United Nations
Economic Commission for Africa

Final report

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

July 21, 2018

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Weather and Climate Information Services for Africa

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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 at addressing a specific gap, in that conventional forecasting tools and analyses are often comparatively static (mostly employing linear approaches) and are narrowly focused on a sector or a specific set of thematic indicators. We instead employ a systemic approach, consider social, economic and environmental indicators within a sector, and link them across sectors to generate dynamic projections that allow to estimate policy outcomes 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, agriculture production depends on the amount of productive agriculture 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 the 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: a Business As Usual (BAU) case that does not include climate trends, a Climate scenario (which uses forecasted precipitation variability), and an Adaptation scenario (which includes interventions to improve climate resilience).

- In the **BAU scenario** we see growing population and GDP over time. Total population of Mozambique is projected to reach 69.2 million people by 2050; Uganda's population reaches 109.4 million people; the population of Cameroon increases by 24.4 million people to 51.04 million inhabitants by 2050. This leads to higher land use for agriculture, more 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% increase in precipitation variability (growing over time) compared to the BAU case. Several impacts of climate change are explicitly modeled, as presented in Table 1.

Climate impact	**Floods**	**Droughts**
Population affected by extreme events	X	X
Lifetime of agriculture land		X
Productive cropland	X	X
Load factor conventional	X	X
Load factor renewable	X	
Evapotranspiration rate		X

Damages to roads	X	

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

- Overall, climate impacts are projected to reduce agriculture GDP by between 12.1% and 16.7%. 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 impacts are most visible in Mozambique and reduce agriculture production on average by approximately 26%. The reduction in agriculture production compared to the BAU scenario translates into a reduction in value added. Agriculture value added, or GDP, in Mozambique is reduced by approximately 24% on average throughout the simulation time, and reductions for Cameroon and Uganda reach up to 14.2% and 12.4% respectively.

- Increasing precipitation variability and higher temperatures pose a threat to power generation capacity and impact electricity generation efficiency. The forecasted 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.

- The **Adaptation scenario** assumes the implementation of interventions to reduce the vulnerability of climate impacts. To increase the resilience of the agriculture sector, a transition towards organic farming practices is simulated. In the energy sector, the implementation of decentralized renewable energy aims at reducing 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 agriculture sector considerably. While the amount of total cropland remains the same as in the Climate scenario, total annual agriculture production increases on average by 5%. The highest impact is observed for Cameroon, where total agriculture production increases by 3.12 million tons in 2050.

- In addition to beneficial economic impacts, the transition towards organic farming increases employment creation in the agriculture sector. The increase in agriculture employment for all three countries is projected at 2.5%, 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 towards 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% and 2.8% higher than in the Climate scenario, which corresponds to a value up to 245 additional hours (or approximately 10 days) of electricity availability per year.

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

- Projections for the water sector indicate that the introduction of efficient (drip) irrigation has the potential to significantly reduce water consumption and boost productivity. The most significant savings are achieved in Mozambique, where introducing drip irrigation yields average water savings of 27.9 trillion m3 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% and 14.4% (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 together 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 agriculture production. In other words, it removes a bottleneck for the agriculture sector and increases its resilience. Drip irrigation also significantly reduces the energy requirements for water pumping, which reduces the total energy demand.

- The decentralization of power generation capacity benefits employment creation. Establishing solar power and small renewables generates maintenance employment and contributes to improved productivity in rural areas.

- Using a **nexus approach** allows to identify potential synergies and bottlenecks that could render a project (or an investment) more or less attractive or economically viable. We find 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, it 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 definitely 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, and climate resilient future.

This project aims at addressing a specific gap, in that conventional forecasting tools and analyses are often comparatively static (mostly employing linear approaches) and are narrowly focused on a sector or a specific set of thematic indicators. We instead employ a systemic approach, consider social, economic and environmental indicators within a sector, and link them across sectors to generate dynamic projections that allow to estimate policy outcomes for all economic actors.

In fact, many tools are being 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, & Lombardi, 2014). But the results being produced by these tools are not all that useful for the end-users they are designed to support in the first place (Rozema & Bond, In press). This is because they miss the capability to present the cross-sectoral impacts of interventions, leaving room to the creation of (unexpected) side effects.

Current research has already pointed out that there is a need for more appropriate decision-support tools for development bank investors (ADB 2014) 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, & Lombardi, 2014). This is because most impact assessment tools are designed to evaluate one single dimension of development (i.e. economic, social or environmental), and only their combined use is likely to provide effective support to decision making. Moreover, many tools and methodologies are developed following frameworks that cannot be easily customized to the local context, which prevent analysts and decision makers from utilizing the results of the assessment to inform their specific development priorities (Wallhagen & Glaumann, 2011).

The modeling work presented in this report is designed to support development planning, especially in the context of climate resilience, which 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 will become more effective.

2. Implementing the Nexus approach with Causal Loop Diagrams

The main drivers of change of the three sectors analyzed (agriculture, energy and water) are summarized in three Causal Loop Diagrams (CLDs). These CLDs include the main indicators analyzed, their interconnections with other relevant variables in the sector and the feedback loops they form.

CLDs are the starting point for the development of the mathematical (stock and flow models) described in more depth in Section 3. Model results are instead presented in Section 2.

The creation of a CLD 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 basicto-advanced knowledge of the analyzed issues' systemic properties. Having a shared understanding is crucial for solving problems that influence several sectors or areas of influence, which are normal in complex systems. Since the creation of a CLD touches upon (and relies on) cross-dimensional knowledge, all the parties involved in the decision-making process and implementation of an investment need a shared understanding of the factors that generate the problem and those that could lead to a solution, to effectively implement successful private-public partnerships. As such, the solution should not 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 favor, to solve the problem, rather than generating it.

In this context, the role of feedbacks is crucial. It is often the very system we have created that generates the problem, due to external interference, or to 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. We are too often prone to analyze the current state of the system, or to extend our investigation to a linear chain of causes and effects, which 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 relation (see Table 1):

- 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.

Variable A	*Variable B*	*Sign*
↑	↑	+
↓	↓	+
↑	↓	-
↓	↑	-

Table 1. Causal relations and polarity

Circular causal relations 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). CLDs 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, Andersen, Deal, Garet, & Shaffer, 1983). *Feedbacks (also called feedback loops is 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) counter and reduce change 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, 2002)*).A difference between the actual and perceived states of a process can often be important to explain 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, with agriculture yield being 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.*

There are several strengths and weaknesses to the use of CLDs, as presented in Table 2.

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

Table 2. Strengths and weaknesses of CLDs

2.1. Agriculture

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

Agriculture production depends on the amount of productive agriculture land and the yield per hectare of cropland. Productive agriculture 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.

Climate impacts considered in the agriculture sector are the impacts of floods and droughts on available land, and land productivity, as well as on livestock.

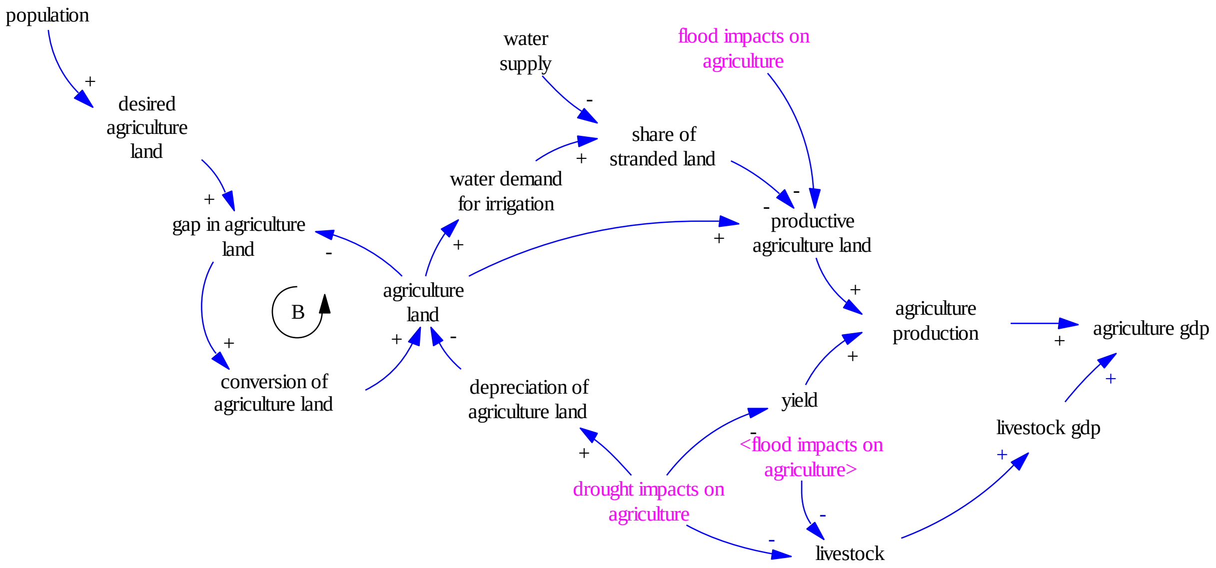

Figure 1: CLD Agriculture

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 CLD 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 labor income in the energy sector depend on the amount of installed capacity (O&M 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. operations of power plants) and efficiency in thermal conversion (i.e. higher temperatures leads to lower efficiency in fuel burning for electricity generation), and the damages to power generation capacity caused by floods.

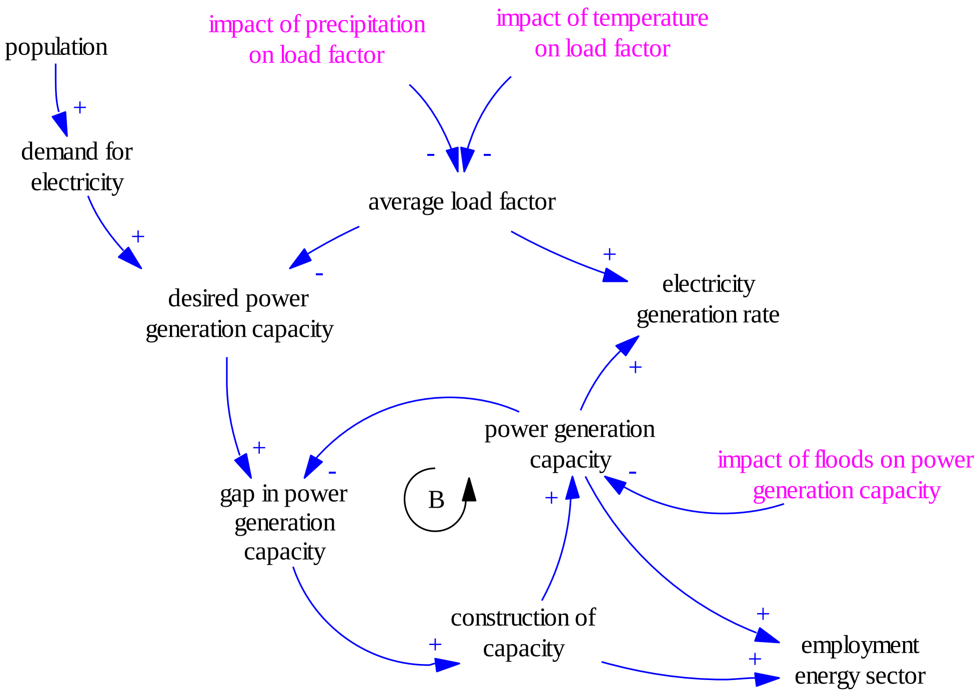

Figure 2: CLD Energy

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 agriculture land.

