VULNERABILITY, IMPACTS AND ADAPTATION ASSESSMENT IN THE EAST AFRICA REGION

CHAPTER 12: ENERGY, TRANSPORT, AND ASSOCIATED INFRASTRUCTURE IN EAST AFRICA – FUTURE SCENARIOS

NOVEMBER 2017

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CHAPTER 12:

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CONTENTS

ACRONYMS

ADB	Asian Development Bank
AIC	Akaike information criterion
AR	Autoregressive
DFID	Department for International Development (U.K.)
DJF	December–February
EAC	East African Community
EACPP	East Africa Community Power Pool
EAPMP	East Africa Power Master Plan
EAPP	Eastern Africa Power Pool
EIA	Environmental impact assessments
FiT	Feed-in-Tariffs
FPE	Final prediction error
GDP	Gross domestic product
GW	Gigawatt
GWh	Gigawatt hour
HQ	Hannan-Quinn
IPCC	Intergovernmental Panel on Climate Change
JJAS	June–September
kW	Kilowatt
kWh	Kilowatt hour
kWp	Kilowatts peak
LCPDP	Least Cost Power Development Plan
LPG	Liquified petroleum gas
LVB	Lake Victoria Basin
MA	Moving average
MAM	March–May
ML	Maximum likelihood
MW	Megawatt
NBI	Nile Basin Initiative
NCCRS	National Climate Change Response Strategy
OND	October–December
PV	Photovoltaic
SBC	Schwarz Bayesian criterion
UCM	Unobserved Components Model
UNEP	United Nations Environment Programme
USAID	United States Agency for International Development
VIA	Vulnerability, Impacts and Adaptation Assessment

1. INTRODUCTION

Energy is a prerequisite for the socioeconomic development of any nation. Energy services are an essential input to the economic activity that supports growing enterprises and creates jobs. They also contribute to social development through education and public health and help to meet the basic human need for food and shelter. Energy has been linked directly to such important challenges as poverty alleviation, climate change, environmental protection, and food security.

Energy demand is continually increasing, especially for heating, lighting, cooking, transportation, and industrial use. Much of the energy currently used is generated using resources such as petroleum, coal, and natural gas. These non-renewable resources eventually will be depleted and they contribute to environmental problems such as global warming and climate change. Other energy sources, such as solar, wind, and hydropower, are nearly inexhaustible as they are continually renewed.

1.1 THE ENERGY SECTOR IN THE EAST AFRICAN COMMUNITY

The Partner States of the East African Community (EAC) have abundant and diverse energy resources. The principal energy resources are large and small hydropower, biomass, geothermal, solar, wind, liquid natural gas, peat, and coal. Biomass[1] is the predominant energy resource used by the rural population while electricity and petroleum are the drivers of economic sectors. Table 1 shows the installed hydropower capacity in the EAC countries.

Table 1: Installed hydropower capacity in the EAC countries

Country	Installed capacity (MWe)	Hydroelectric potential (MWe)	Hydropower supply (MWe)	Access (% of population)
Burundi	50	1,700	35.35	10
Kenya	2,294	6,000	829	50
Rwanda	145	400	78.9	18
Tanzania	1,490	4,700	553	24
Uganda	853.5	2,200	695	9

Figure 1 shows the energy balance for all EAC countries. Burundi, Tanzania, and Uganda depend heavily on biomass for their energy needs.

[1] Due to high dependence on biomass, the deforestation rate for EAC Partner States is between 73,000 to 133,600 hectares per year.

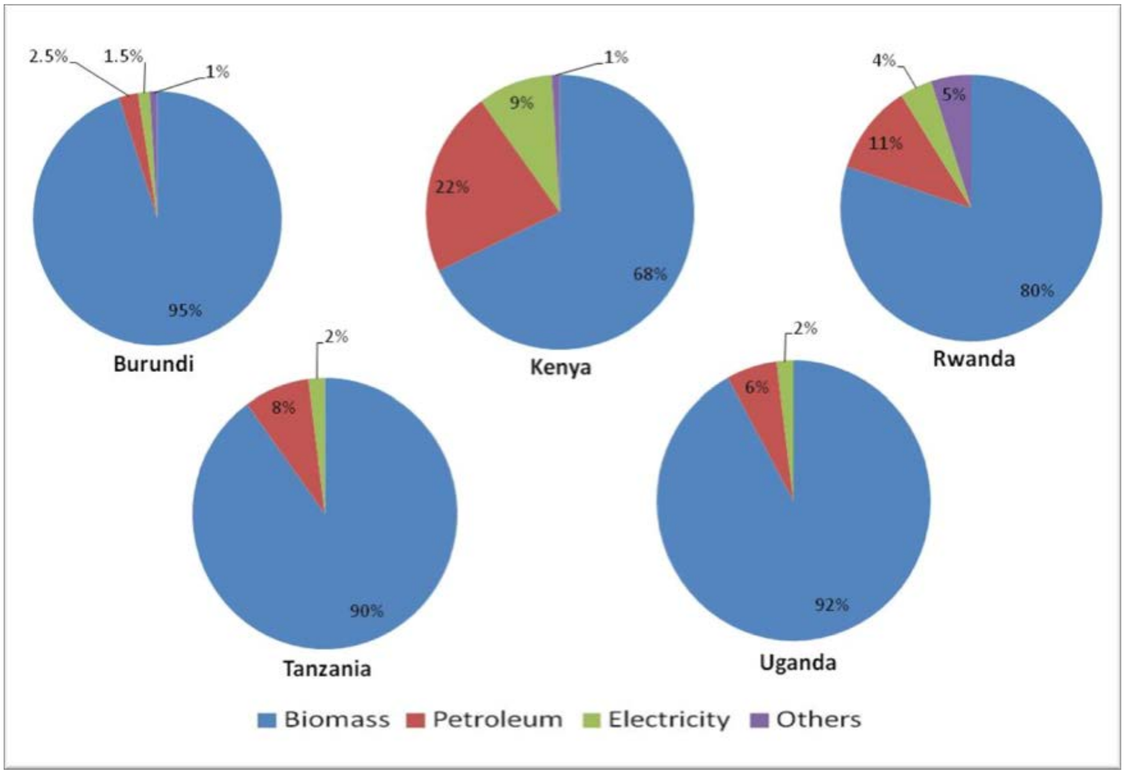
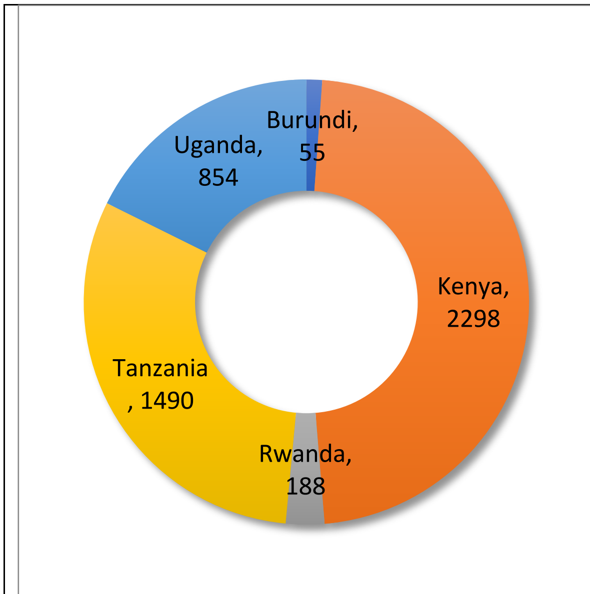
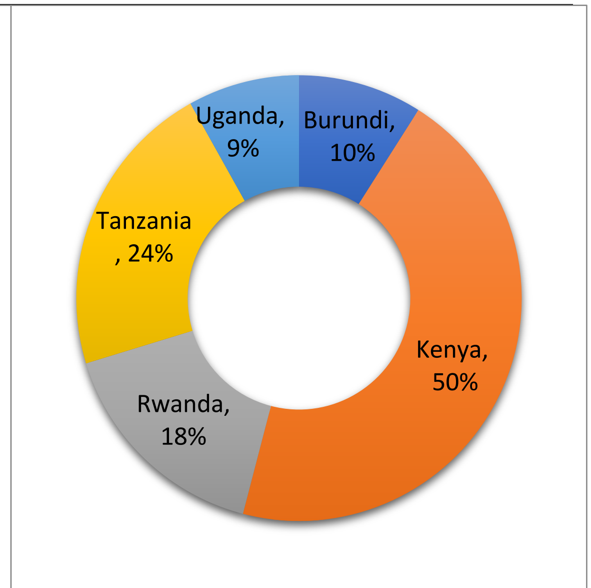


Figure 1: Energy balance for EAC Partner States

The development visions of all EAC Partner States recognize that energy is a vital input to development. Energy is identified as a foundational sector and an infrastructural "enabler" upon which to build the economic, social, and political pillars. For example, in 2013, the percentage share of electricity to gross domestic product (GDP) was 0.6 percent in Rwanda, 0.9 percent in Uganda, 1.1 percent in Kenya, and 1.8 percent in Tanzania.

All five Partner States have low access to electricity and high dependence on hydropower. Total installed electricity generation capacity in the EAC in 2015 was 4,832 megawatts and the rate of access to electricity was 9–50 percent (Figure 2).





(a) Installed Capacity (MW)	**(b) Electricity Access Rate (%)**

Figure 2: Installed capacity and electricity access rate in the EAC as of 2015 (source: EAC 2015)

Large hydropower generation accounts for 35–90 percent of total power generation in the EAC (Burundi, 90 percent; Rwanda, 60 percent; Kenya, 35 percent; Tanzania, 37 percent; and Uganda, 81 percent). The general trend shows decreasing generation from large hydro (Figure 3).

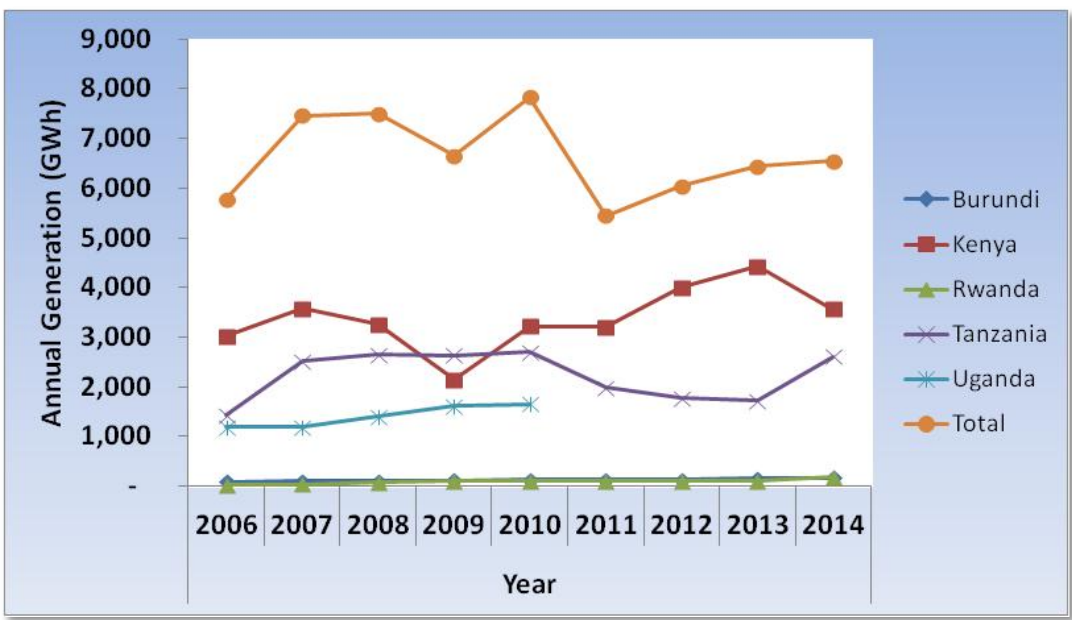


Figure 3: Annual hydroelectricity generation (GWh) trend in the EAC (2006–2014 (source: EAC 2015)

To meet current and future power demand, and to improve power supply security, the Partner States:

1. Developed Power Master Plans aimed at increasing power generation and diversifying sources to include geothermal, natural gas, wind, solar, and coal. While diversification will increase in future years, hydropower will remain a major supply technology (Figure 4).
2. Participate in the Eastern Africa Power Pool (EAPP), East Africa Community Power Pool (EACPP), and Southern Africa Power Pool.

