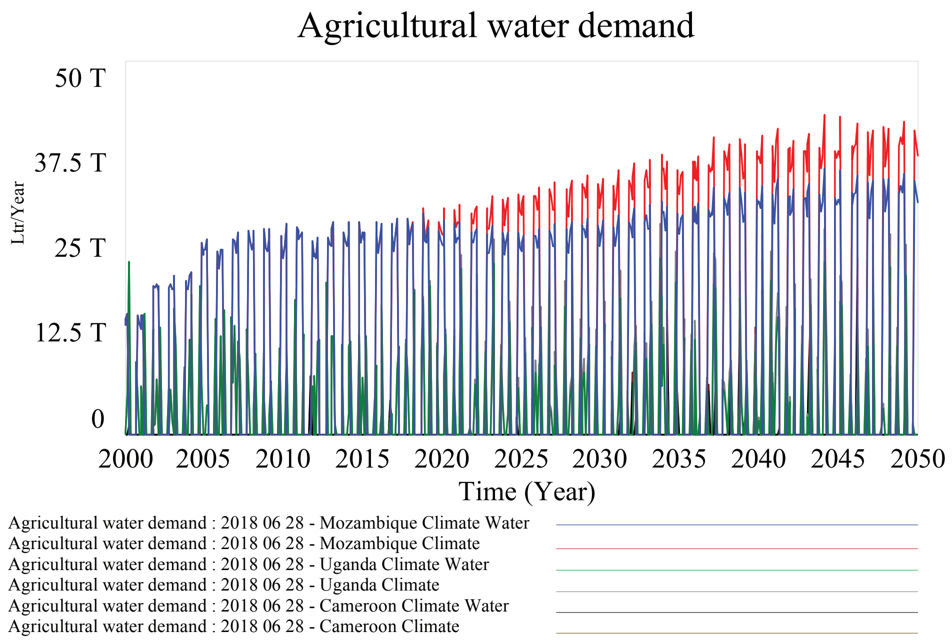


Table 28: Total net benefits of all interventions

Category	Unit	Mozambique	Uganda	Cameroon
Investment				
Renewable energy	mn USD	91 209	10 344	20 940
Investments	mn USD	73 693	9 008	15 298
Operation and maintenance costs	mn USD	17 516	1 335	5 642
Organic agriculture	mn USD	6 506	6 731	6 248
Irrigation	mn USD	6 439	6 669	5 987
Investments in drip irrigation	mn USD	4 599	4 766	4 218
Operation and maintenance irrigation	mn USD	1 840	1 904	1 768
Total investment and costs	mn USD	104 153	23 744	33 174
Avoided costs				
Conventional energy	mn USD	41 857	5 880	14 260
Investments	mn USD	26 298	4 309	8 279
Operation and maintenance costs	mn USD	15 559	1 570	5 981
Total avoided costs	mn USD	41 857	5 880	14 260
Added benefits				
Labour income energy	mn USD	20 986	5	1.4
Agricultural GDP	mn USD	2 242	3 657	6 116
GDP from access to energy	mn USD	1 731	14 279	112 842
GDP from additional land	mn USD	5 652	6 998	10 037
Total added benefits	mn USD	30 611	24 940	128 996
Net benefits	bn LCU*	-31 685	7 075	110 082

4.3.5. Summary of results

The net benefits of interventions aimed at improving climate resilience are summarized in table 28. Overall, net benefits are projected for Uganda ($7.07 billion) and Cameroon ($110.08 billion), while the simulated scenarios indicate a net loss for Mozambique ($-31.69 billion), mainly attributable to the forced transition to renewable energy (the expansion of renewable energy being faster than the decommissioning of existing capacity).

With regard to sectoral interventions, between 2018 and 2050, investments in sustainable farming range between $6.25 billion and $6.73 billion. Total cumulative costs (investment and operation and maintenance) for efficient irrigation are in a comparable range, with $5.99 billion and $6.67 billion, of which approximately 71.4 per cent is upfront capital investment. The amount of investment required for irrigation ranges between $4.22 billion in Cameroon and $4.77 billion in Uganda.

The shift to renewable power generation capacity reduces the required investments and operation and maintenance costs for conventional power generation capacity. The magnitude of savings depends on the current amount and use factor of power generation capacity and on the current use of renewables.