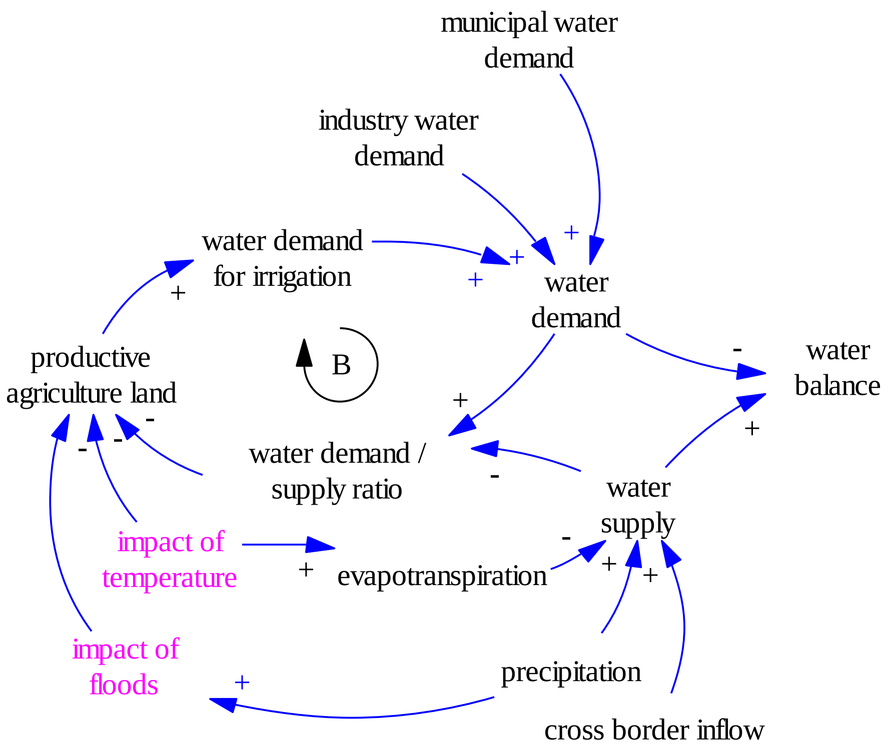

Figure 3: CLD water sector

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 to setup the model Tables with the data used as reference modes are attached in a separate file.

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

Agriculture land, cropland, total agriculture production and information on livestock was obtained from the FAOSTAT database (FAO, 2018a). Data on historical precipitation and trends in precipitation was obtained from the World Bank Climate Change Knowledge Portal (World Bank, 2018). Information on the efficiency of irrigation technology was obtained from (Sauer, et al., 2010). Crop water requirements estimated based on Maize FAO CROPWAT Website (FAO, 2018b). Electricity generation capacity and power generation (generation = demand) (TSP, 2018).

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

<u>*Cameroon:*</u>

Energy capacity and production (Ndongsok & Ruppel, 2017)
Labor income (Glassdoor, 2016)
Roads: (LCA, 2018)

Mozambique:

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

Uganda:
Salary 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 SDG 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, agriculture 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 through 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:

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

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. Agriculture water demand is calculated as

$$\text{agriculture water demand} = \text{cropland} * (\text{water demand per hectare of agriculture land} + \text{water losses due to irrigation})$$

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 agriculture and the water lost due to irrigation.

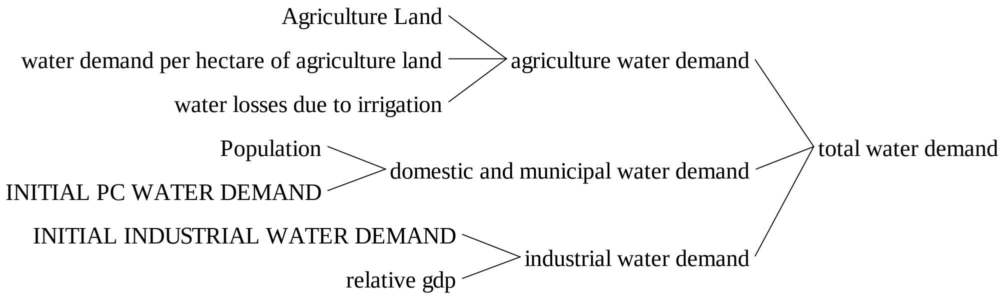

Figure 4: Causes tree total water demand

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.

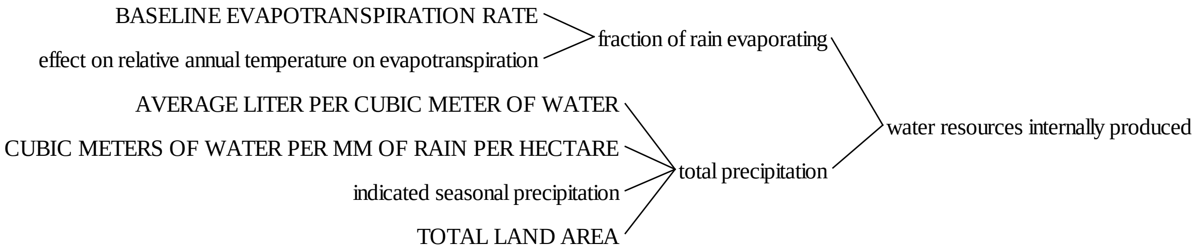

Figure 5: Causes tree water resources internally produced

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 mm of precipitation into liters. The equation for total precipitation is

Total precipitation =

indicated seasonal precipitation * TOTAL LAND AREA * CUBIC METERS OF WATER PER MM OF RAIN PER HECTARE * AVERAGE LITER PER CUBIC METER OF WATER

The fraction of rain evaporating is calculated based on a baseline evapotranspiration rate and the impact of temperature on evapotranspiration. The latter variable captures the effect that increasing temperature has on evapotranspiration rates.

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

Agriculture production

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

$$\text{Agriculture land}_{t+1} =$$

$$\text{Agriculture land}_{t0} + \text{land conversion for agriculture}_{t0} - \text{depreciation rate agriculture land}_{t0}$$

The depreciation rate of agriculture land depends on the stock value and the average lifetime of agriculture 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 agriculture land, the depreciation rate of agriculture 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 agriculture land - Agriculture Land) / TIME TO CONVERT LAND FOR AGRICULTURE + depreciation rate agriculture land

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

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

productive agriculture land =

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

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

---

affected agriculture land =

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

---

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

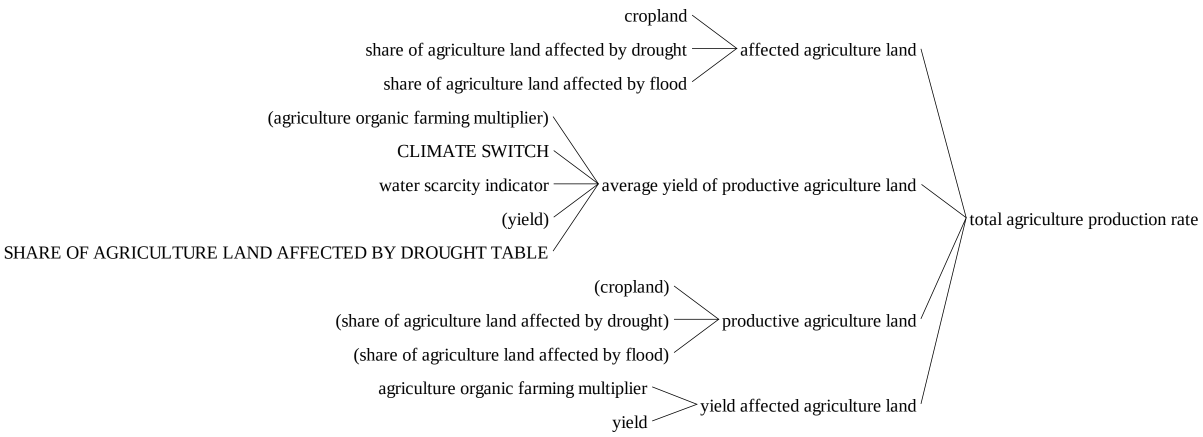

Figure 6: Causes tree total agriculture production rate

The share of agriculture production affected by flood is determined based on the flood indicator and a table function derived from a DESINVENTAR dataset. The share of agriculture 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 agriculture land at risk of drought. The following equation is used to determine the share of agriculture land affected by drought

---

share of agriculture 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 agriculture land affected takes a value between “0” and “1”, which is equivalent to 0% and 100% of agriculture land affected respectively.

Agriculture production is calculated as the sum of production from productive and affected agriculture land respectively. 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.

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total agriculture production rate =

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

---

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

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

Agriculture water demand

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

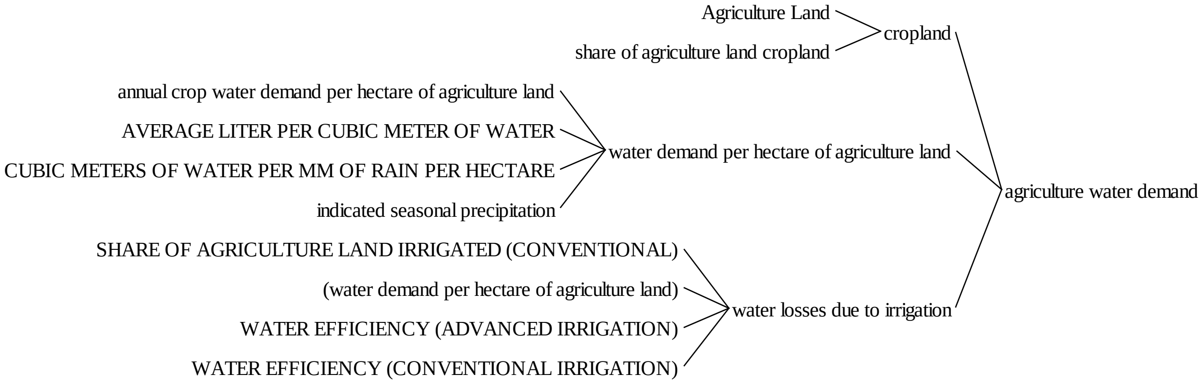

Figure 7: Causes tree agriculture water demand

The water demand per hectare of agriculture 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:

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annual crop water demand per hectare of agriculture 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 crop land 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 agriculture land =

MAX (annual crop water demand per hectare of agriculture land – indicated seasonal precipitation, 0)
* CUBIC METERS OF WATER PER MM OF RAIN PER HECTARE
* AVERAGE LITER PER CUBIC METER 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 mm per hectare to liters per hectare.

The second component of agriculture 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 agriculture 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 agriculture land/"WATER EFFICIENCY (CONVENTIONAL IRRIGATION)"*"share of agriculture land irrigated (conventional) policy"

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

water demand per hectare of agriculture land/"WATER EFFICIENCY (CONVENTIONAL IRRIGATION)"*"SHARE OF AGRICULTURE LAND IRRIGATED (CONVENTIONAL)"

+water demand per hectare of agriculture land/"WATER EFFICIENCY (ADVANCED IRRIGATION)"*(1-"SHARE OF AGRICULTURE LAND IRRIGATED (CONVENTIONAL)"))

An IF THEN ELSE function is used to simulate different water use scenario 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 agriculture 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% inefficient).

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 respectively. 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 respectively. 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 livestock head multiplier.

3.5. Food security and population affected module

The model estimates the total affected population 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.

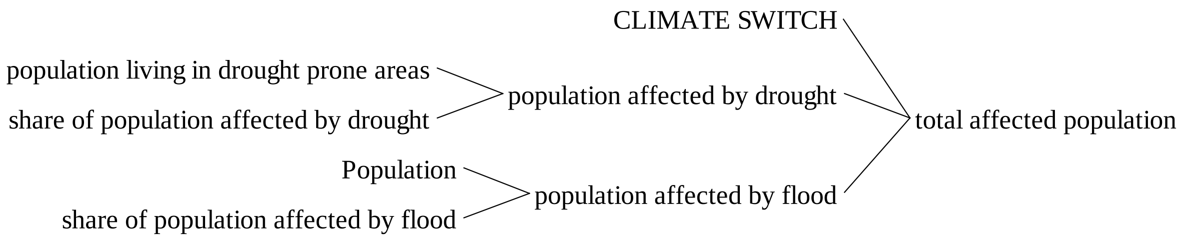


Figure 8: Causes tree total affected population

The impacts of floods and droughts occur gradually and depend on the strength of the events which is indicated by the flood and water scarcity indicators respectively. Floods are assumed to potentially occur all over the 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 drought prone areas are affected starting from precipitation levels of 30% 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 amount 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 from population to the domestic food supply and the baseline imports of food. Total food demand is calculated by multiplying population by a food demand per capita value. Food supply for human consumption depends on total agriculture production and the share of agriculture production that are not cash crops and is intended for human consumption.

total food production =

total agriculture production rate * SHARE OF AGRICULTURE PRODUCTION FOR FOOD SUPPLY

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

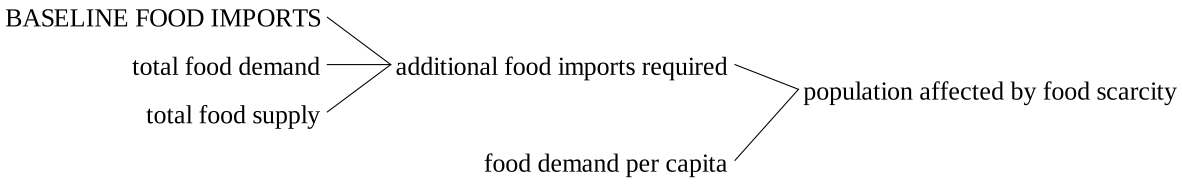


Figure 9: Causes tree population affected by food scarcity

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.