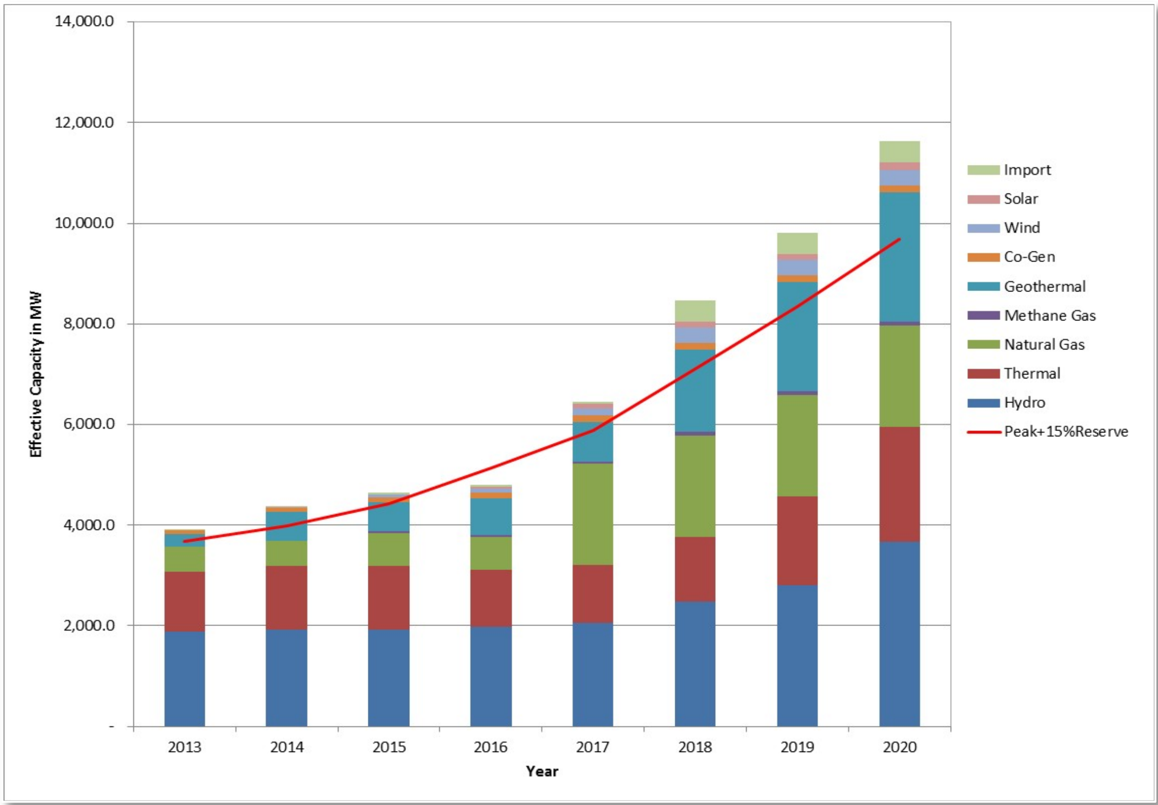


Figure 4: Projected effective electricity generation capacity growth (source: EAC 2015)

1.2 EAC Vision 2050

The rationale for Vision 2050 is to "provide a catalyst for the region to enhance economic transformation and move the EAC into a higher income cohort and subsequently achieve an upper-middle-income status." By creating a conducive environment for investment, coupled with effective institutional capacities, the Vision anticipates that the region will expand its production capacity and widen its exports, both by composition and value (EAC 2016). Through "effective resource management," it is envisaged that the EAC "will be transformed into an upper-middle-income region within a secure and politically united East Africa based on the principles of inclusiveness and accountability."

Achievement of these goals will include developing and building an infrastructure and transport network for the movement of both people and goods that is efficient, inexpensive, and regionally competitive; adopting energy and information technology that is easily accessible to citizens; and leveraging the comparative and competitive advantages of the region to build industrialization on the structural transformation of the agriculture and manufacturing sectors through adding value and diversifying production. The EAC is planning or implementing several projects and programs in the power sector to help accomplish these goals:

- **Implementation of the EAC Power Master Plan:** Priority projects identified in the master plan are implemented by the Partner States.
- **Establishment of a Regional Power Market:** The EAC is working closely with the EAPP and other regional organizations to develop a regional power market that will facilitate power exchange among Partner States and with other regions.
- **Power Interconnection Code:** The EAC and EAPP have developed a regional grid code (Interconnection Code) to govern the design and operation of power interconnections among Partner States.
- **Cross-Border Electrification Program:** Border towns are electrified using the nearest and most economical medium- and low-voltage grid. Partner States have identified candidate towns. The EAC Cross-Border Electrification Policy guides the implementation of cross-border electrification projects and development of shared renewable energy resources.
- **EAC Energy Security Policy Framework:** The EAC, in collaboration with the United Nations Economic Community for Africa, is developing an energy security framework that will guide the region toward ensuring an energy-secure future. There is no mention in the report of how the sector will deal with climate change and its impacts on the sector.

The EAC has the smallest per capita power generation and electricity access rates on the continent, and has lagged in developing a regionally integrated vision for a power pool. To fulfill its vision, apart from developing the energy sector in general, it needs adequate plans to invest in technologies that will combat climate change in the sector. The broader vision is ambitious: serve 278 million people by 2050, 92.9 percent access to safe water, 90 percent access to electricity, 100 percent access to health services, produce 270 million metric tons of food, and construct 65,700 kilometers of paved roads (Figure 5). To manage the goals and pillars of Vision 2050, energy infrastructure needs to be built while taking climate change and extreme events into consideration.

Vision	**Vision** To become a globally competitive upper-middle-income region with high quality of life for its population based on the principles of inclusiveness and accountability						**Principles**
	Mission To widen and deepen economic, political, social, and cultural integration						
	Aspirations						
Goals	Access to affordable and efficient transport, energy, and communication for increased regional competitiveness	Enhanced agricultural productivity for food security and a transformed rural economy	Structural transformation of the industrial and manufacturing sector through value addition and product diversification based on comparative advantage for regional competitive advantage	Effective and sustainable use of natural resources with enhanced value addition and management	Leverage on the tourism and services value chain and build on the homogeneity of regional cultures and linkages	Well-educated and healthy human resources	
Pillars	Infrastructure development	Agriculture, food security and rural development	Industrialization	Natural resource and environmental management	Tourism and services development	Human capital development	
Enablers	Political will						
	Good governance, peace, and security						
	Science, technology, and innovation						
	Research and development						
	Gender and women's empowerment						
	Financial resources						

Figure 5: Framework for EAC Vision 2050 (source: EAC 2016)

2. IMPACTS OF CLIMATE VARIABILITY AND CLIMATE CHANGE ON THE ENERGY SECTOR

2.1 IMPACTS OF CLIMATE CHANGE ON HYDROPOWER

Climate change will affect various regions differently and each region will face unique challenges as the climate changes. It is known that floods, droughts, glacial melt, increasing temperatures, and variability in the timing, location, and amount of precipitation, are all signals of climate change. These can affect hydroelectric generation by increasing water resources and hydropower potential in some regions and diminishing them in others.

Changes in temperature and in rainfall patterns can have profound effects on river systems and directly affect hydroelectric production. Melting glaciers and snow in the mountains can change the flow of the downstream rivers and have an impact on power generation. Severe storms within the basins of power generating plants can threaten hydropower infrastructure and cause flooding of entire river basins. Hydropower is dependent on river discharge to create electricity. Generally, the lower the river discharge, the less electricity a hydropower facility can generate. Differing scales and types of hydropower are more vulnerable to climate change phenomena. Figure 6 shows the impacts of climate change on power production; Box 1 provides more detailed information.

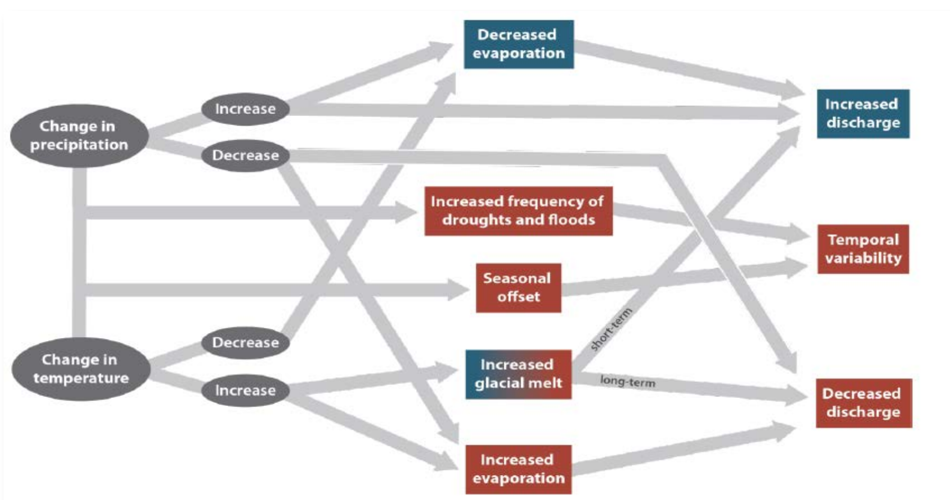


Figure 6: Climate change effects on hydropower, Note: Red indicates effects that are typically detrimental to hydroelectric production; blue indicates effects that typically improve hydroelectric production potential (ource: Blackshear et al. 2011)

Box 1: Effects of climate on hydropower generation

- Evaporation: Increased evaporation reduces electricity generation for all types of dams. Due to the direct relationship between the surface area of a water body and its rate of evaporation, the geometry of reservoirs determines their susceptibility to evaporation. Reservoirs with higher ratios of surface area to volume are more vulnerable to losing capacity from evaporation, which reduces a facility's power production capacity. Retrofitting reservoirs to make them deeper with a smaller surface area would reduce evaporation, but this can be very expensive. Planned projects should take reservoir shape into consideration in their design to reduce evaporation and maximize power potential.
- Discharge: An increase in annual river discharge can result in a corresponding increase in hydropower production. However, fluctuations in river discharge have different effects on different types of generation facilities. For example, run-of-river dams, because they are directly dependent on river flow may be more vulnerable to decreased discharge. Reservoir dams, in contrast, are able to compensate for decreased amounts of water through adjustments to the reservoir management plan. (See Figure 20 in the appendix.)
- Temporal variability: Climate change will increase the temporal variability of precipitation events, which could pose problems for hydroelectric generation. For example, more severe and frequent floods and droughts due to such changes will affect generation. Seasonal offsets, or the altering timing and magnitude of precipitation for traditional rainy and dry seasons and peak snowmelt, will occur as well.
- Floods: Flooding can increase river flows, and therefore hydropower generation, if the excess river flow level remains within the dam's reservoir capacity. However, extreme floods can be destructive to dams, either directly through damage to structural components or indirectly through the deposition of large sediment and debris loads that block dam spillways. Dams upstream of the reservoir can help control the flood pulse of a river and help buffer hydroelectric dams from flooding impacts.
- Droughts: Droughts may present the most obvious threat to hydroelectric generation, as they reduce the amount of water available to produce electricity. Many regions have experienced droughts in the past several decades that greatly reduced energy production, reducing up to half of their electrical production capacity in some cases. Droughts in areas exclusively dependent on hydropower for electricity generation would face blackouts in some drought senarios.
- Glacial melt: Glaciers act as natural water towers that provide water to downstream areas. As glaciers retreat in response to climate change, runoff to rivers will increase in the short term. Once the glaciers are gone, however, long-term decreases in annual runoff and stream discharge will reduce electricity production.