Benefits are generated by increasing access to water and electricity. Renewable and decentralized energy increases access to and availability of electricity, which results in increased total economic performance of around 1.5 per cent to 2 per cent per year (using the value added created per MWH of power generation). Furthermore, additional water from more efficient irrigation increases the carrying capacity of the agricultural sector and hence increases total production.

5. Discussion: the relevance of a nexus approach

Adaptation to climate change to improve resilience has the potential both to reduce the impacts of climate change and improve the baseline (i.e. create additional value).

The results of the analysis have shown that including climate impacts in simulations has significant impacts on the performance and costs of the agricultural, water and energy sectors. Climate impacts are forecast to reduce agricultural GDP by between 12.1 per cent and 16.7 per cent by 2050. Climate change also brings additional costs, e.g. in power generation capacity.

As we have seen, the simulation of climate adaptation measures indicates, not only the potential to reduce costs, but also the possibility to generate net benefits, as summarized in table 27. Uganda and Cameroon show considerable net benefits, while Mozambique incurs a net loss (due to the forced transition to renewable energy and lower use factor).

What is most interesting in the context of the nexus approach is that several synergies emerge when linking together the agriculture, energy and water models.

Between water and agriculture, and between agriculture and energy, this is evident through the implementation of drip irrigation. The implementation of drip irrigation reduces the pressure on water resources and makes water available for other purposes (e.g. domestic consumption, livestock, industry, etc.), or for additional agricultural production. In other words, it removes a bottleneck for the agricultural sector and increases its resilience.

Drip irrigation also significantly reduces the energy requirements for water pumping, which reduces the total energy demand for agricultural production, also increasing the resilience of the sector to possible power shortages.

In addition, by establishing renewables, the decentralization of power generation capacity benefits total employment. Establishing solar power and small renewables generates maintenance employment and contributes to improved productivity in rural areas by providing access to electricity, supporting the diversification of the economy and hence increasing its resilience.

As a result, using a nexus approach allows potential synergies and bottlenecks to be identified that could render a project (or an investment) more or less attractive in terms of economic viability. In our analysis we have primarily found positive synergies, with savings emerging in water and energy use that both increase climate resilience and at the same time lead to stronger economic performance for the sectors. Similarly, cross-sectoral impacts emerge for health and livelihoods, where investing in climate adaptation not only improves climate resilience, but also increases the social and economic resilience of the local population.

6. Conclusions

The work presented in this report entailed the creation of sectoral simulation models for agriculture, energy and water. These models were then connected to one another to carry out a more systemic analysis in the form of the nexus approach.

Different versions of these models were developed: a template, or research version, and three customizations at the national level (to Cameroon, Mozambique and Uganda). The structure of the model was intentionally kept very similar across countries, with minimal customization (to support cross-validation and benchmarking, but also to keep the models simple), but parametrization was performed using exclusively country data.

The analysis shows that it is crucial to include climate impacts in any economic analysis in the context of the agricultural, energy and water sectors. The outcomes of changing weather dynamics and trends are meaningful. The analysis of climate adaptation scenarios also shows the outcomes of interventions in terms of reducing costs and generating new benefits. Importantly, synergies also emerged across sectors, indicating that the nexus approach can provide valuable inputs to policy formulation and investment assessments, including in the context of climate resilience and disaster risk reduction.

More work is required on data collection, model development (especially for the creation of local capacity), and dissemination of results. This could perhaps be done through the same infrastructure used for climate information services. The potential impact on the ground both for planning and immediate action by farmers is considerable when these tools are used in synergy.

7. Recommendations

Eight main recommendations emerge from the analysis carried out and presented in this report:

Incentivize the use of systemic planning, across sectors and including social, economic and environmental performance indicators. This is needed to implement the nexus approach.

Use a multi-stakeholder approach to ensure that all key indicators are considered and that policies are formulated and implemented effectively.

Support the development of new quantitative models that implement knowledge integration across disciplines, and fully account for climate science (to incorporate weather forecasts, and project climate impacts as well as policy/investment outcomes on climate vulnerability, adaptive capacity and resilience).

Increase investment in the collection, processing and use of weather information, including early warning systems.

Invest in climate information services to disseminate information in a timely manner. This would serve as a foundation for improved planning and more timely intervention.

Require the preparation of integrated economic analysis (i.e. cost-benefit analysis that includes the economic valuation of social and environmental project/investment outcomes).