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 damages to renewable capacity. The construction 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 the 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 a 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 damages from adverse weather to capacity. The depreciation rate captures the decommissioning of capacity at the end of its lifetime.

Depreciation Rate Other Renewable =

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

To capture that the amount of capacity is 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. Damages to renewable capacity from adverse weather events are 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 what scenario shall be 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. O&M 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 the total employment in the energy sector are displayed in Figure 10.

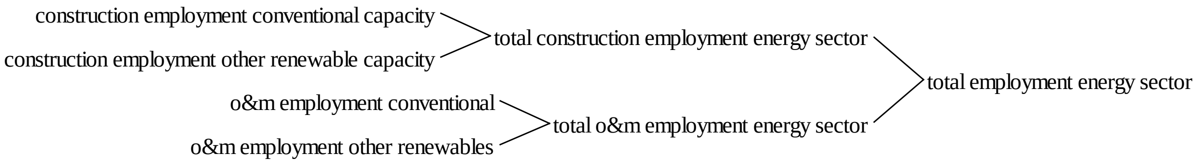


Figure 10: Causes tree total employment energy sector

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 O&M employment from conventional and renewable capacity yields the total O&M employment in the energy sector.

Labor income from the energy sector is calculated by multiplying the employment by capacity type by an average salary in the energy sector. The sum of labor income from conventional and renewable

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.

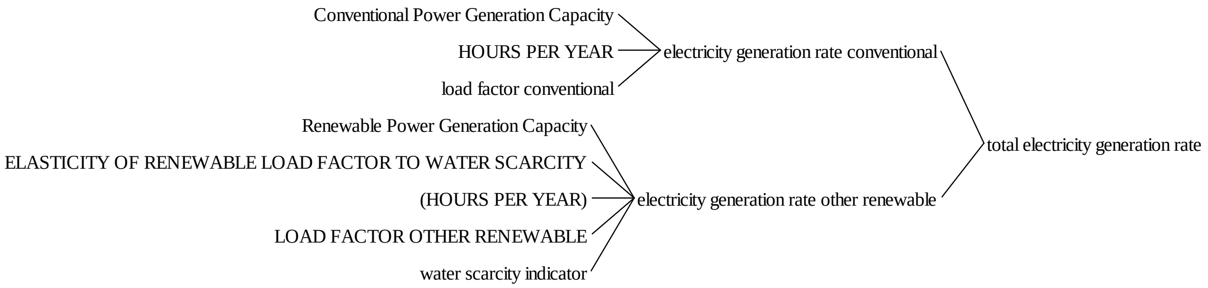


Figure 11: Causes tree total electricity generation rate

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 the effect of precipitation and the effect of 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.

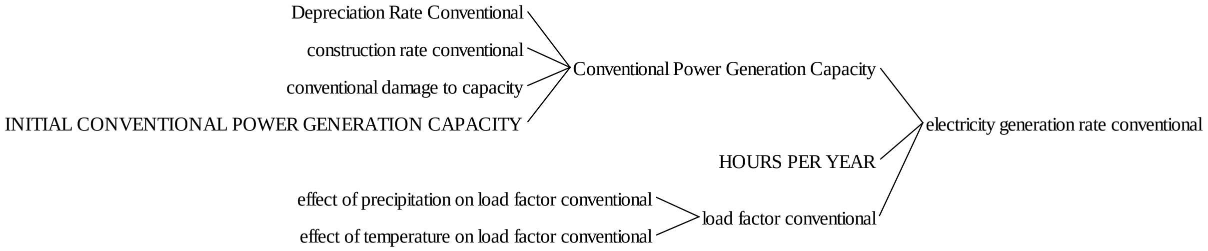


Figure 12: Causes tree conventional electricity generation

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 an effect of 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.

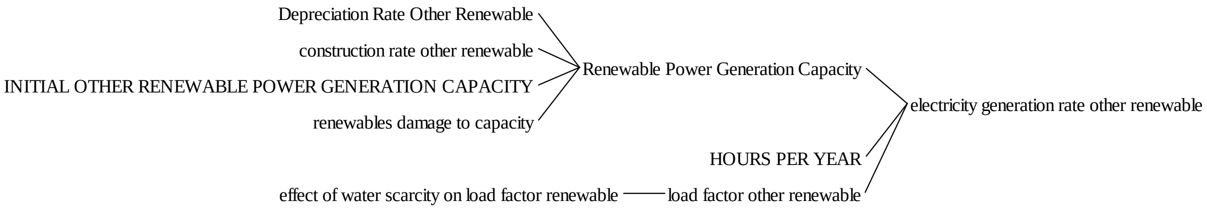


Figure 13: Causes tree renewable electricity generation

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 in the begin 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 being of the simulation.

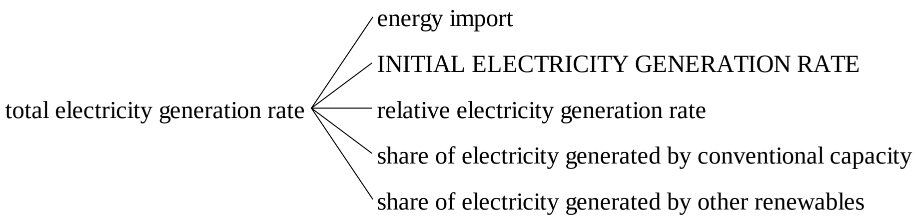


Figure 14: Uses tree total electricity generation rate

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 O&M costs for the respective capacity, as illustrated in Figure 15.

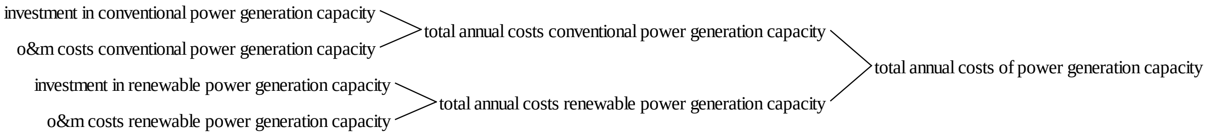


Figure 15: Causes tree total annual costs of power generation capacity

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 (LCOE) and hence consists of annualized capital investments per MWh and the current O&M 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 O&M cost and salaries and wages per MWh of renewable electricity. These values are obtained by dividing current O&M 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.

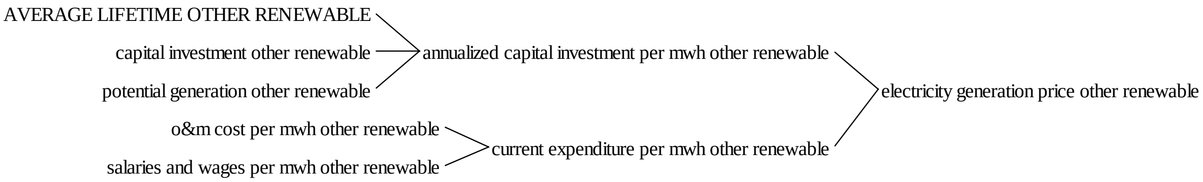


Figure 16: Causes tree electricity generation price renewable generation

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 instead uses existing projections from the UN Population Prospects. Table 2 presents the assumptions for both drivers from 2016 forward.

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%	

Table 2: Assumptions for key variables in the model

Based on the abovementioned assumptions, the total population of Mozambique is projected to reach 69.2 million people by 2050, which represents a net increase of 40.3 million people compared to 2016. Uganda's population reaches 109.4 million people, which is equivalent to a net increase of 67.5 million people. The population of Cameroon increases 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 instead compared the population of Cameroon to World Bank Data (World Bank Data, 2018) up to 2016. This is presented for validation purposes, and show that the historical simulation of the model closely matches data.

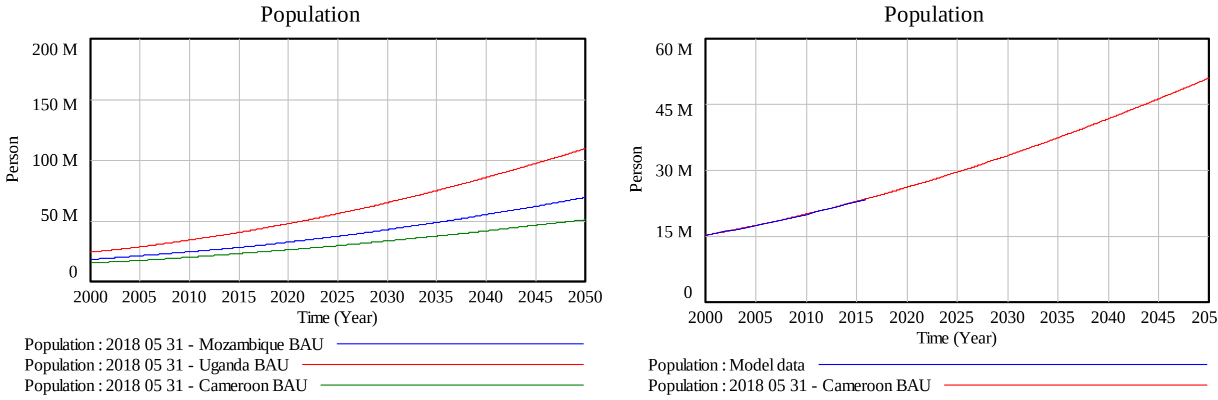


Figure 17: Population trends

Mozambique shows strong economic growth with GDP projected to quadruple by 2050. Projections indicate that the GDP of Cameroon more than triples between 2018 and 2050. Uganda's total GDP is instead projected to increase by 153.8% and hence more than double relative to 2018. The development for GDP of the three countries over time is summarized in Table 3.

Total GDP	Unit	2018	2020	2025	2030	2040	2050
Mozambique BAU	bn MZN	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 BAU	bn Ush	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 BAU	bn CFA	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%*

Table 3: Total GDP

4.1.2. Agriculture

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

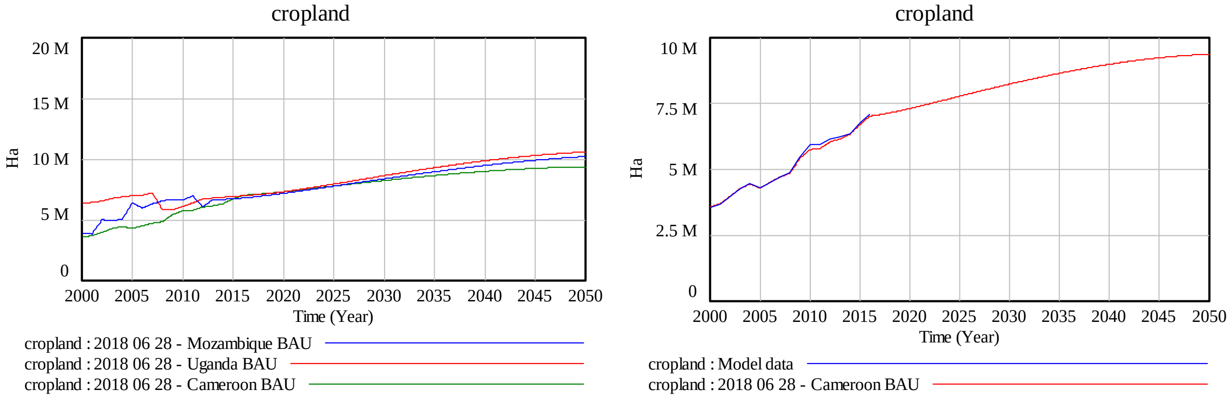


Figure 18: Total Cropland BAU scenario

Total agriculture production in Cameroon is projected to increase by 31.1% (consistently with the forecasted change of agriculture land) from 47.7 million tons in the year 2018 to 63.9 million tons in the year 2050, which represents a net increase of 26.8 million tons. In the absence of climate impacts (analyzed 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 are projected to increase by 48.7% and 46.5% 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 for Mozambique. Figure 19 illustrates projected agriculture production for all three countries in the BAU scenario, and compares the total agriculture production rate of Cameroon to historical agriculture production, for validation purposes.