Source: Blackshear et al. 2011.

2.2 Climate Change Implications for Energy and Environment

The Fifth Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC) found that climate change is "unequivocal, and that human activities, particularly emissions of carbon dioxide, are very likely to be dominant cause." Changes have been observed throughout the globe: weather patterns are changing, sea levels are rising, the oceans and atmosphere are warming, the extent and volume of snow and ice are diminishing. The major findings from this report indicate that:

- **Global energy demand is increasing and, with growing energy generation, greenhouse gas emissions are increasing.** The trend will likely continue, driven by rising population and economic growth. Increased use of coal-based energy generation in the past few years has reversed a long-term trend toward decarbonization of energy.
- **Climate change presents increasing challenges for energy generation and transmission.** Increasing temperatures, changing precipitation patterns, and an increasing number and severity of extreme weather events will affect energy production and delivery. The supply of fossil fuels, and the generation and transmission of thermal and hydropower, will also be affected unless adaptation options are implemented.
- **Greenhouse gas emissions can be cut significantly using a variety of measures.** These include cutting emissions from the extraction of fossil fuels and switching to lower-carbon fuels (for examples, coal to gas), improving the efficiency of transmission and distribution, increasing the use of renewable energy sources and nuclear generation, introducing carbon capture and storage, and reducing energy demand.
- **Global political action to address climate change would have serious implications for the energy sector.** To meet the internationally agreed 2°C temperature increase target it would be necessary to transform the energy industry over the next few decades.
- **Creating incentives for investment in low-carbon technologies will be a key challenge** for governments and regulators to achieve carbon reduction targets. Reducing greenhouse gas emissions has collateral benefits, such as improved health and increased employment, but supply-side mitigation measures also carry risks.

The potential impacts of climate change on the energy sector are summarized in Table 2.

Table 2: Potential impacts on the energy sector

Fossil Fuel Extraction and Transport	
Temperature increase	• Damage to pipelines by melting permafrost (as soil subsidence threatens structural integrity)
Precipitation increase; flooding	• Reduced coal quality (higher moisture content of opencast mining) • Increased coal availability (e.g., if coal seam fires are extinguished) • Reduced output (if floods affects mines) or availability (if floods affect transport)
Drought or precipitation decrease	• Reduced coal availability (less water for mine air conditioning and operations, higher probability of seam fires) • Reduced shale oil or gas availability (very large water demands for drilling and removing drilling mud) • Soil shrinkage due to drought could affect oil and gas pipelines
Storm strength and/or frequency increase	• Reduced coal production (if storms affect opencast excavation equipment) • Reduced oil production (if storms affect coastal or offshore oil platforms)
Hydropower	
Precipitation (including drought)	• Changing annual or seasonal patterns can affect river flows and water levels behind dams, either reducing or increasing power output • Siltation can reduce reservoir storage capacity • Increased uncertainty in water flows can affect power output and generation costs

Extreme events (glacier melting, floods)	• Floods and glacial lake outburst floods can damage or destroy infrastructure
Higher air temperature, wind speeds, and humidity	• Can increase surface evaporation, reducing water storage and power output
Wind Power	
Wind speed	• Changes in wind speed can reduce generation (turbines cannot operate in very high or very low winds) • Within operational wind speeds, output is affected greatly by wind speed • Changes in wind patterns and duration affect output (e.g., ability to forecast output)
Air temperature	• Changes in extreme cold periods can affect output (e.g., through turbine blade icing)
Storm surges	• Damage to offshore wind farms
Extreme events	• Damage to infrastructure • Difficult access to offshore locations (e.g., for maintenance)
Solar Photovoltaic Power	
Temperature increases	• Lowers cell efficiency and energy output • Lowers capacity of underground conductors if high ambient temperature increases soil temperature
Precipitation increases	• Can wash away dust (short term) but reduces panel efficiency (less solar radiation) • Snow accumulation on panel reduces efficiency
Wind speed; turbidity	• Increased efficiency and output with cooling effect of wind • Scouring of panel and lower output if air is gritty/dusty
Cloud cover	• Increase lowers efficiency/output • Rapid fluctuations in cloud cover can destabilize grid
Extreme events	• Can damage systems (e.g., lightning strikes)
Transmission and Distribution	
Temperature increase	• Can reduce electricity carrying capacity of lines • Can increase losses within substations and transformers
Precipitation and flooding	• Heavy rains and flooding can undermine tower structures through erosion • Snow and ice damage transmission and distribution lines (e.g., through sagging) • Drought can increase dust damage • Flooding can damage underground cables and infrastructure in general
High wind speeds	• Strong winds can damage transmission and distribution lines
Extreme events (flood, typhoons, drought)	• High temperatures, storms, erosion, or flooding can damage control systems through loss of information and communications technology service or reduce quality of service • Ice storms can do devastating damage to power transmission and distribution networks

Source: Adapted from ADB 2012.

2.3 Impacts of Climate Change on the Power Sector in East Africa

East Africa has been prone to periodic extreme climatic events including flooding and prolonged dry spells, which will be exacerbated by climate change. Rainfall changes and variations are expected to be more sporadic and unpredictable in East Africa in the future, resulting in periods of prolonged drought alternating with periods of high rainfall leading to floods (IPCC 2007). This has been evident for several decades with prolonged droughts in 1983/84, 1991/92, 1995/96, 2004/2005, and the La Niña–related drought of 1999/2001, all of which led to reduced water levels in the region. Similarly, El Niño–related floods were experienced in 1997/98.

More recently, a 2011 drought affected hydropower generation in most of the East African countries. Droughts in 2012–2013 had severe effects on the Mugere (5MW) and Rwegura (18MW) power stations in Burundi. In Uganda, several mini-hydropower stations in the western region are served by rivers originating from the glacier on Mount Ruwenzori, which is retreating. The melting of the ice cap has a negative effect on downstream water catchments. This can effect eco-tourism and, in turn, the entire economy.

Studies in recent years have examined the impacts of climate variability on the regional and national energy sector and consequently on other economic sectors. For example, *Future Hydropower Scenarios under the Influence of Climate Change for the Riparian Countries of Lake Victoria Basin* (2010) showed that the Lake Victoria Basin (LVB), which includes parts of all the five EAC Partner States, suffers from electric power shortages despite its immense hydropower potential, which is underexploited. The report concluded that hydropower generation is vulnerable to climate variability and change and that the increasing demand for water due to the rising population and economic growth will only exacerbate this vulnerability.

Climate variability and change will severely affect energy infrastructure. The Initial National Communication for Tanzania detected the effects of climate change in flood damage to some hydropower installations on the Rufiji River (URT 2003). While past flooding has not resulted in damage to turbines, it has been a problem for the dams, which are filling due to sedimentation. The national energy services company (TANESCO) has reported that several smaller reservoirs are filling rapidly and in about 15 years will only be able to run at 30–40 percent of capacity and will be unable to meet peak demand. In Burundi, the Rwegura and Mugere rivers in the Congo Basin support the largest input of hydropower in the country but are prone to floods and landslides. In Rwanda, the Ministry of Disaster Management and Refugees (MIDIMAR 2012) found that the southern, western and northern provinces are prone to floods, siltation, landslides.

As noted earlier, climate change and variability have implications for the timing and magnitude of river discharge that could pose challenges to hydropower generation. Hydro stations experienced significant power generation and water flow variability between 1981 and 2014. Figure 7 highlights changes in power generation of Mtera and Kidatu power stations in Tanzania where a drastic decline in power generation occurred during the droughts of 2006 and 2013. In Rwanda (Ntaruka and Mukungwa) the patterns were different: after 1998 power generation declined up to 2003–2004 when it increased slightly only to drop to its lowest recorded level in 2006–2007. Since 2006–07 power generation has recovered to its former levels. In Kenya, the flow of Tana River has been on the decline (Figure 8) thus affecting the production of electricity in that country.

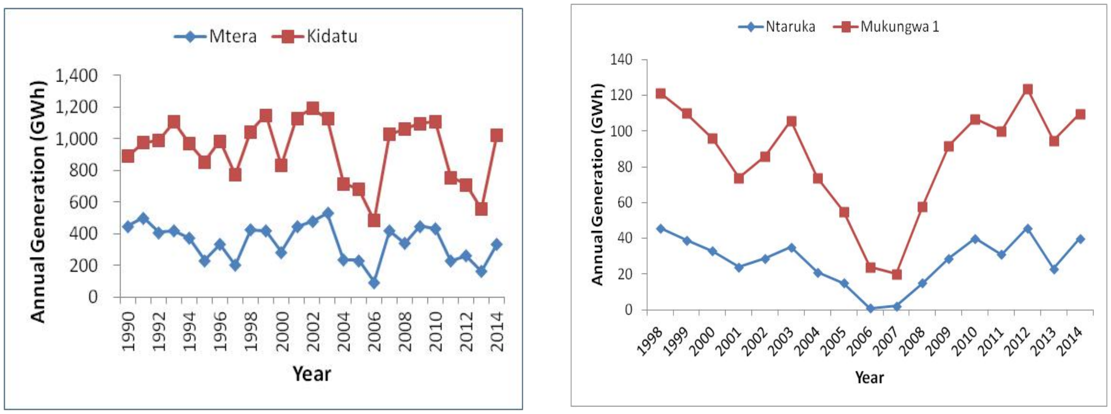


Figure 7: Power generation variability in Tanzania and Rwanda

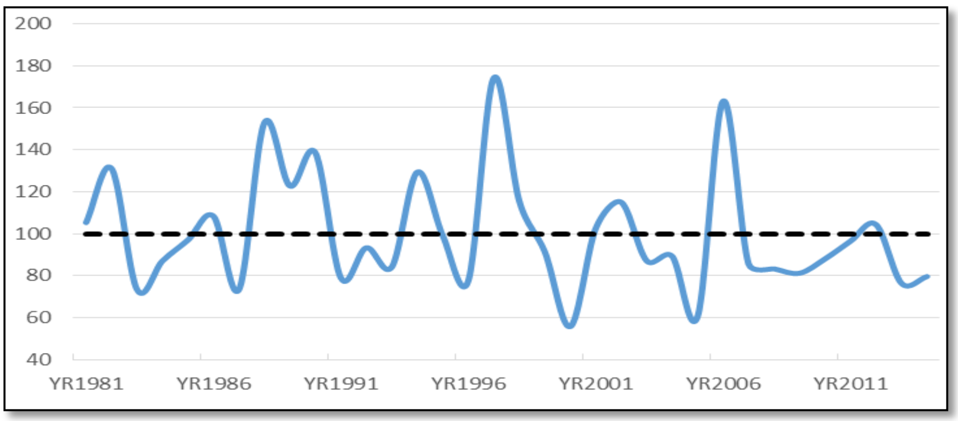


Figure 8: Flow variability in the Tana River

Drought years result in serious power supply shortages. During previous droughts, EAC countries were forced to rely on expensive thermal-powered generators, which contributed to increased generation costs and escalated electricity tariffs. These increases affected domestic, commercial, medium industries, and large industries alike. The analysis shows that during drought years (such as 2005–2008) hydro generation decreased while tariffs increased in almost all countries (Figure 9). For example, between 2005 and 2008 domestic tariffs increased 8 percent in Kenya, 17 percent in Burundi, 30 percent in Rwanda, 52 percent in Uganda, and 70 percent in Tanzania.