Establish a technical interministerial working group, supported by representatives of academia, responsible for assessing sectoral and systemic resilience, with the goal of strengthening policy coordination.

Carry out an annual assessment of the potential budgetary savings emerging from the improvement of climate resilience and provide incentives for private investment aimed at reducing climate vulnerability.

References

Ayoki, M. (2012). Uganda's Emerging Middle Class and its Potential Economic Opportunities. Retrieved from Munich Personal RePEc Archive: https://mpra.ub.uni-muenchen.de/78843/1/MPRA_paper_78843.pdf.

Bassi, A., Bečić, E., & Lombardi, N. (2014). An Introduction to the Assessment of Sustainable Paths, Models and Metrics. Asian Social Science, 10(11), 17-27.

Economies Africaines. (2017). Mozambique - THE ROAD NETWORK. Retrieved from Economies Africaines - Le site économique de "toutes les Afriques": http://www.economiesafricaines.com/en/countries/mozambique/infrastructures/the-road-network.

FAO. (2018a). FAOSTAT data. Retrieved from Food and Agriculture Organization of the United Nations: http://www.fao.org/faostat/en/#data.

FAO. (2018b). Crop Water Information. Retrieved from Food and Agriculture Organization of the United Nations: http://www.fao.org/land-water/databases-and-software/crop-information/en/.

Forrester, J. (1961). Industrial Dynamics. MA, Camebridge: MIT Press.

Forrester, J. (2002). Road Maps: A guide to learning System Dynamics. Camebridge: Systen Dynamics Group, Sloan School of Management, MIT.

Glassdoor. (2016, 12 07). TOTAL Salaries. Retrieved from https://www.glassdoor.com/Salary/ TOTAL-Cameroon-Salaries-EI_IE1038.0,5_IL.6,14_IN52.htm.

LCA. (2018, 05). 2.3 Cameroon Road Network. Retrieved from Logistics Capacity Assessment: http://dlca.logcluster.org/display/public/DLCA/2.3+Cameroon+Road+Network;jsessionid=11EC7F55DEF1748311E125AC4458B3D2.

Meadows, D. (1980). The unavoidable A Priori. In J. Randers, Elements of the system dynamics method (pp. 23-57). Camebridge: MIT Press.

Ndongsok, D., & Ruppel, O. (2017). State of the electricity production and distribution in Cameroon . Retrieved from Konrad-Adenauer-Stiftung e.V: http://www.kas.de/wf/doc/kas_50984-1522-2-30.pdf?171211182600.

Roberts, N., Andersen, D., Deal, R., Garet, M., & Shaffer, W. (1983). Introduction to Computer Simulation. The System Dynamics Approach. MA: Addison-Wesley.

Rozema, J., & Bond, A. (In press). Framing effectiveness in impact assessment: Discourse accommodation in controversial infrastructure development. Environmental Impact Assessment Review.

Sauer, T., Havlík, P., Schneider, U., Schmid, E., Kindermann, G., & Obersteiner, M. (2010). Agriculture and resource availability in a changing world: The role of irrigation. doi:10.1029/2009WR007729: Water Resources Research 46.

TSP. (2018). Historical Electricity Installed Capacity Statistics. Retrieved from The Shift Project: http://www.tsp-data-portal.org/Historical-Electricity-Capacity-Statistics#tspQvChart.

UNDESA. (2018). United Nations Department of Economic and Social Affairs - Population trends. Retrieved from http://www.un.org/en/development/desa/population/theme/trends/index.shtml.

UNEP. (2014). Using Models for Green Economy Policymaking.

WageIndicator. (2018). Minimum Wages in Mozambique with effect from 01-04-2018 to 31-03-2019. Retrieved from https://wageindicator.org/main/salary/minimum-wage/mozambique.

Wallhagen, M., & Glaumann, M. (2011). Design consequences of differences in building assessment tools: a case study. Building Research & Information, 39(1), 16-33.

World Bank. (2018). The World Bank Climate Change Knowledge Portal. Retrieved from http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisCCode=CAF.

World Bank Data. (2018). World Bank Open Data. Retrieved from https://data.worldbank.org/.

Printed in Addis Ababa, Ethiopia by the ECA Printing and Publishing Unit.
ISO 14001:2015 certified. Printed on chlorine free paper.

WISER is supported by:

UKaid
from the British people