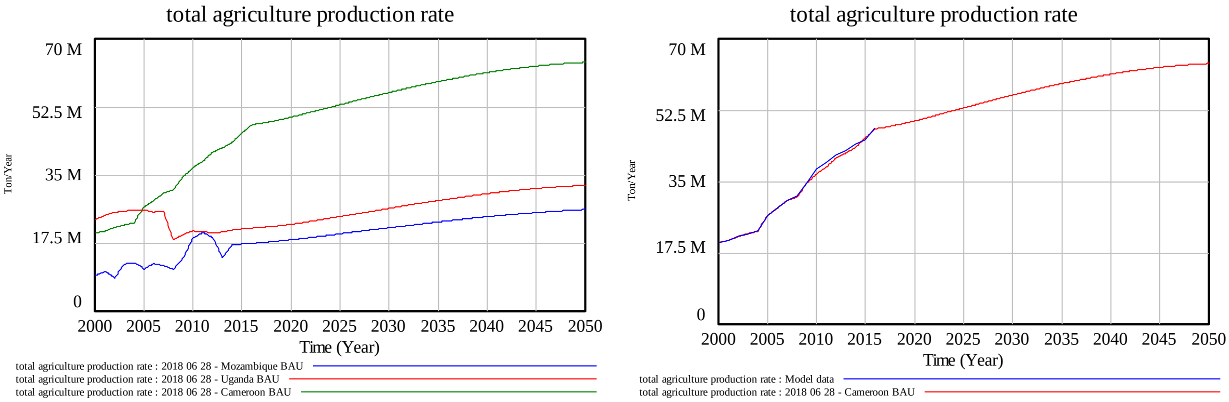


Figure 19: Total agriculture production rate BAU scenario

The expansion of agriculture 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.

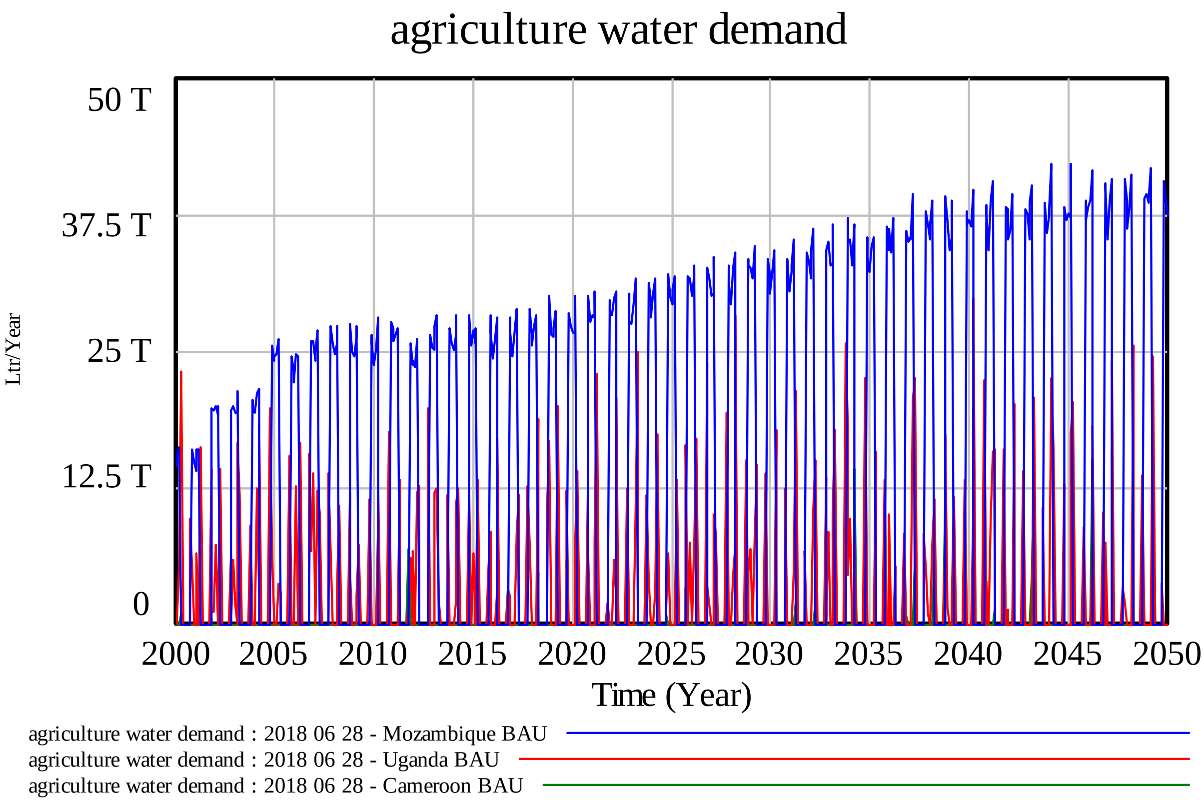


Figure 20: Water demand for irrigation

Employment in the agriculture is projected to increase by 30% in Cameroon, 45% in Mozambique and 47% in Uganda. By 2050, this represents a net job creation of 667,500 jobs, 973,600 jobs and 1.04 million jobs for Cameroon, Mozambique and Uganda respectively. Uganda's agriculture sector is projected to provide employment for 3.17 million people, followed by Mozambique with 3.07 million people and Cameroon with 2.81 million people employed. Agriculture employment for Cameroon, Mozambique and Uganda is depicted in Figure 21.

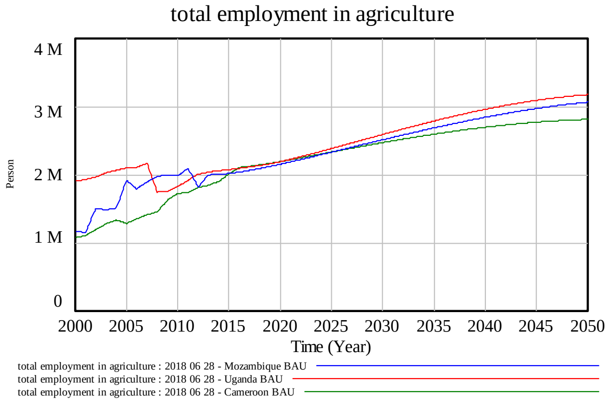


Figure 21: Total employment in agriculture BAU scenario

The increase in agriculture production translates into an increase of agriculture GDP (Table 4). The contribution of Uganda's agriculture sector increases by increases by 54% from Ush 14.8 trillion in 2018 to Ush 22.9 trillion in 2050, representing a net increase of Ush 8.16 trillion. During the same period, Mozambique's agriculture GDP is projected to increase by MZN 111.5 billion from 49 billion in 2018 to MZN 160.7 billion in 2050, which represents an increase of 44.1%. Cameroon's agriculture GDP increases by CFA 708 billion from CFA 2.56 trillion in 2018 to CFA 3.27 trillion in 2050.

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

Table 4: Agriculture GDP BAU scenario

In Uganda, the value added from livestock in the year 2050 is projected to be 85% higher compared to 2018 and increases its contribution to agriculture GDP from 17.4% to approximately 21%. By 2050, the livestock sectors in Mozambique and Cameroon are projected to increase economic output by 36% and 17% respectively, which is equivalent to an increase of MZN 5.05 billion and CFA 85.8 billion. The contribution of the livestock sector to total agriculture GDP decreases for both Cameroon and Mozambique. Between 2018 and 2050, the contribution of livestock value added to agriculture GDP declines from 20.0% to 18.4% in Cameroon and from 12.5 to 11.8% 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 for 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.

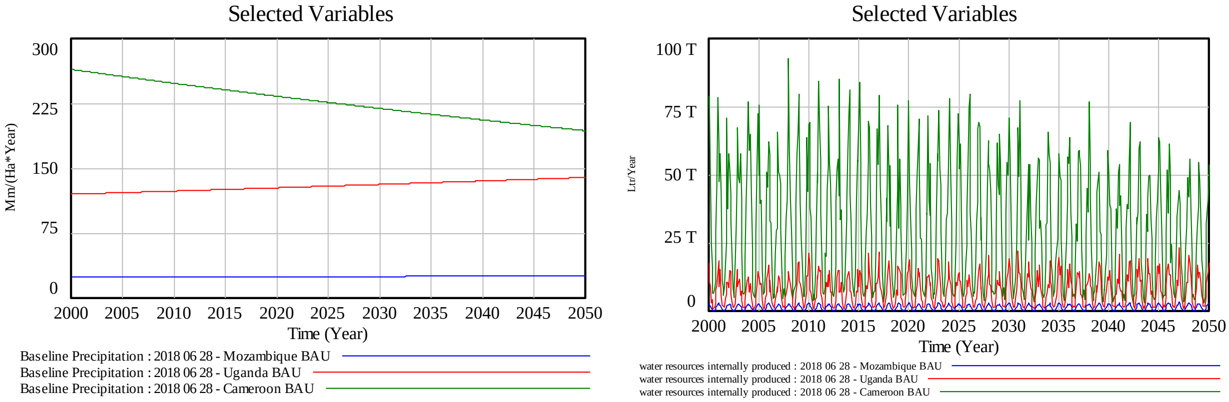
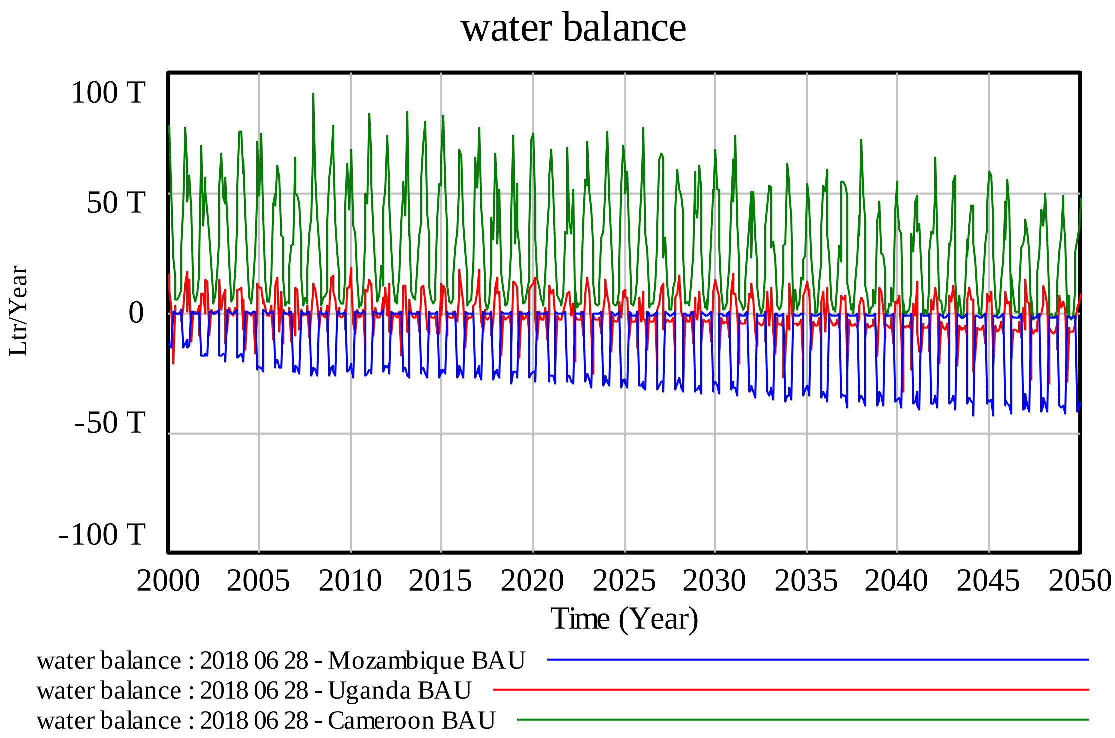


Figure 22: Baseline precipitation and water resources internally produced

Population growth and the expansion of agriculture land both put additional pressures on water resources. Especially in Mozambique, the expansion of agriculture more than doubles the water deficit during the dry season, which increases significantly 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 for all three countries. The water balance and water stress indicators for all three countries are depicted in Figure 23.