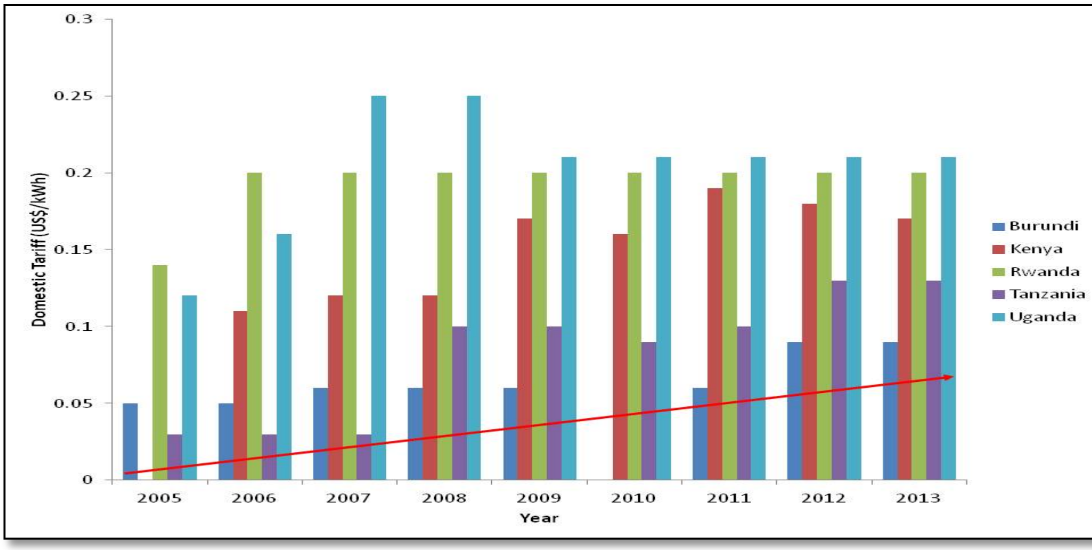


Figure 9: Domestic electricity tariff trend (2005–2013)

Climate variability and change cause serious shortage of electricity and affects all part of a country's economy. Power rationing for both domestic and industrial use makes an economy more vulnerable to climate change–related disasters and leads to inefficient service provision to the public. The examples in Box 2 illustrate these effects.

Box 2: Shortage of electricity affects all of the economy

- The World Bank found that power rationing caused huge economic losses in a number of sectors and estimated the cost to the economy at $1.7 million per day (World Bank 2006).
- An EAC study that considered possible impacts on hydropower by 2030 under "moderate climate change" and "high climate change" scenarios projected losses of 0.7 percent and 1.7 percent of GDP due to decreased rainfall in the central region of Tanzania, where 95 percent of the country's hydropower installations are expected to be located by 2030 (ECA 2009).
- During the 2010 drought, the Government of Tanzania had to contract Emergency Power Producers and paid Tshs. 200 billion as part of the cost for the purchase of electric power generators with capacity of 60MW for Mwanza region and 100MW for Dar es Salaam region. The government also took emergency steps to reduce power rationing in the national grid by funding the purchase of fuel for running the Independent Power Tanzania Ltd. (IPTL) power plant at a cost of Tshs. 18.5 billion.
- The 2011 drought affected hydropower generation in most East African countries. The Kenya Power and Lighting Co. rationed power between 6.40pm and 9.30pm to address generation shortfalls of 70–90MW due to low water levels.[a] TANESCO made similar power cuts in Tanzania.[b] It was estimated that water level at Mtera dam, the largest hydropower reservoir, was receding by almost 3 centimeters per day.[c]
- In Uganda, the manufacturing industry bore the brunt of power cuts as Umeme Company rationed power to industries.[d] The decrease in Lake Victoria levels from 2004 to 2008 was reflected in the hydropower production and supply of the plants at Nalubale (Owen Falls) and Kiira Dam (UNEP 2009).
- Mogaka et al. (2006) estimated losses in hydropower generation and industrial production due to water shortage during the 1999/2000 drought, which severely affected the Tana River Basin, in the range of US$2 billion.

The impacts of droughts on dams

Alternative source of power (wind energy on Ngong hills, Kenya)

a. http://www.nation.co.ke/news/Blackouts-and-rising-bills-as-drought-bites---/-1056/1207728/-/43fiow/-/index.html
b. http://www.bbc.com/news/world-africa-14192896
c. http://www.trust.org/item/?map=drought-worsens-power-crisis-in-tanzania
d. http://www.commoditiescontrol.com/eagritrader/common/newsdetail.php?type=MKN&itemid=158432&comid=7&cid1=7&varietyid=,26,&varid=0

3. CLIMATE CHANGE AND SECTOR FUTURE PROJECTIONS IN EAST AFRICA

3.1 THE FUTURE EAST AFRICAN CLIMATE

The climate change projections presented in this section were based on the CORDEX downscaled regional climate models. The downscaling was performed using multiple regional climate models as well as statistical downscaling techniques. The projected changes in rainfall, maximum and minimum temperatures presented here were based on the RCP2.6, RCP4.5, and RCP8.5 scenarios for four future time slices: 2020s (2006–2035), 2030s (2016–2045), 2050s (2036–2065), and 2070s (2055–2085). The three Representative Concentration Pathways (RCPs) RCP2.6, RCP4.5, and RCP8.5 and the numbers refer to radiative forcings (global energy imbalances), measured in watts per square meter by the year 2100. The RCP2.6 emission pathway is representative for scenarios leading to very low greenhouse gas concentration levels (van Vuuren et al. 2007). RCP4.5 is a stabilization scenario where total radiative forcing is stabilized before 2100 by employment of a range of technologies and strategies for reducing greenhouse gas emissions (Wise et al. 2009), and RCP8.5 is characterized by increasing greenhouse gas emission over time representative of scenarios leading to high greenhouse gas concentration levels (Riahi et al. 2007).

Results of the projected changes in the annual rainfall component under each of the three scenarios and time periods show relatively little change compared to the projected changes in the seasonal rainfall components. The short rains (October–December, or OND period) are projected to increase over most of the region under all three scenarios. In contrast, the long rains (March–May, or MAM period) are projected to decrease over the northern part but to increase over the southeastern part of the region. The dry season rainfall (June–September, or JJAS) is projected to decrease over most of the region. The projected annual rainfall shows a tendency to increase over the LVB. The remainder of this chapter summarizes the results of the future projections.

3.1.1 Rainfall

- The long rains (MAM period) are projected to decrease over the northern part but to increase over the southeastern part of the region.
- The dry season rainfall (JJAS) is projected to decrease over most of the region (25–50 percent by 2020 and 2030, 50–75 percent by 2050 and 2070).
- The short rains (OND period) are projected to increase over most of the region under all three scenarios (10–25 percent by 2020, 2030 and 25–50 percent by 2050 and 2070).

3.1.2 Maximum Temperature

- By 2020, annual maximum temperatures are anticipated to be 0.5–1.0°C higher under the RCP2.6 and RCP4.5 scenarios but 0.5–1.5°C higher under the RCP8.5 scenario over most of the EAC, with slightly less warming apparent in some coastal areas.
- By 2030, maximum temperatures during the long rains (MAM), the dry season (JJAS), and throughout the year (annual component) will likely increase by 1.0–2.0°C over most of the region but with spatial variations similar to those for 2020. The expected warming extent is greatest during the long rains (MAM) and the dry season (JJAS) and least during the short rains (OND).
- By 2050, annual maximum temperatures are expected to be 1.0–2.0°C higher under RCP2.6, 1.5–2.5°C higher under RCP4.5, and 2.5–3.5°C higher under the RCP8.5

scenarios over most of the EAC, with slightly less warming expected in some coastal areas. The greatest potential warming will likely occur in the dry season (JJAS) and during the long rains (MAM).

- By 2070, projected annual maximum temperatures will likely be 0.5–1.5°C higher under the RCP2.6 scenario, which is notably smaller than the changes anticipated by 2050. This is due to the reduction in radiative forcing expected toward the end of the century due to mitigation measures under the RCP2.6 scenario. In contrast, under the RCP8.5 scenario, the expected annual warming will likely result in temperatures 3.5–4.5°C higher than the reference period, with far greater warming expected during the dry season (JJAS).

3.1.3 Minimum Temperature

- By 2020, annual minimum temperatures will likely be 0.5–1.5°C higher under the RCP2.6 and the RCP4.5 scenarios, but 1.0–2.0°C higher under the RCP8.5 scenario over most of the EAC.
- By 2030, almost all the EAC region will likely be 1.0–2.5°C warmer than the base period, with the greatest warming expected during the dry season months (JJAS) under the RCP8.5 scenario.
- By 2070, the projected increase in the annual minimum temperatures will likely be 4–5°C higher under the RCP8.5 scenario relative to the base period.

Projections for the region are shown below. Hydropower plants are located in the Lake Victoria Basin (Mukunwa I and Ntaruka Stations in Rwanda), Tana Basin (Tana Station in Kenya), and Rufiji Basin (Mtera and Kidatu Stations in Tanzania).

Figure 10: Projected changes in rainfall

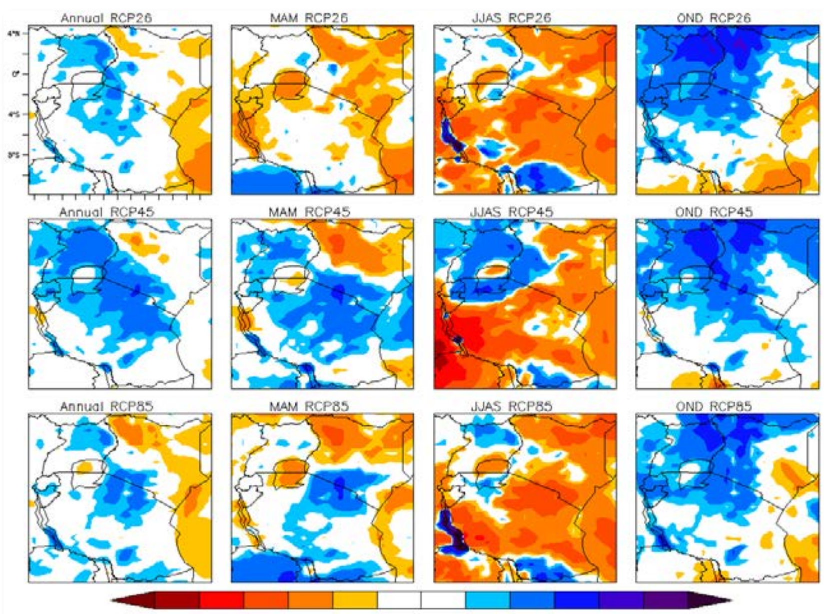


Figure 10a: Projected rainfall changes over the EAC by the 2030s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

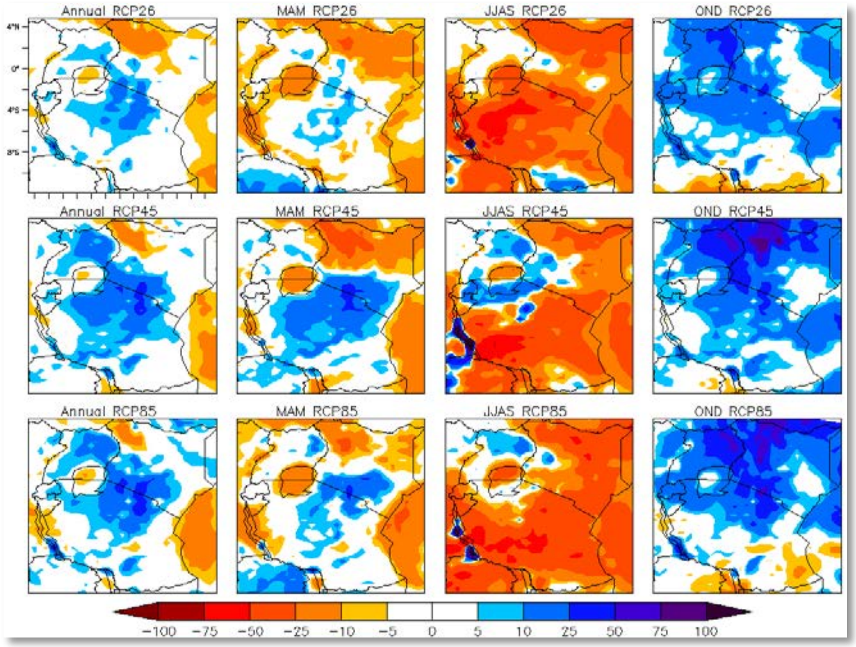


Figure 10b: Projected rainfall changes over the EAC by the 2050s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

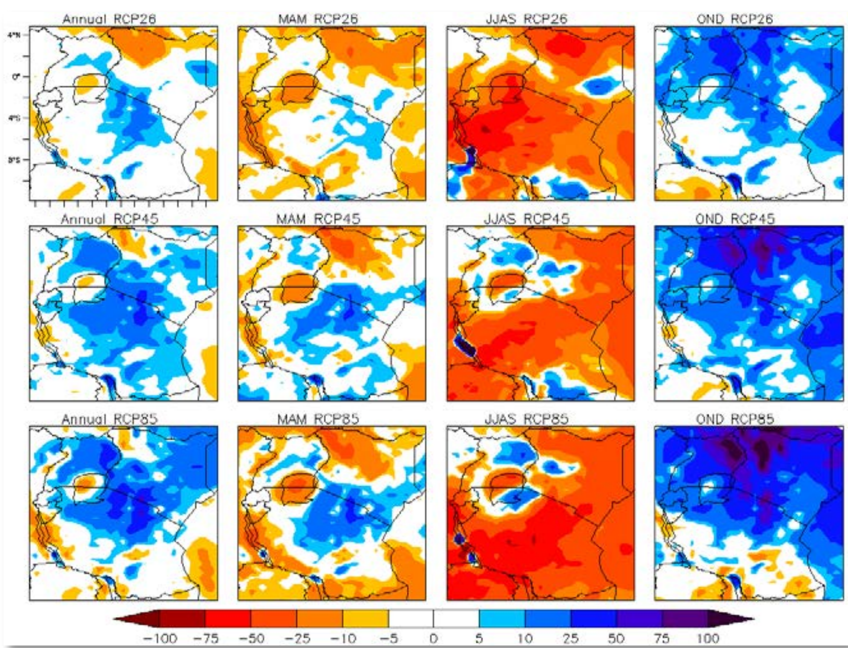


Figure 10c: Projected rainfall changes over the EAC by the 2070s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

Figure 11: Maximum projected temperatures

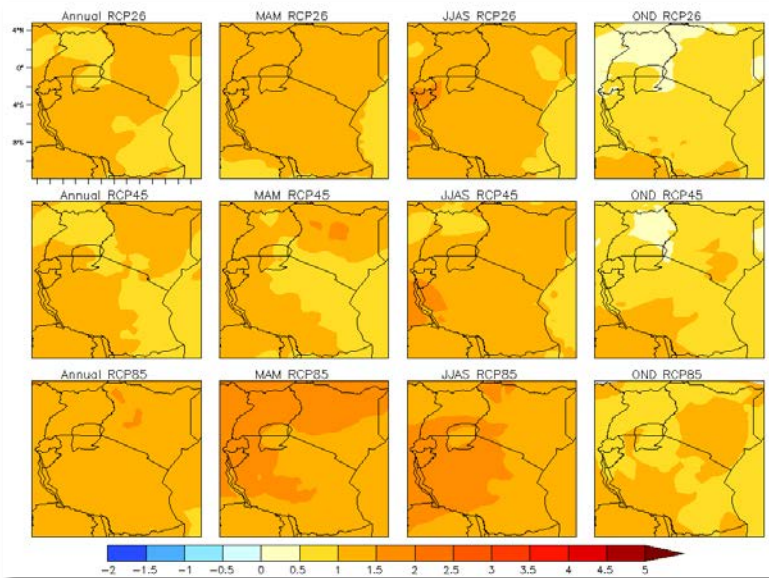


Figure 11a: Projected maximum temperature changes over the EAC by the 2030s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios: RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

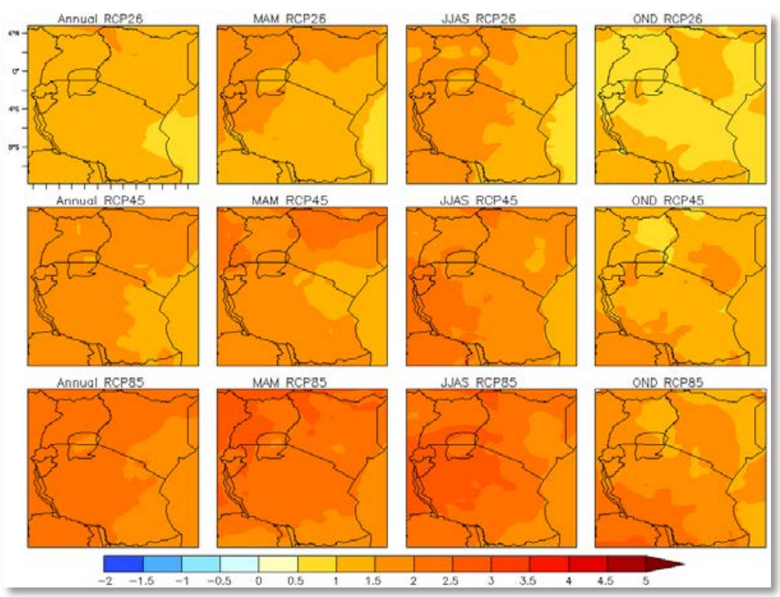


Fig 11b: Projected maximum temperature changes over the EAC by the 2050s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

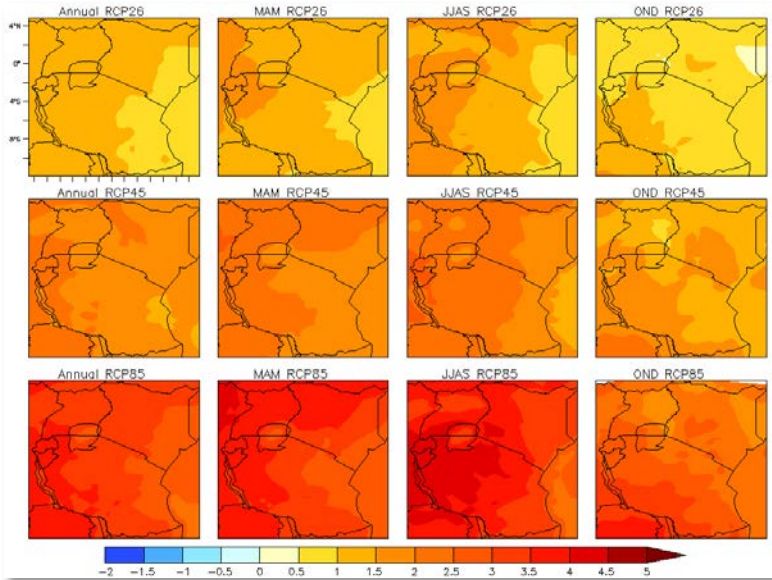


Figure 11c: Projected maximum temperature changes over the EAC by the 2070s in annual (1st column), MAM (2nd column), JJAS (3rd column), and OND (4th column). Each row corresponds to emission scenarios RCP2.6 (1st row), RCP4.5 (2nd row), and RCP8.5 (3rd row).

Figure 12: Rainfall projections 95th percentiles of rainfall in millimeters

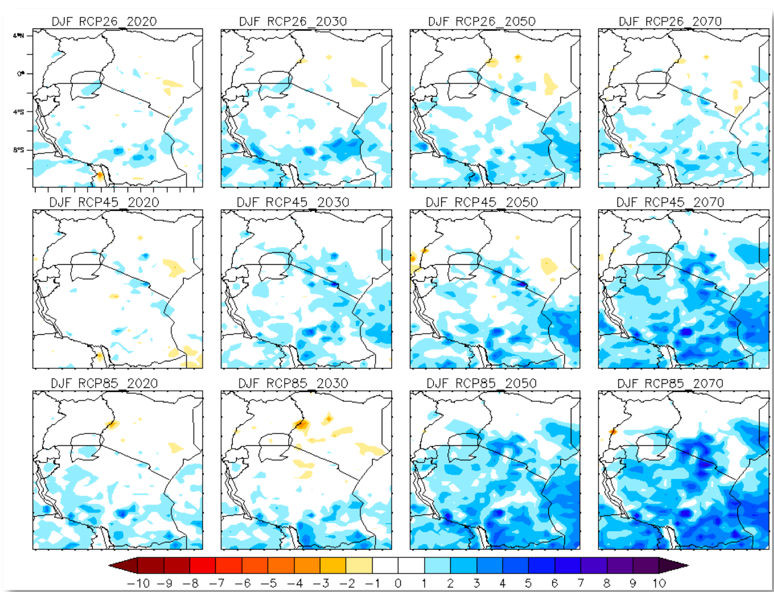


Figure 12a: Differences between the future and baseline (1971–2000) 95th percentile of rainfall in millimeters during the December–February (DJF) season over eastern Africa under the RCP2.6, RCP4.5, and RCP8.5 scenarios.