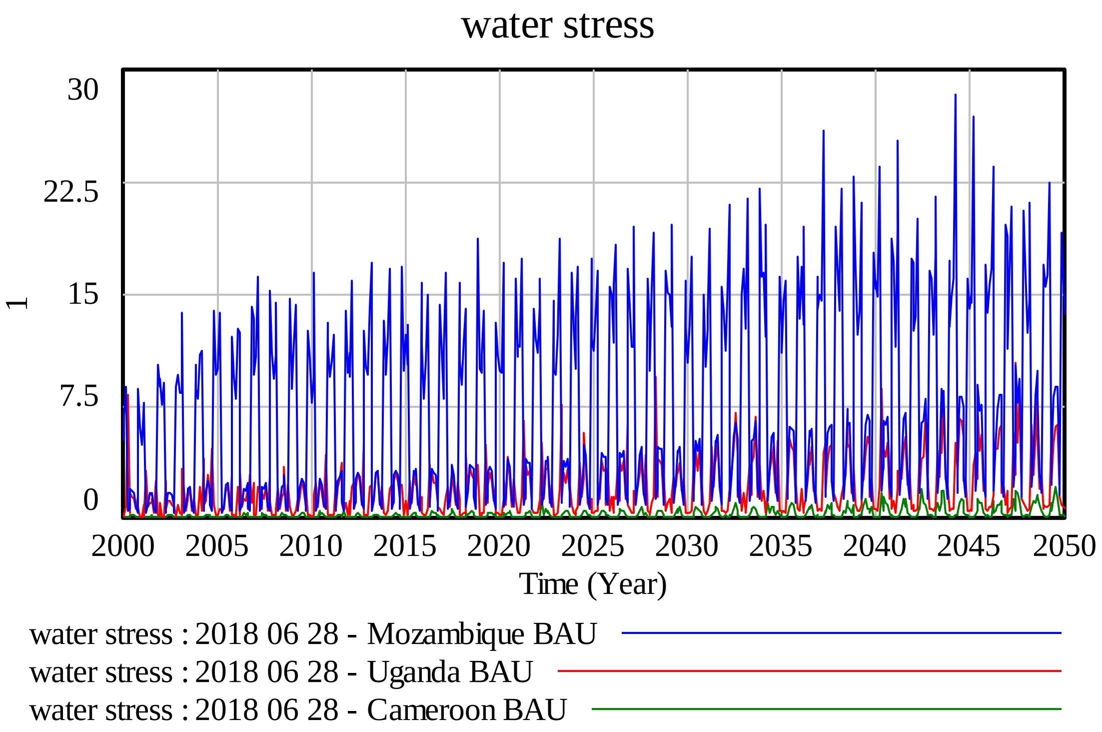


Figure 23: Water balance (top) and water stress (bottom)

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.

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 to 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 to 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 to 2018	*%*	*0.0%*	*9.3%*	*23.5%*	*38.8%*	*55.3%*	*72.7%*

Table 5 provides an overview of the capacity requirements by country over time, and indicates the increase compared to 2018.

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 to 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 to 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 to 2018	*%*	*0.0%*	*9.3%*	*23.5%*	*38.8%*	*55.3%*	*72.7%*

Table 5: Power generation capacity

With the assuming that electricity demand per capita remains constant after 2015, electricity generation increases by 74% in Uganda, 111% in Mozambique and 276% in Cameroon by 2050. Electricity generation for Uganda, Mozambique and Cameroon is projected to reach 310 million MWh, 754 million MWh and 279 million MWh respectively. The graph on the left in Figure 24 shows the development of total electricity generation over time for the three countries. The one on the right presents model outputs for annual electricity generation in Cameroon compared to the historical reference mode, for validation purposes.

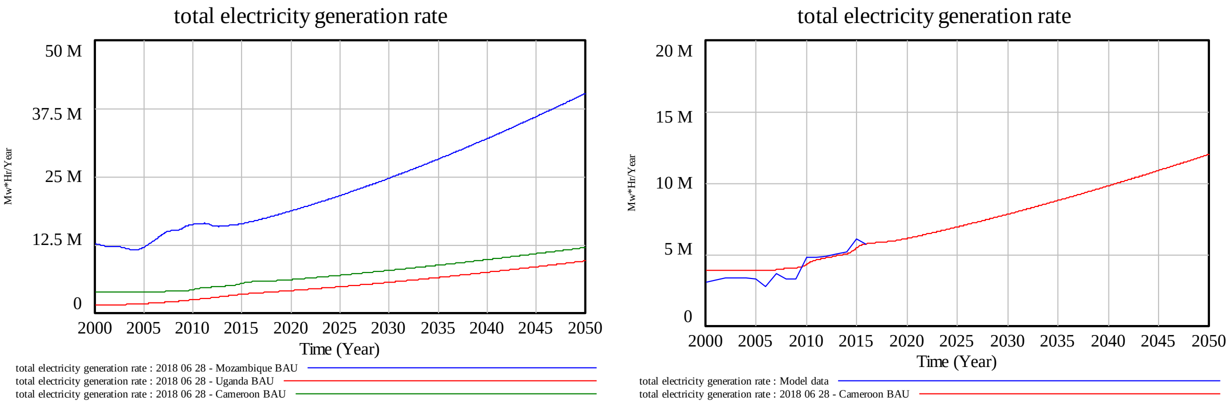


Figure 24: Electricity generation rate BAU scenario

The installation of additional capacity provides employment from construction, as well as from operation and maintenance (O&M). Mozambique's energy sector leads employment creation with 1,910 additional jobs by 2050. Cameroon's and Uganda's energy sectors provide 370 and 540 new jobs respectively.

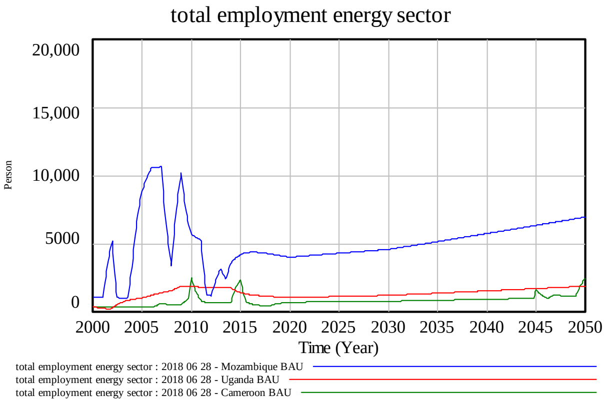


Figure 25: Total employment energy sector BAU scenario

Capital investments and increasing O&M costs from installed capacity lead to higher annual costs of power generation by 2050. These are summarized in Table 6.

Annual cost of power generation	**Unit**	**2018**	**2020**	**2025**	**2030**	**2040**	**2050**
Mozambique BAU	mn MZN	677.4	721.6	830.3	948.6	1'198.7	1'431.4

% change to 2018	*%*	*0.0%*	*6.5%*	*22.6%*	*40.0%*	*77.0%*	*111.3%*
Uganda BAU	mn Ush	177.5	181.1	197.7	213.3	256.9	309.7
% change to 2018	*%*	*0.0%*	*2.1%*	*11.4%*	*20.2%*	*44.7%*	*74.5%*
Cameroon BAU	mn CFA	101.1	133.1	153.7	170.9	206.4	380.0
% change to 2018	*%*	*0.0%*	*31.6%*	*52.0%*	*69.0%*	*104.1%*	*275.7%*

Table 6: Annual cost of power generation BAU scenario

4.2. Climate scenario

4.2.1. Assumptions

The assumptions for population and GDP remain unchanged in the climate scenario. On the other hand, the Climate scenario introduces a 0.5% 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.

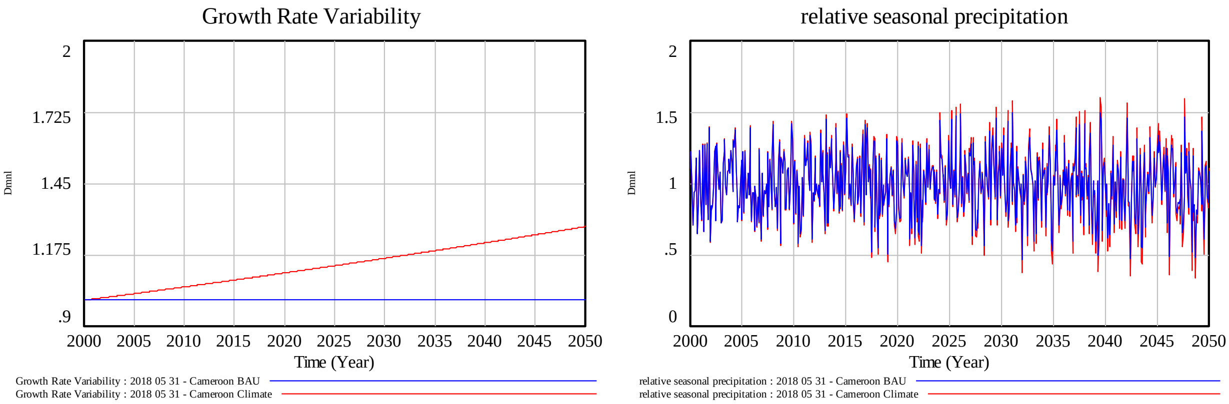


Figure 26: Growth rate in precipitation variability and relative seasonal precipitation Climate scenario

In addition to the assumptions made for the BAU scenario, the Climate scenario assumes impacts of adverse weather, as presented in Table 7.

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

Table 7: Climate impacts in the model by type of event

The inclusion of adverse climate events shows impacts on population, especially for that portion that lives in areas affected by climate events. Table 8 shows the total number of people that are affected (on average) every year, as well as the average share of population affected, which ranges between 0.8% and 2.1% of total population.

Population affected	**Unit**	**2018-2020**	**2020-2025**	**2025-2030**	**2030-2035**	**2035-2040**	**2040-2045**	**2045-2050**
Mozambique BAU	mn People	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	mn People	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	mn People	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%*

Table 8: Population affected by adverse climate events (5-year annual averages)

4.2.2. Agriculture

While the amount of cropland remains unchanged compared to the BAU scenario, productive cropland and agriculture production in the Climate scenario are affected by adverse weather and water shortages. Figure 27 compares total cropland in the BAU 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.

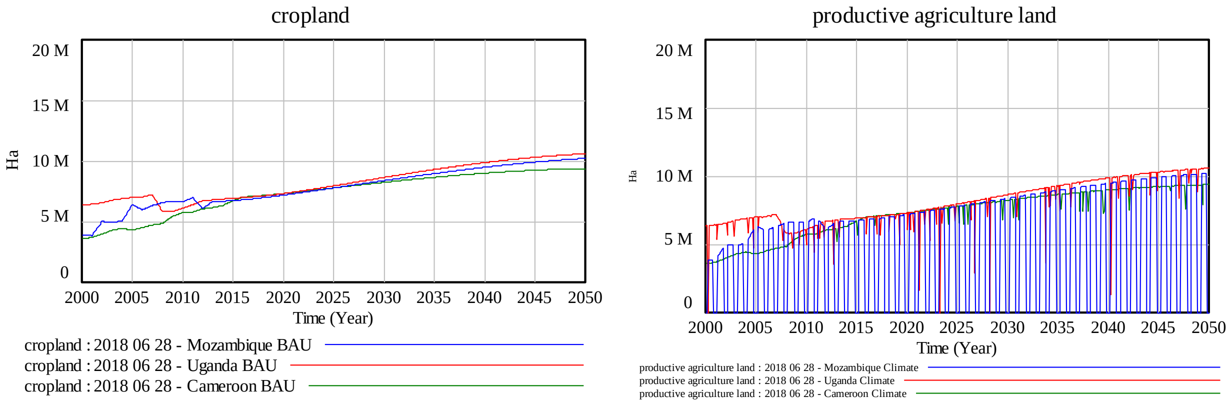


Figure 27: Productive cropland BAU and Climate scenario

The impacts of adverse weather and water shortages reduce agriculture production through the year depending on the frequency and magnitude of adverse climate events. Total agriculture production in the BAU and Climate scenario are compared in Figure 28.