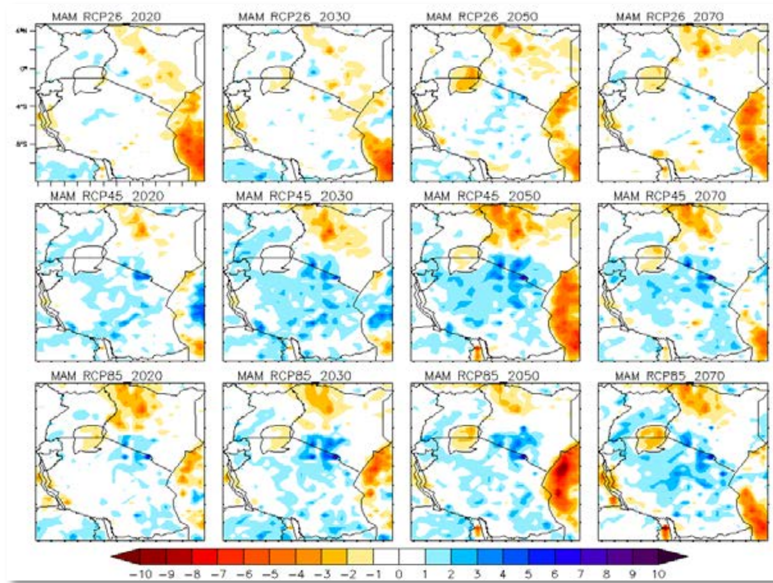


Figure 12b: Differences between the future and baseline (1971–2000) 95th percentile of rainfall in millimeters during the MAM season over eastern Africa under the RCP2.6, RCP4.5, and RCP8.5 scenarios.

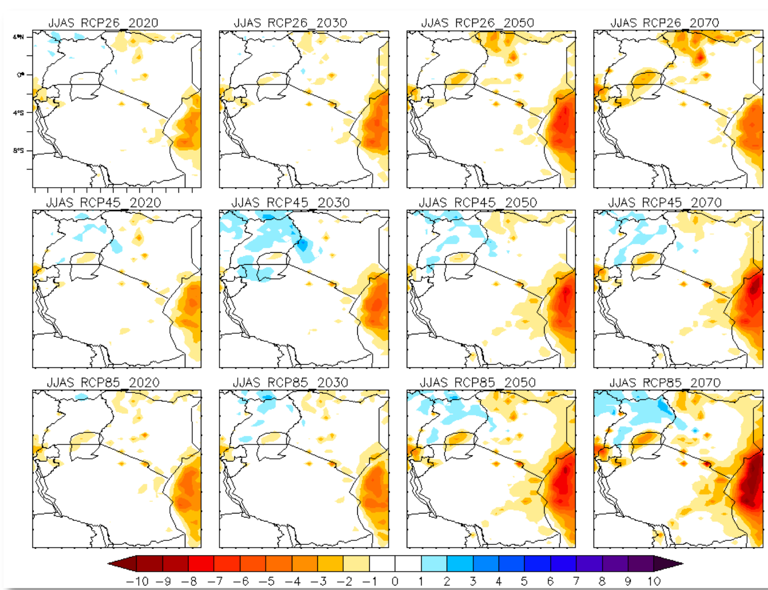


Figure 12c: Differences between the future and baseline (1971–2000) 95th percentile of rainfall in millimeters during the JJAS season over eastern Africa under the RCP2.6, RCP4.5 and RCP8.5 scenarios.

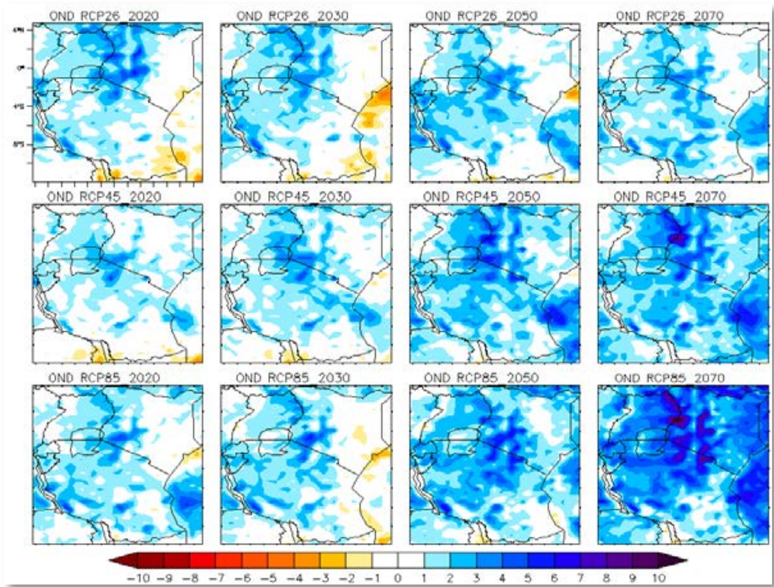


Figure 12d: Differences between the future and baseline (1971–2000) 95th percentile of rainfall in millimeters per day for the OND season over eastern Africa under the RCP2.6, RCP4.5, and RCP8.5 scenarios.

3.2 MODELING FUTURE SECTOR PROJECTIONS

3.2.1 Approach and Methodology—Statistical Analysis and Forecasting

Statistical methods for time series analysis and forecasting were used to analyze temporal variation in a variety of time series of historic observations. The time series (response variables, for example, power generation) were related to various time series of predictors (explanatory variables, such as rainfall, minimum and maximum temperatures). The relationships established for the historic response series were used to forecast the likely future trajectories of the response series.

A primary goal of univariate time series analysis is to model variation in the series and use the model to forecast future values of the series. The same applies to multivariate time series. However, analysis of the relationships among the component series may be of additional interest for multivariate series. Other goals for analyzing time series, often only of secondary interest, include smoothing trend patterns, interpolating (estimating missing values), and modelling the structure of the series. The analysis typically involves careful consideration and modelling of several characteristics of time series, including seasonality, cycles, trend, and autocorrelation.

The VARMAX (Vector Autoregressive Moving Average Processes) model was used to model the dynamic relationships between the response and the predictor variables and to forecast the response variables for most of the response variables. These extended models allow for the following (see Annex 1 for details):

- Modeling of several time series together.
- Accounting for relationships among the individual component series with current and past values of the other series.
- Feedback and cross-correlated explanatory series are allowed.
- Cointegration of time component series to achieve stationarity.
- Seasonality.

- Autoregressive errors.
- Moving average errors.
- Mixed autorergressive and moving average errors.
- Lagged values of the explanatory series and more.
- Unequal or heteroscedastic covariances for the residuals.

3.2.2 Case Studies: Energy Projection for 2030, 2050, and 2070 for Selected Sites

All three climate change scenarios predict that the LVB region is likely to see increases in both minimum and maximum temperature in future, but the annual rainfall component under the three scenarios in the time windows show little change compared to the projected changes in the seasonal rainfall components. The short rains (OND) are projected to increase over most of the region under all the three scenarios (10–25 percent by 2020 and 2030, and 25–50 percent by 2050 and 2070). By contrast, the long rains (MAM period) are projected to decrease over the northern part but to increase over the southeastern part of the region. The dry season rainfall (JJAS) is projected to decrease over most of the region (25–50 percent by 2020 and 2030, and 50–75 percent by 2050 and 2070). The projected annual rainfall shows a tendency to increase over the LVB. The combined effects of changing temperature and precipitation will generally decrease streamflow in some rivers across the region. In addition, streamflow will likely become more variable with lower flows during drought periods and higher flows during wet periods than experienced in the past.

Rwanda—Mukungwa 1 and Ntaruka Hydropower Plants

The average power yield at Mukungwa 1 hydropower plant averaged 57.7 Gwh during the period 1998–2016. In the same period, power generation at Ntaruka power plant averaged 27.6 Gwh. Though the precise percentages differed between the two power plants, the forecast patterns of variation in power production at Mukungwa 1 and Ntaruka are very similar. Relative to their corresponding baselines, the forecast power production for both will likely increase during 2015–2030 and 2051–2070 but decrease during 2031–2050 and 2071–2100 under the RCP 2.6 scenario. For Mukungwa 1 the forecast amount of increase is 9.7 percent for 2015–2030 but 8.9 percent for 2051–2070. In contrast, the forecast amount of decrease in power production is 8.9 percent for 2031–2050 and 6.5 percent for 2071–2100. The changes in power generation forecast for Ntaruka are 3.1 percent for 2015–2030, -12.4 percent for 2031–2050, 4.4 percent for 2051–2070, and -8.7 percent for 2071–2100. Under the RCP4.5 scenario, increases in power production are forecast during 2015–2030 and 2031–2050 followed by declines in power yields during 2051–2100 relative to the baseline in both power plants. Finally, under the RCP8.5 scenario, the average power generation is forecast to decrease during 2015–20151 but to increase during 2071–2100 for both power plants. The forecast average increases or declines for each power plant under the RCP4.5 and RCP8.5 scenarios is shown in Table 17 (see Appendix II) and Figures 13a–c.

Figure 13: Forecast average generation for Mukungwa and Ntaruka power plants

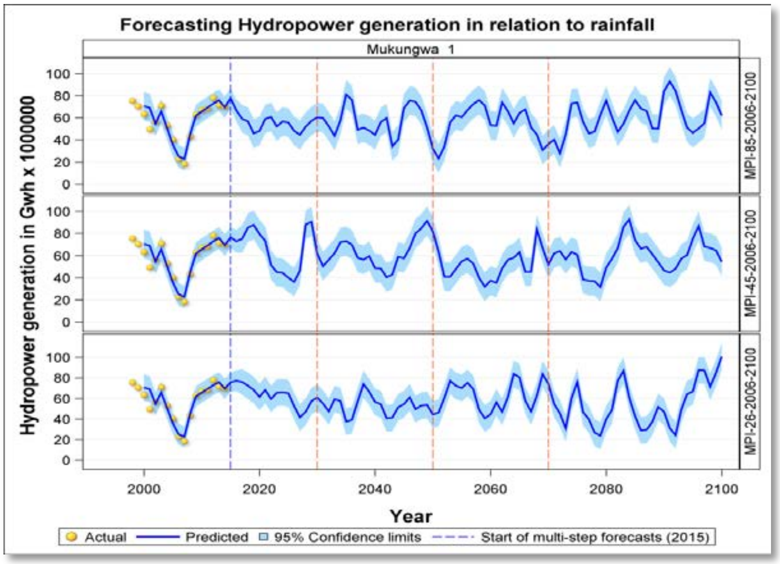


Figure 13a: Projected hydropower generation for Mukungwa 1 station in Rwanda for RCP2.6, RCP4.5, and RCP8.5.

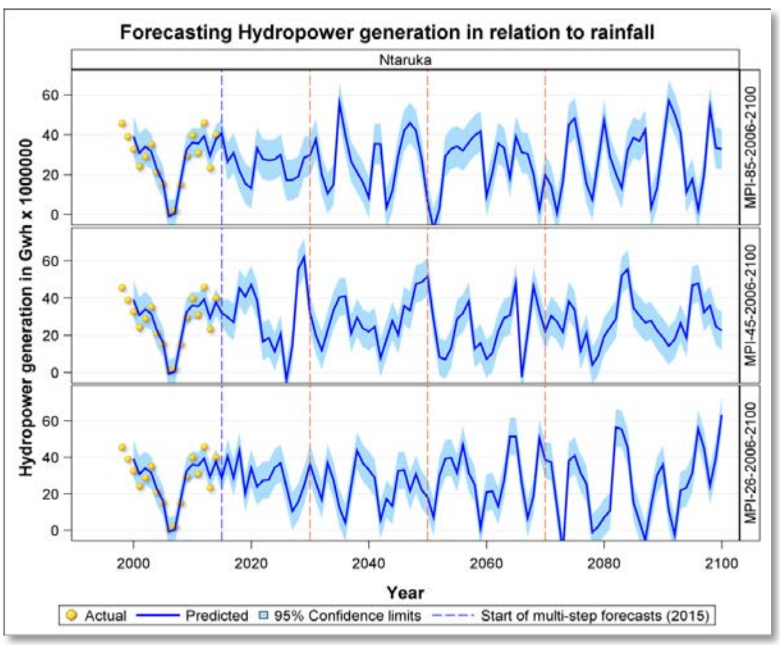


Figure 13b: Projected hydropower generation for Ntaruka station in Rwanda for RCP2.6, RCP4.5, and RCP8.5.

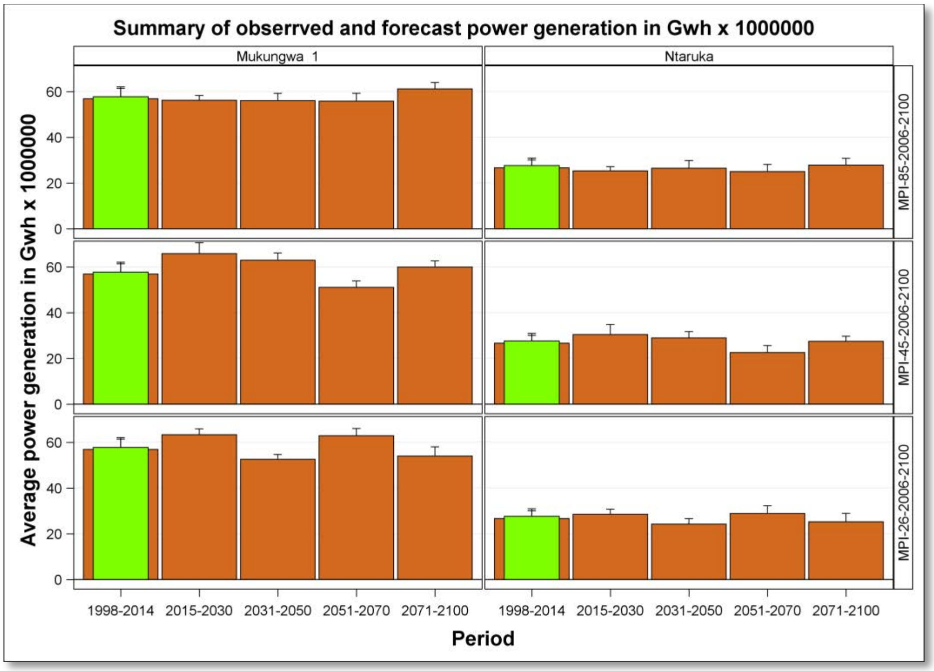


Figure 13c: Projected hydropower generation for Mukungwa and Ntaruka for the periods 2015–2030, 2031–2050, 2051–2070, and 2071–2100, Note: Green bar is observed power generation and brown bar predicted.

Tanzania—Kidatu and Mtera Hydropower Plants

The average power generated at the Kidatu plant during 1990–2014 was 931.9 Gwh. This average was used as the benchmark for assessing anticipated changes in power generation in Kidatu under each of the three climate change scenarios during 2015–2100. A common feature of the forecasts of power generation in Kidatu under all three scenarios is a pronounced cyclical fluctuation in the amount of power generated over time. The cycles imply that future power generation will likely be much higher or lower than average during certain periods, reflecting fluctuations in rainfall, which control river basin discharge. In general, the forecasts suggest a declining trend in the expected power output relative to the baseline. The forecast percentage decline in relative to the benchmark is estimated to be -8.5 percent during 2015–2030, -10.9 percent for 2031–2050, -5.5 percent for 2051–2070, and -21.6 percent for 2071–2100 under the RCP2.6 scenario. Under the RCP4.5 scenario, the forecast is 4.2 percent for 2015–2030, -9.8 percent for 2031–2050, -9.0 percent for 2051–2070, and -20.8 percent for 2071–2100. The estimates for the RCP8.5 scenarios (1.4 percent, -5.3 percent, -0.2 percent, and -18.7 percent) are comparable to those for the RCP2.6 scenario (Figure 14c and Table 18).

Power production at the Mtera plant also shows cyclical variation over time, a pattern similar to that forecast for Kidatu. However, only about one-third as much power was produced at Mtera during 1990–2014 compared to Kidatu, merely 349.4 Gwh. As with Kidatu, power output at Mtera is forecast to decline substantially over time. The extent of the forecast declines will vary depending on the realized climate change scenario. For the RCP2.6 scenario power yield is forecast to change by 7.1 percent for 2015–2030, -12.4 percent for 2031–2050, -10.3 percent for 2051–2070, and -1.3 percent percent for 2071–2100 relative to the baseline average. The corresponding percentage changes in power output at Mtera over the same periods are forecast to amount to 42.0 percent, 13.6 percent, -23.4 percent, and -15.8 percent for the RCP4.5 scenario and 12.5 percent, 2.8 percent, 1.7 percent, and -23.9 percent for the RCP8.5 scenario (Figures 14 a–c and Table 18).

Figure 14: Forecast for hydropower generation in relation to rainfall

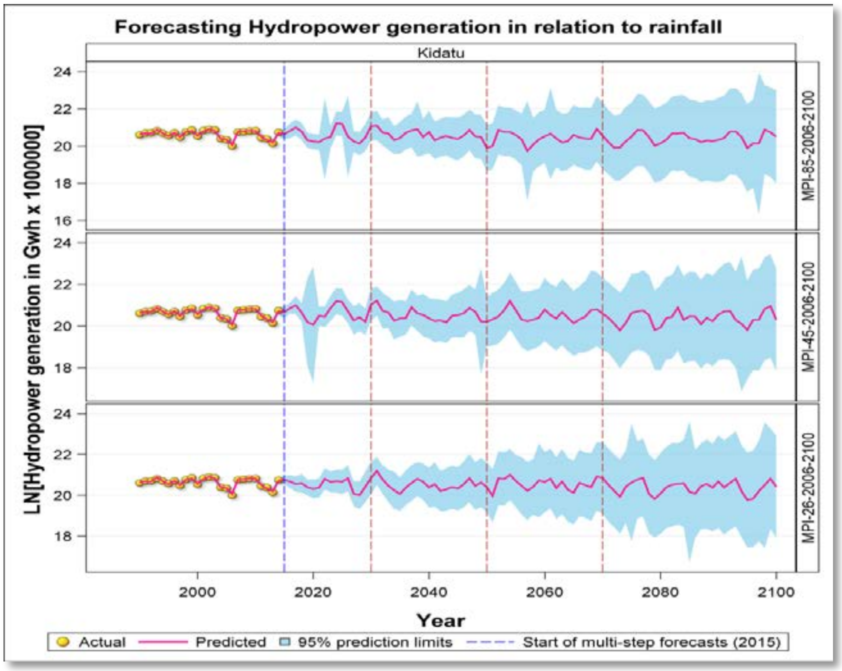


Figure 14a: Projected hydropower generation for Kidatu station in Tanzania for RCP2.6, RCP4.5, and RCP8.5

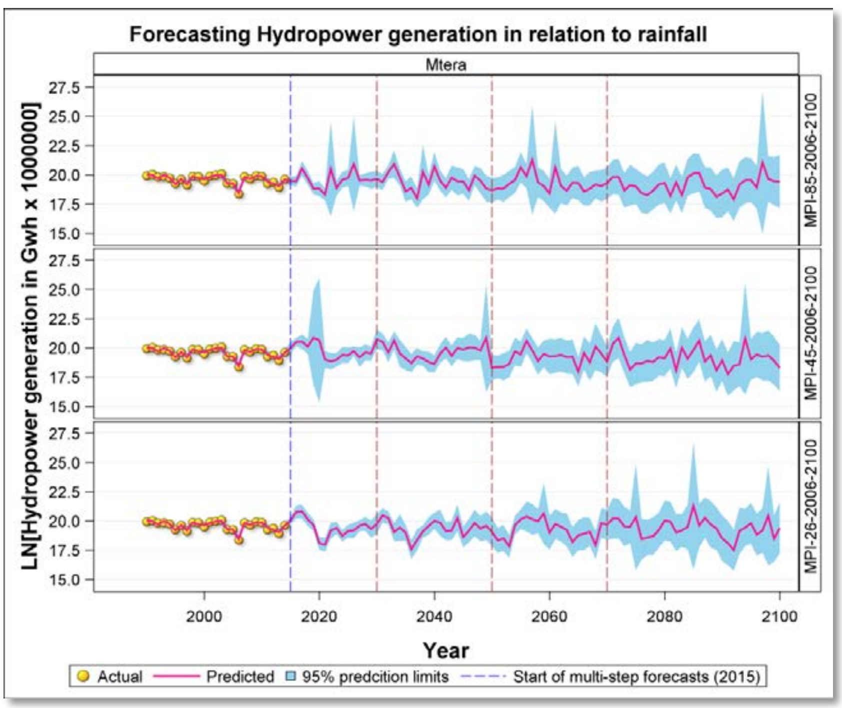


Figure 14b: Projected hydropower generation for Mtera station in Tanzania for RCP2.6, RCP4.5, and RCP8.5

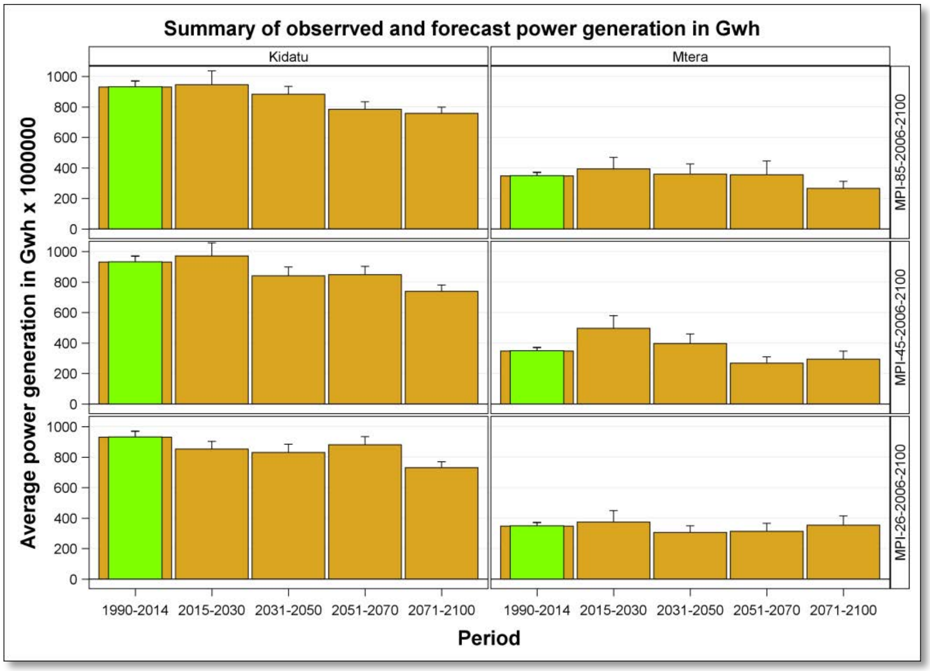


Figure 14c: Projected hydropower generation for Kidatu and Metra station in Tanzania for the periods 2015–2030, 2031–2050, 2051–2070, and 2071–2100, Note: Green bar is observed power generation and brown bar predicted.

Tana River in Kenya

Power generation at the Tana River plant is forecast to fall below the 1990–2009 average of about 15 Gwh during 2010–2030. Thereafter, power yield is forecast to increase over time, reaching an average of about 15 Gwh by 2070–2100 under the RCP2.6 and RCP8.5 scenarios, but somewhat less under the RCP4.5 scenario. The anticipated increase in power yield after 2010–2030 will likely be lowest for the RCP2.6 scenario, intermediate for the RCP4.5 scenario, and highest for the RCP8.5 scenario (Figure 15 and Table 19).