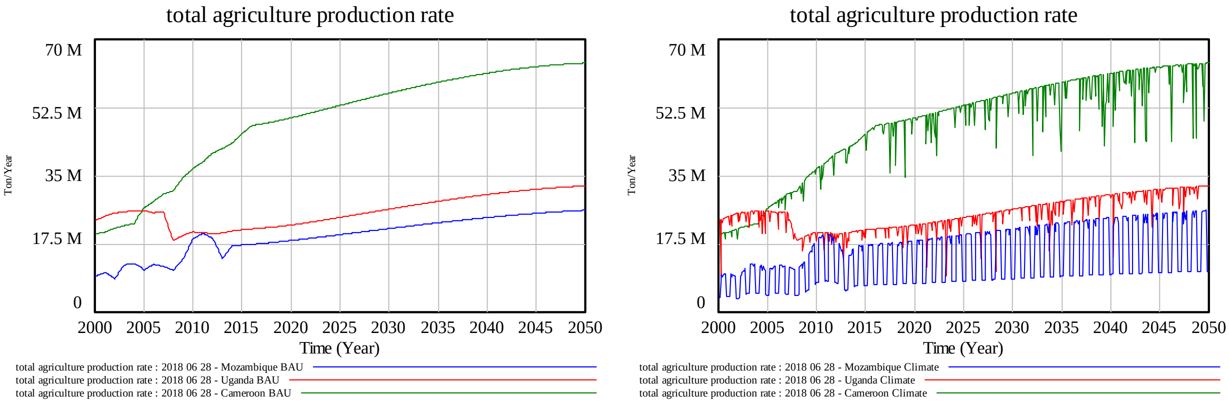


Figure 28: Total agriculture production in the BAU and Climate scenario

The impacts of water scarcity and adverse weather impacts are most visible in Mozambique and reduce agriculture production on average by approximately 26%. The impact of climate and water scarcity on total agriculture production rates in Cameroon and Uganda range between 1.9% to 3.9% and 0.5% to 2.1% respectively. The average production rates for the BAU and Climate scenario are summarized in Table 9.

Agriculture production	**Unit**	**2018-2020**	**2020-2025**	**2025-2030**	**2030-2035**	**2035-2040**	**2040-2045**	**2045-2050**
Mozambique Climate	mn Ton / Year	1.12	1.18	1.28	1.37	1.47	1.54	1.60
Mozambique BAU	mn Ton / 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 Ton / Year	1.82	1.90	2.08	2.25	2.42	2.56	2.65
Uganda BAU	mn Ton / 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 Ton / Year	3.99	4.20	4.46	4.64	4.82	4.96	5.09
Cameroon BAU	mn Ton / 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 9: Agriculture production in the BAU and CIS scenario

The increase in climate variability strongly impacts water demand for irrigation in Cameroon and increases water requirements for agriculture production by 22% and up to 100%. This implies that increasing variability might potentially double water demand for irrigation during certain years in the future. Climate impacts on the Ugandan agriculture sector are less marked with additional water requirements between 3.1% and 13%. Mozambique is projected to experience additional water requirements of only 0.2% during the peak season. This may seem counterintuitive, but it is due to the fact that most of Mozambique's cropland already suffers water scarcity through the year. The development of water demand for irrigation over time is summarized in Table 10.

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%*

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%*

Table 10: Water demand for irrigation in the BAU and Climate scenario

Figure 29 illustrates employment in the agriculture sector in the Climate scenario compared to the BAU 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% of agriculture employment is threatened (or turned into seasonal jobs) through water scarcity and climate impacts, which leaves around 1.26 million jobs at risk by 2050. The impact on employment in the agriculture sector of Cameroon and Uganda are in the range between 0.5% to 2.6% and 0.3% to 2.7% respectively.

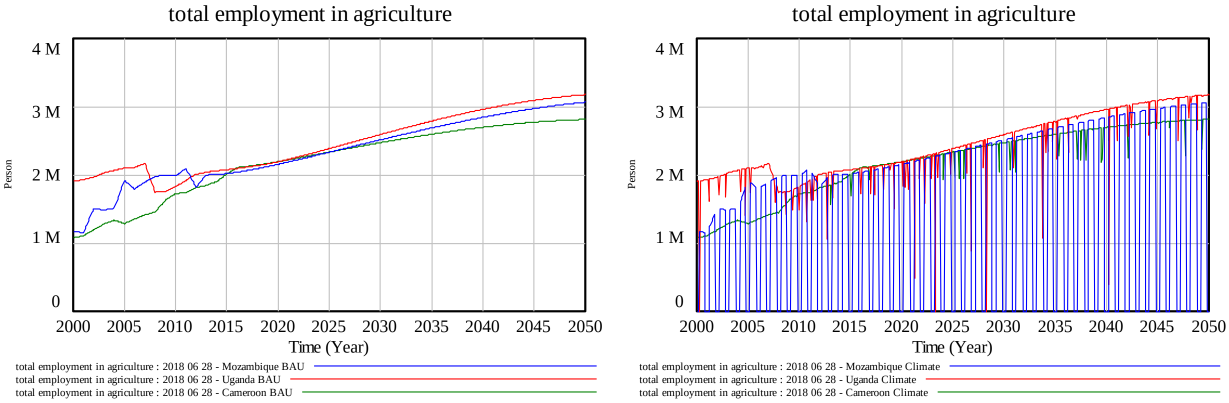


Figure 29: Total employment in agriculture BAU scenario

The reduction in agriculture production compared to the BAU scenario translates into a reduction in value added. Agriculture value added, or GDP, in Mozambique is reduced by approximately 24% on average throughout the simulation time, and reductions for Cameroon and Uganda reach up to 14.2% and 12.4% respectively. Despite experiencing the smallest impact in relative terms, the cumulative reduction in agriculture GDP is the highest in Cameroon with CFA 8.38 trillion (USD 14.9 billion) compared to the baseline. The cumulative reduction for Uganda totals Ush 37.17 trillion (USD 9.9 billion) by 2050, and reductions in Mozambique is projected to total MZN 367.8 billion (USD 6.2 billion).

Agriculture GDP	**Unit**	**2018**	**2020**	**2025**	**2030**	**2040**	**2050**
Mozambique Climate	bn MZN	84.66	87.95	94.89	101.23	111.23	120.95
Mozambique BAU	bn MZN	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 Ush	13'970.07	14'353.52	15'871.60	17'107.79	18'339.91	20'658.28
Uganda BAU	bn Ush	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 CFA	2'464.57	2'524.08	2'614.70	2'748.34	2'784.98	2'803.36
Cameroon BAU	bn CFA	2'559.26	2'612.64	2'760.03	2'903.77	3'141.51	3'267.16
Climate vs BAU	*%*	*-3.7%*	*-3.4%*	*-5.3%*	*-5.4%*	*-11.3%*	*-14.2%*

Table 11 provides an overview of the development of agriculture GDP between 2018 and 2050 for the BAU and Climate scenario respectively.

Agriculture GDP	**Unit**	**2018**	**2020**	**2025**	**2030**	**2040**	**2050**
Mozambique Climate	bn MZN	84.66	87.95	94.89	101.23	111.23	120.95
Mozambique BAU	bn MZN	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 Ush	13'970.07	14'353.52	15'871.60	17'107.79	18'339.91	20'658.28
Uganda BAU	bn Ush	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 CFA	2'464.57	2'524.08	2'614.70	2'748.34	2'784.98	2'803.36
Cameroon BAU	bn CFA	2'559.26	2'612.64	2'760.03	2'903.77	3'141.51	3'267.16
Climate vs BAU	*%*	*-3.7%*	*-3.4%*	*-5.3%*	*-5.4%*	*-11.3%*	*-14.2%*

Table 11: Agriculture GDP BAU and climate scenario

4.2.3. Water

In addition to population growth and the expansion of agriculture land, the increasing variability and higher evapotranspiration rates put additional pressures on water resources and increases the uncertainty of water supply. Table 12 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 agriculture land in Uganda, projections indicate a negative water balance after 2025 and hence an increasing exploitation of existing groundwater stocks. The average reduction in Uganda’s water balance totals 5 billion m3 per year between 2018 and 2050. Cameroon’s average water balance is projected to decrease by 6.6 billion m3 by 2050, which is equivalent to a 27.9% reduction compared to 2018. Mozambique’s water balance is projected to further decrease by 68.8% from an average shortage of 5.98 trillion m3 in 2018 to an average shortage of 10.1 billion m3 annually.

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	19'036
% change to 2018	*%*	*0.0%*	*8.8%*	*8.6%*	*-5.9%*	*-10.7%*	*-21.6%*	*-26.6%*

Table 12: Water balance Climate scenario

4.2.4. Energy

Increasing precipitation variability and higher temperatures pose a threat to power generation capacity and impact electricity generation efficiency. The forecasted 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, damages to power generation capacity significantly increase the costs of the energy sector. Compared to the baseline, Cameroon requires an additional cumulative investment of CFA 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 MZN 221.1 billion.

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**

Table 13Table 13 provides an overview of the incurred damages to capacity, the total economic damages and the annualized damages 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**

Table 13: Impacts on power generation capacity

The climate impacts forecasted are projected to reduce the average efficiency of power generation capacity by between 1% and 3.3% across all three countries. Impacts can vary based on the frequency and magnitude of adverse climate events, and the technologies used to generate electricity. Figure 30 compares electricity generation rates between the BAU and Climate scenario for all three countries. The spikes in electricity generation occur as consequence of capacity damages during flood events. The model assumes that damaged capacity is replaced, and that capacity construction takes place to satisfy the expected demand.

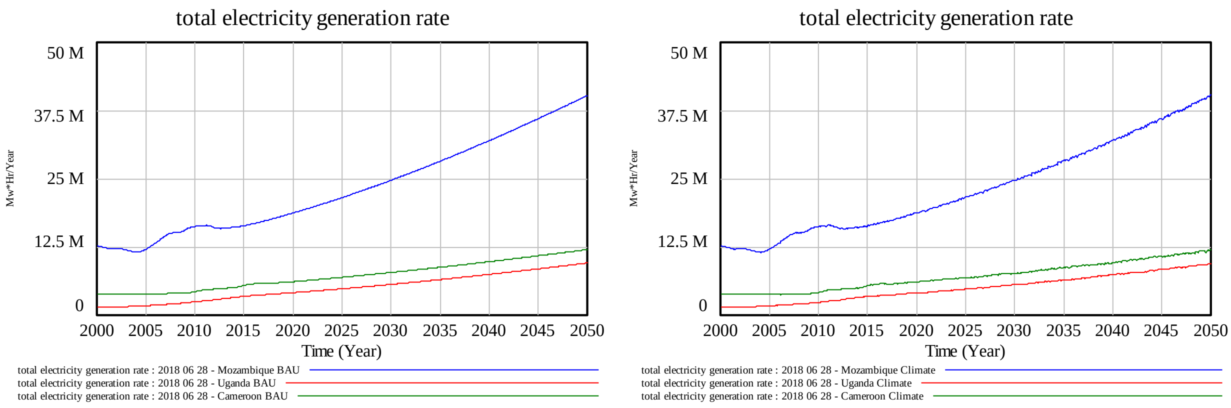


Figure 30: Electricity generation BAU and Climate scenario

Table 14 shows the average electricity generation rates between 2018 and 2050 in 5-year intervals.

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%*

Table 14: Electricity generation BAU and climate scenario

Total employment in the energy sector increases due to the need to replace damaged capacity. The increase in employment stems from construction only. On average, employment in the energy sector of Mozambique, Cameroon and Uganda increases by 26.2%, 67.1% and 17.9% 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 reconstruction periods of capacity damaged by floods.

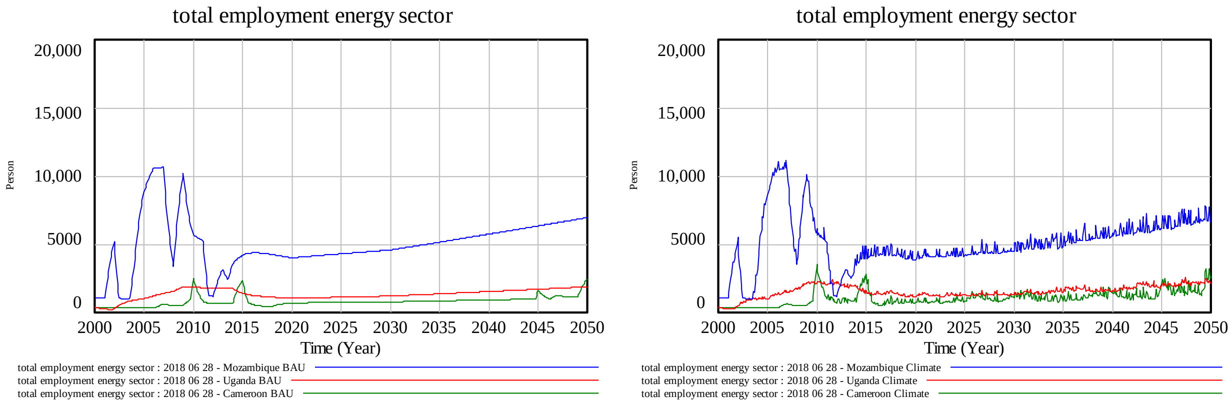


Figure 31: Total employment energy sector BAU and Climate scenario

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 of the agriculture, 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 what is the potential for cost mitigation, and for restoring baseline economic performance.

Category	**Unit**	**Mozambique**	**Uganda**	**Cameroon**
Value added				
Agriculture 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				
Labor 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*

Table 15Table 15 provides a summary of the cumulative economic impacts (by 2050) of introducing climate change trends in the simulation of the three sectors analyzed.

Category	Unit	Mozambique	Uganda	Cameroon
Value added				
Agriculture 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				
Labor 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*

Table 15: Integrated assessment of costs and benefits

Climate impacts are projected to reduce agriculture GDP by between 12.1% and 16.7%. Furthermore, additional investments in power generation capacity are required to replace capacity that is damaged during flood events. Due to the fact that more labor is required to replace power generation capacity, total labor income is projected to increase through additional employment.

Table 16 provides an overview of the physical impacts of climate events by sector.

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 16: Physical impacts Climate scenario

Table 17 presents annualized values of climate related impacts across all sectors. The cumulative values are annualized over 30 years. The results of the agriculture sector will serve for illustration purposes. Key impacts observed in the agriculture sector is that total production decreases while total water demand increases. The cumulative reduction in agriculture production indicated in Table 16 translates to 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 to 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 agriculture value added.

Sector	**Unit**	**Mozambique**	**Uganda**	**Cameroon**
Agriculture				
Total production	mn Tons / Year	-0.30	-0.86	-1.71
Agriculture 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
Labor 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

Table 17: Annualized impacts over 30 years Climate scenario

4.3. Adaptation scenario

4.3.1. Assumptions

The adaptation scenario assumes the implementation of interventions to reduce the 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 agriculture sector, a transition towards organic farming practices is simulated. In the energy sector, the implementation of decentralized renewable energy aims at reducing the vulnerability of power generation capacity to climate impacts. Finally, to increase water security, a transition to drip irrigation is assumed. Table 18 summarizes the assumptions by sector and intervention.

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 labor 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%	

Table 18: Assumptions Adaptation scenario

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 towards organic farming increases the productivity of the agriculture sector considerably. While the amount of total cropland remains the same as in the Climate scenario, total annual agriculture production increases on average by 5%. The highest impact is observed for Cameroon, where total agriculture production increases by 3.12 million tons in 2050. The increase for Uganda and Mozambique is projected at 1.59 million tons and 0.86 million tons in 2050 respectively. Total agriculture production for the Adaptation and the Climate scenarios is illustrated in Figure 32.

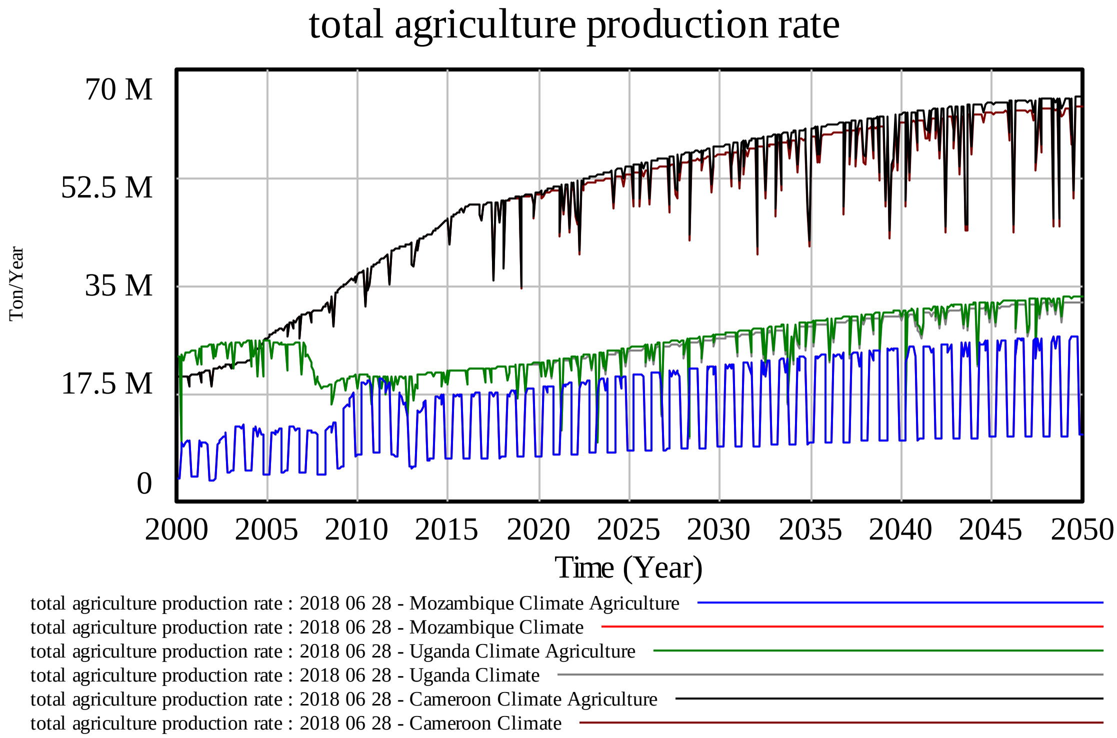


Figure 32: Total agriculture production Adaptation vs Climate scenario

Table 19 summarizes the development of agriculture production in the Adaptation scenario and the Climate scenario, in 5-year intervals.

Agriculture production	Unit	2018-2020	2020-2025	2025-2030	2030-2035	2035-2040	2040-2045
Mozambique Adaptation	mn Ton / Year	1.12	1.21	1.34	1.42	1.53	1.60
Mozambique Climate	mn Ton / 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 Ton / Year	1.80	1.92	2.16	2.31	2.52	2.61
Uganda Climate	mn Ton / 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 Ton / Year	4.02	4.35	4.69	4.89	5.09	5.26
Cameroon Climate	mn Ton / 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%*

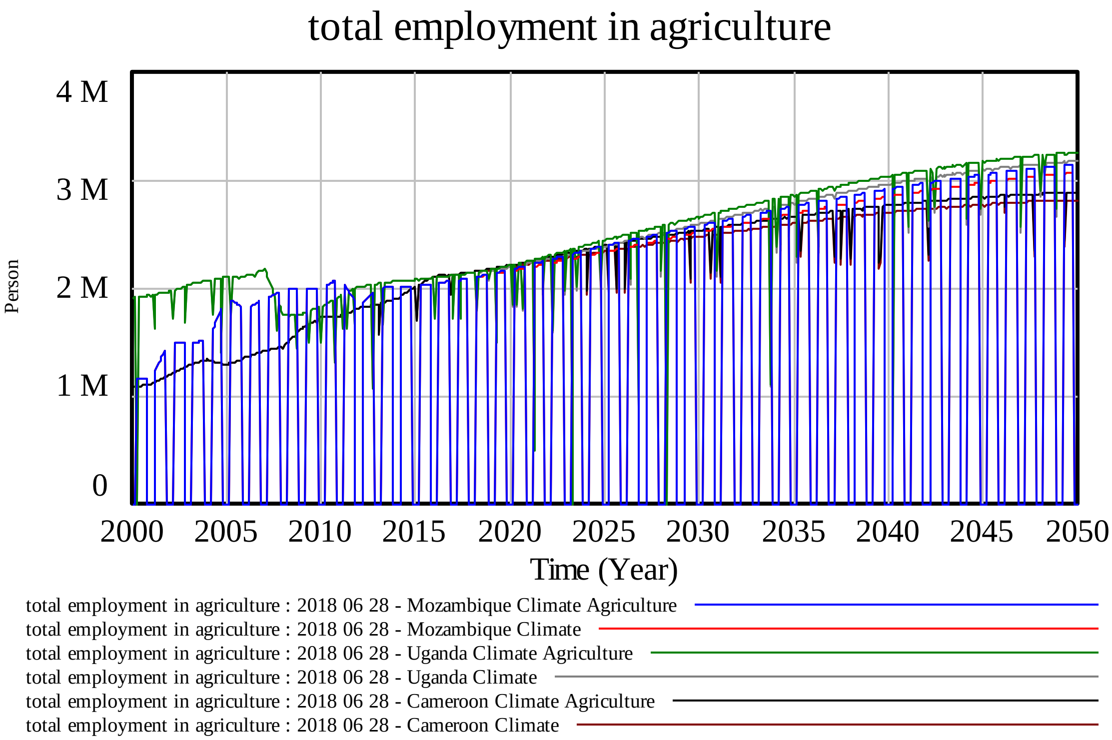
Table 19: Agriculture production Adaptation vs Climate scenario

The increase in agriculture production leads to an increase in agriculture GDP of 4.5% in Mozambique, 5.0% in Uganda and 5.06% in Cameroon. Cumulatively, the increase in Cameroon's agriculture GDP totals CFA 3.44 trillion between 2018 and 2050, which is equivalent to an increase of CFA 114.7 billion over 30 years. The cumulative additional GDP for Uganda and Mozambique during the same period is Ush 13.74 trillion and MZN 133 billion respectively. In the long run, the application of organic farming practices increases the agriculture GDP between 4.4% and 4.7%.[1] Table 20 provides an overview of agriculture GDP in the Climate scenario and the Adaptation scenario, and indicates the percent change observed between the two scenarios.

Agriculture GDP	**Unit**	**2018**	**2020**	**2025**	**2030**	**2040**	**2050**
Mozambique Adaptation	bn MZN	84.91	89.29	99.01	105.66	116.13	126.31
Mozambique Climate	bn MZN	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 Ush	14'009.23	14'569.83	16'558.18	17'853.01	19'144.57	21'572.26
Uganda Climate	bn Ush	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 CFA	2'471.40	2'561.11	2'725.47	2'866.30	2'910.05	2'934.75
Cameroon Climate	bn CFA	2'464.57	2'524.08	2'614.70	2'748.34	2'784.98	2'803.36
Adaptation vs Climate	*%*	*0.3%*	*1.5%*	*4.2%*	*4.3%*	*4.5%*	*4.7%*

Table 20: Agriculture GDP in the Adaptation scenario

In addition to beneficial economic impacts, the transition towards organic farming increases employment creation in the agriculture sector. The increase in agriculture employment for all three countries is projected at 2.5%, 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 agriculture GDP and employment is illustrated in Figure 33.



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[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.

Figure 33: Employment agriculture Adaptation vs Climate scenario

Between 2018 and 2050, the transition towards organic farming requires investments of CFA 3.52 trillion in Cameroon, Ush 25.28 trillion in Uganda and MZN 386 billion in Mozambique. Table 21 illustrates the required investments and the additional value added realized through the transition towards organic farming.

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

Table 21: Net benefits 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 22 provides an overview of the break-even costs and price premium for organic agriculture.

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%

Table 22: Break even conditions for organic farming Adaptation scenario

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 a 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 scenario. 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% and 2.8% higher than in the Climate scenario, which corresponds to a value up to 245 additional hours (or approximately 10 days) of electricity availability per year.

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[2] The assumed investments costs per hectare of organic agriculture are assumed at USD 100 per hectare per year.

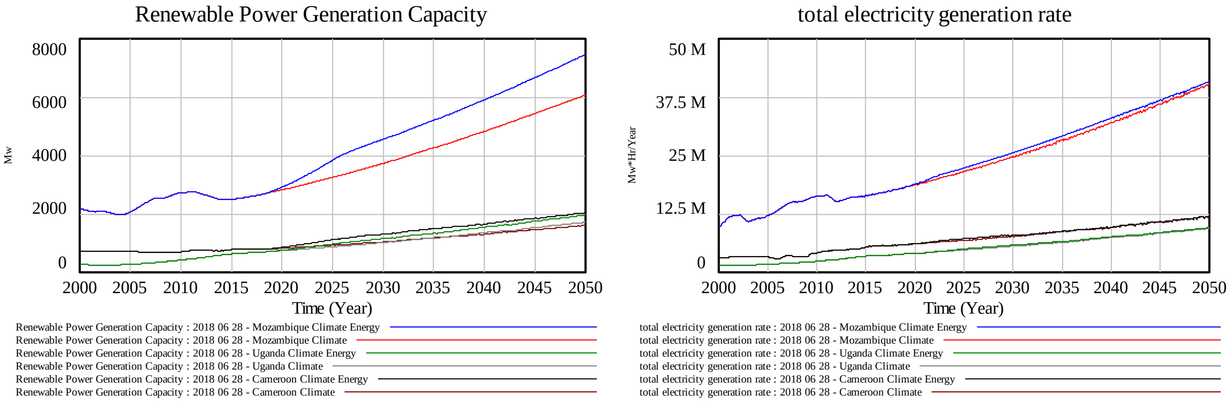

Figure 34: Renewable capacity and electricity generation Adaptation vs Climate scenario

The transition of towards 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% and 2.5% respectively, and employment in Cameroon's energy sector is projected to decrease by 0.7%.

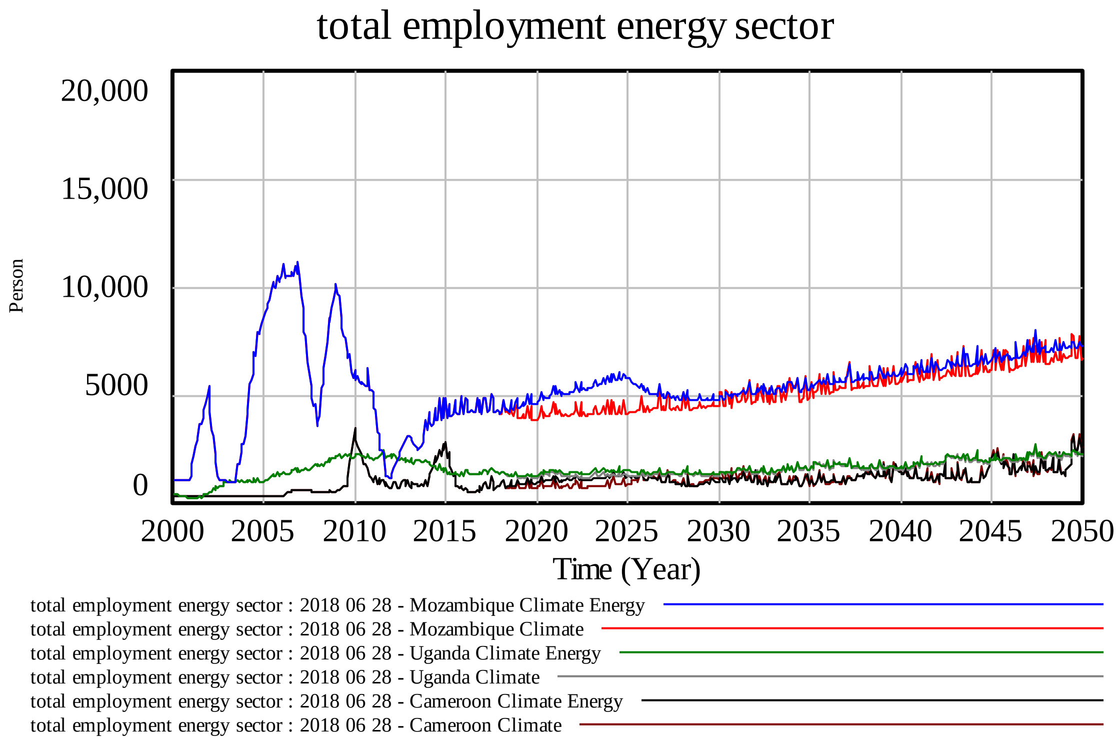

Figure 35: Energy sector employment Adaptation and Climate scenario

Despite the fact of improved economic productivity through increased electricity access, the transition towards renewable energy needs to be balanced with the currently stock of installed capacity, to avoid idle capacity and the need to use sub-optimally thermal power capacity. Table 23 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 case of Uganda and Cameroon. In the case of Mozambique, the 15% increase in renewable capacity creates overcapacity, which results in a net loss of USD 9.46 billion between 2018 and 2050. This indicates that too ambitious investments in renewable energy bear 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.

Investments	**Unit**	**Mozambique**	**Uganda**	**Cameroon**
Renewable capacity	mn USD	75'153	9'119	15'768
Investment	*mn USD*	*73'693*	*9'008*	*15'298*
O&M 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*	*8'279*
O&M cost	*mn USD*	*1'297*	*131*	*498*
Added benefits				
GDP from access to energy	mn USD	17'115	20'775	25'393
Labor income	mn USD	20'986	5.1	1.4
Total Net benefits	**mn USD**	**-9'458**	**16'100**	**18'404**

Table 23: Net benefits energy sector Adaptation scenario

The physical and economic damages resulting from adverse weather in the Adaptation and Climate scenario area compared in Table 24. The decentralization of the power grid reduces climate related damages cumulatively by between 38 MW and 500 MW in the three countries. The increase in electricity production and the reduction in physical damages indicate that the electricity generation sector is less vulnerable towards climate change impacts. However, despite the reduction in damages to physical capacity, the cumulative economic value of damages increases by between 0.4% and 4% compared to the Climate scenario due to higher capacity costs of renewable capacity. This is equivalent to an average increase between USD 1.5 million and USD 8.8 million per year between 2018 and 2050.

	Adaptation scenario		**Climate scenario**		**Difference**	
Total damages 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 24: Climate impacts on Power generation capacity Adaptation vs Climate scenario

4.3.4. Water

Projections for the water sector indicate that the introduction of efficient (drip) irrigation has the potential to significantly reduce water consumption and boost productivity. The most significant savings are achieved in Mozambique, where introducing drip irrigation yields average water savings of 27.9 trillion m3 per year over a 30-year period. During the same time, the projected water savings obtained in Uganda and Cameroon average 7.26 and 1.54 trillion m3 respectively. If water savings are used to irrigate additional cropland, the total amount of cropland could be increased by between 12.8% and 14.4% (assuming that the same amount of water is used, when water efficiency increases the number of hectares irrigated can also increase). Table 25 compares water demand for irrigation in the Adaptation scenario to the Climate scenario. In the long run, water demand for irrigation could be reduced by 16.7%.

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%*

Table 25: Water demand for irrigation Adaptation vs Climate scenario

Introducing drip irrigation would require additional cumulative investments between USD 6 billion and USD 6.67 billion between 2018 and 2040 (see Table 26). The development of water demand from agriculture in the Adaptation and Climate scenario 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 agriculture land productivity.

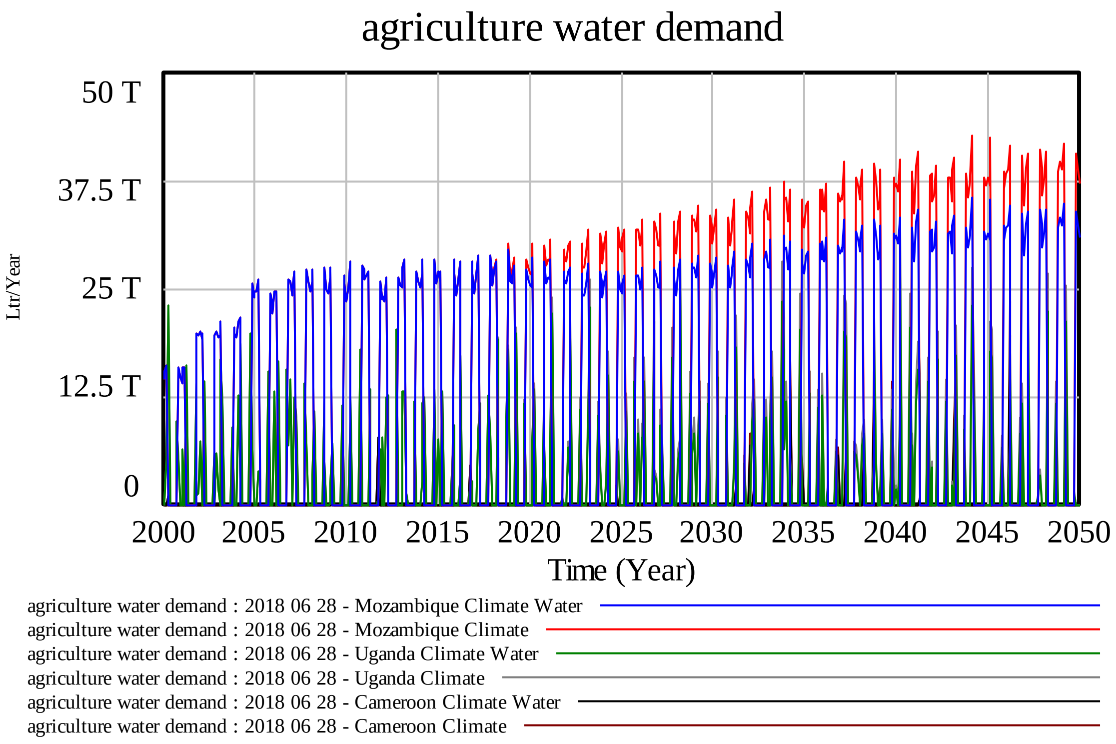

Figure 36: Agriculture water demand Adaptation vs Climate scenario

4.3.5. Summary of results

The net benefits of interventions that aim at improving climate resilience are summarized in Table 26. Overall, net benefits are projected for Uganda (USD 7.07 billion) and Cameroon (USD 110.08 billion), while the simulated scenarios indicate a net loss for Mozambique (USD -31.69 billion), which is mainly attributable to the forced transition to renewable energy (with the expansion of renewable energy being faster than the decommissioning of existing capacity).

Concerning sectoral interventions, between 2018 and 2050, investments for sustainable farming range between USD 6.25 billion and USD 6.73 billion. Total cumulative costs (investment and O&M) for efficient irrigation are in a comparable range, with USD 5.99 billion and USD 6.67 billion, of which approximately 71.4% are upfront capital investments. The amount of investments required for irrigation ranges between USD 4.22 billion in Cameroon and USD 4.77 billion in Uganda.

The shift towards renewable power generation capacity reduces the required investments and O&M costs for conventional power generation capacity. The magnitude of savings depends on the current amount of and use factor of power generation capacity, and on the current use of renewables.

Benefits are generated by increasing the access to water and electricity. Renewable and decentralized energy increases the access and availability of electricity, which is results in increased total economic performance by around 1.5% to 2% 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 agriculture sector and hence increases total production.

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*
O&M cost	*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*
O&M 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*
O&M cost	*mn USD*	*15'559*	*1'570*	*5'981*
Total avoided costs	**mn USD**	***41'857***	***5'880***	***14'260***
Added benefits				
Labor income energy	mn USD	20'986	5	1.4
Agriculture 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**

Table 26: Total net benefits of all interventions

5. Discussion: the relevance of a Nexus approach

Adaptation to climate change, to improve resilience, holds potential for both reducing 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 agriculture, water and energy sectors. Climate impacts were forecasted to reduce agriculture GDP by between 12.1% and 16.7% in 2050. Climate change also brought additional costs, e.g. in power generation capacity.

The simulation of climate adaptation measures indicated, as mentioned above, not only the potential to reduce costs, but also the possibility to generate net benefits, as summarized in Table 26. Uganda and Cameroon show considerable net benefits, while Mozambique incurs a net loss Mozambique (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, in both cases this is evident through the implementation of drip irrigation. 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 agriculture production. In other words, it removes a bottleneck for the agriculture sector and increases its resilience.

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

In addition, the decentralization of power generation capacity through establishing renewables benefits total employment. Establishing solar power and small renewable 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 to identify potential synergies and bottlenecks that could render a project (or an investment) more or less attractive in terms if 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, it also increases social and economic resilience for 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 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 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 agriculture, energy and water sector. The outcomes of changing whether dynamics and trends are meaningful. The analysis of climate adaptation scenarios also shows outcomes of interventions on (1) reducing costs and (2) generating new benefits. Importantly, synergies also emerged across sectors, indicating that the nexus approach can provide valuable inputs to policy formulation and investment assessments, also in the context of climate resilience and disaster risk reduction (DRR).

More work is required for data collection, model development (especially for the creation of local capacity), and dissemination of results. This could be done possibly through the same infrastructure used for Climate Information Services (CIS), and the potential for 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:

1. Incentivize the use of systemic planning, across sectors and including social, economic and environmental indicators of performance. This is needed to operationalize the nexus approach.
2. Use a multi-stakeholder approach, to ensure that all key indicators are considered and that policies are formulated and implemented effectively.
3. 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).
4. Increase investment in the collection, processing and use of weather information, including early warning systems.
5. Invest in Climate Information Services, also to disseminate information in a timely manner. This would serve as a foundation for improved planning and more timely intervention.
6. Require the preparation of integrated economic analysis (i.e. cost benefit analysis that includes economic, as well as the economic valuation of social and environmental project/investment outcomes).

7. Establish a technical inter-ministerial working group, supported by representatives of academia, responsible for assessing sectoral and systemic resilience, with the goal to strengthen policy coordination.

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

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