Figure 15: Projected hydropower generation for Tana station

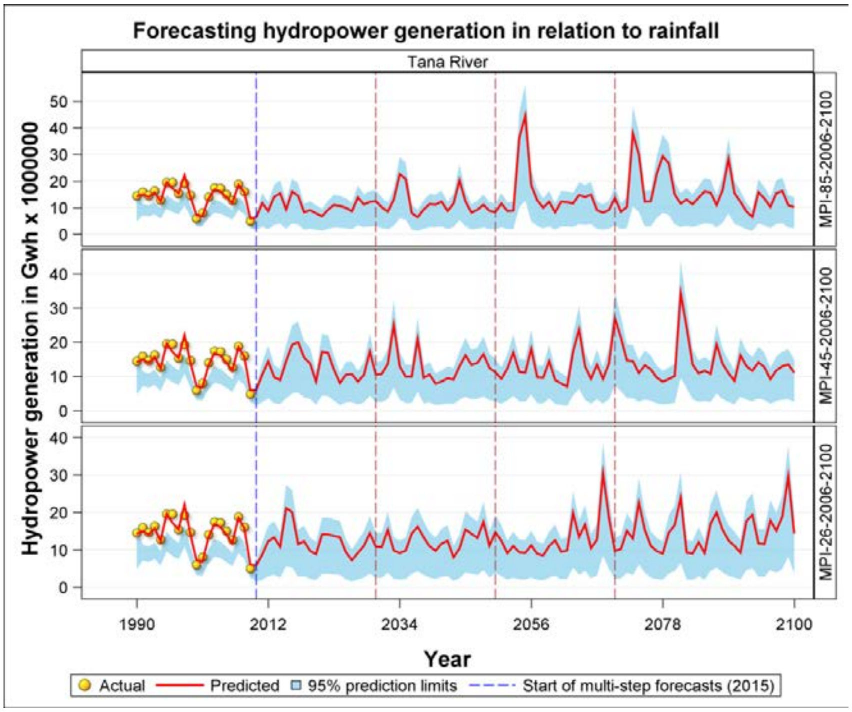


Figure 15a: Projected hydropower generation for Tana station in Kenya for RCP2.6, RCP4.5, and RCP8.5.

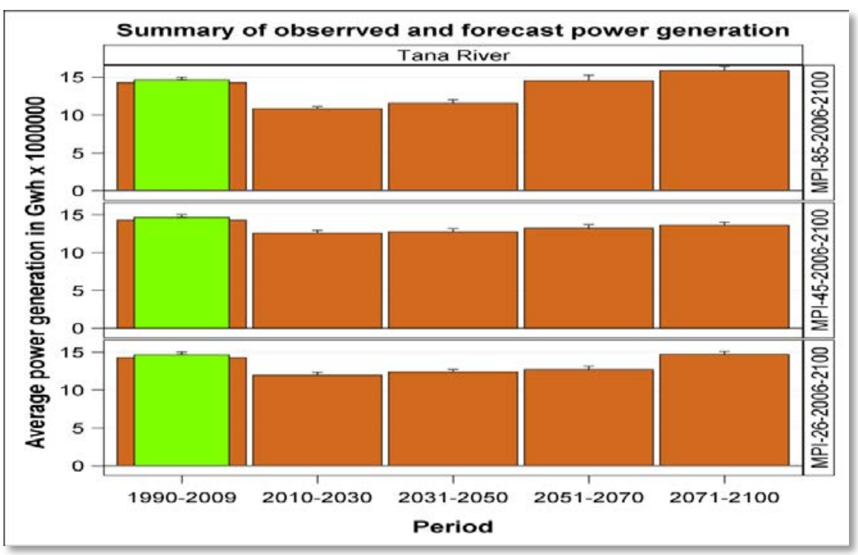


Figure 15b: Projected hydropower generation for Tana River, Kenya, for the periods 2015–2030, 2031–2050, 2051–2070 and 2071–2100. Note: Green bar is observed power generation and brown bar predicted.

4. SECTOR ADAPTATION PRACTICES, OPTIONS, AND CONSTRAINTS

4.1 Key Issues to Consider

Hydropower supplies about 20 percent of the world's electricity, but Sub-Saharan Africa (excluding coal-heavy South Africa) gets 60 percent of its electricity from this source—and many countries get more than 80 percent (Figure 16). Drought-caused blackouts are common and are expected to get worse with climate change. Hundreds more dams are being planned, many of them in regions that are already highly dependent on hydropower. This map shows hydro-dependency across the continent. It includes proposed dams in these places and presents information about droughts and reduced river flows that have already affected the energy sectors in these countries.

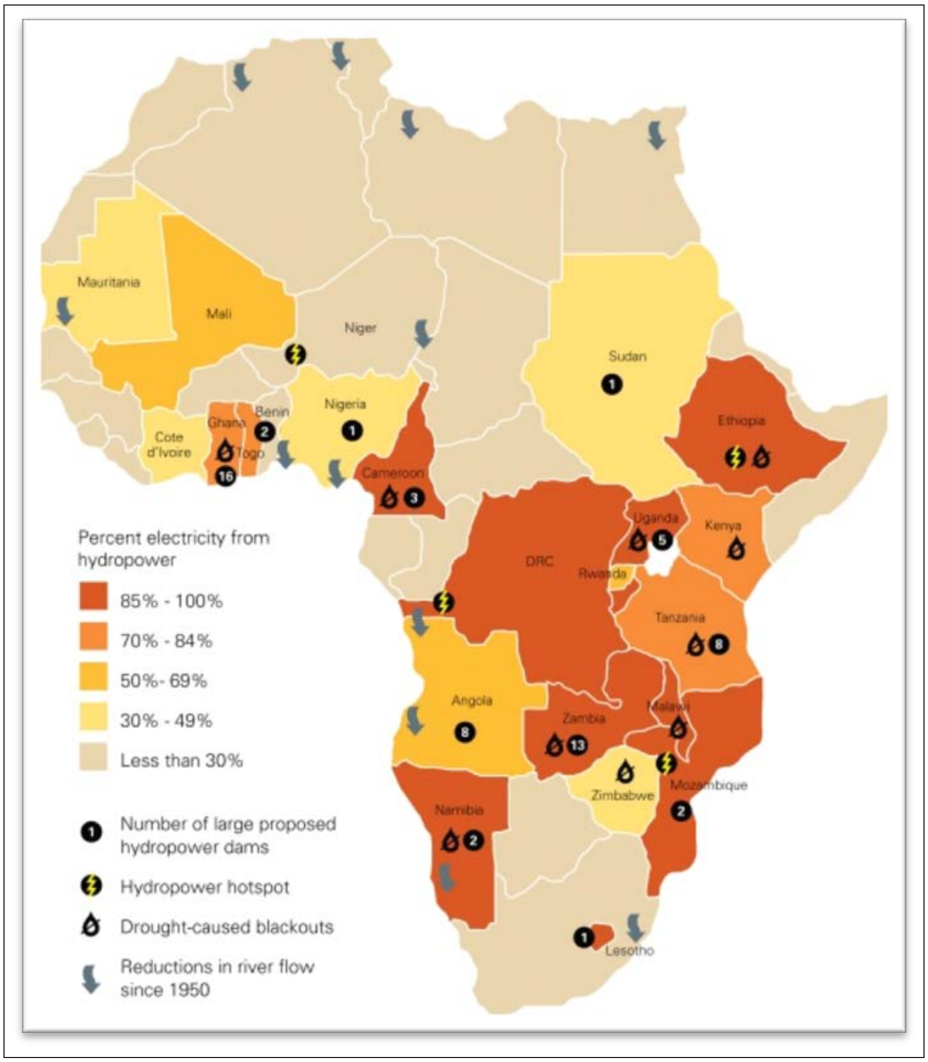


Figure 16: Hydro-dependency in Africa (source: https://www.internationalrivers.org/resources/ hydrodependency-in-africa-risky-business-3447)

Future climate change could lead to additional and potentially large economic costs in the EAC. Aggregate data indicate that net economic costs could be equivalent to a further 1 to 2 percent of GDP per year by 2030 in Tanzania (DFID 2011), 1 percent of GDP each year by 2030 in Rwanda (SEI 2009), and 3 percent of GDP each year by 2030 in Kenya. Figure 17 shows projected economic costs (2030 and 2050) of climate change losses as a share of GDP in Africa and the EAC.

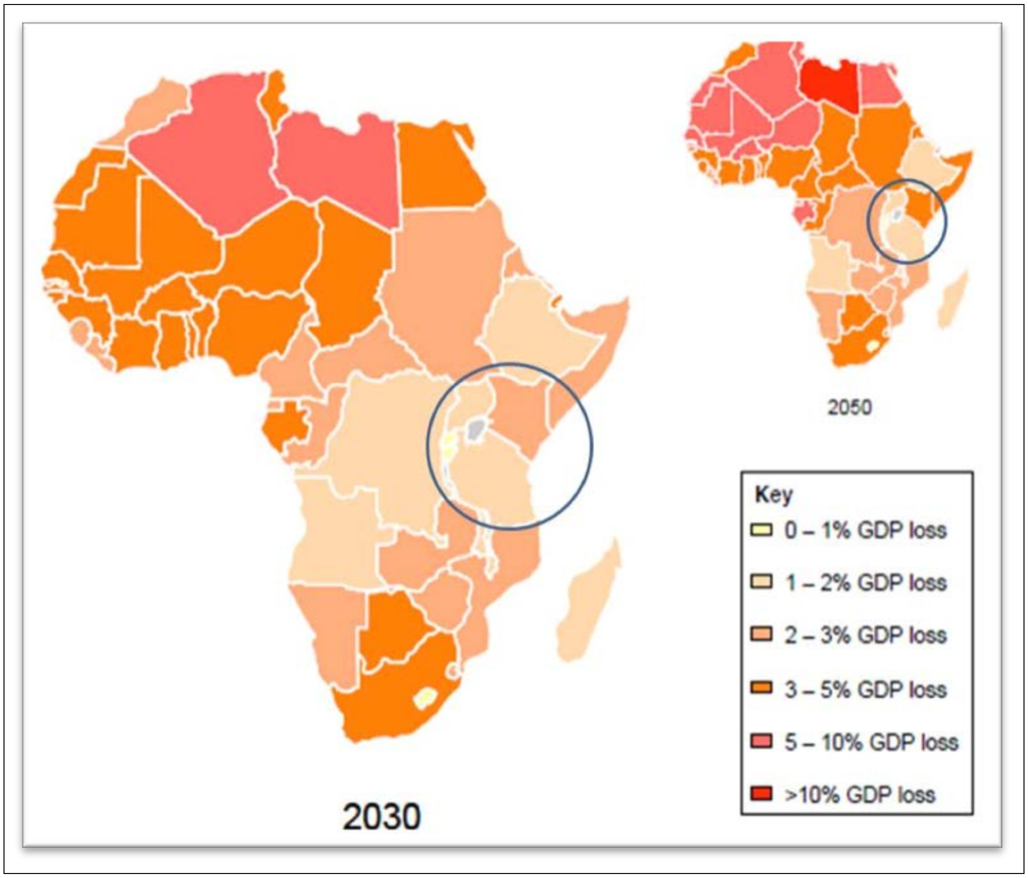


Figure 17: Projected annual economic costs from climate change in Africa and the EAC (source: SEI 2009 and FUND national model)

The contribution of electricity to GDP in 2013 was 1.8 percent in Tanzania, 0.9 percent in Uganda, 1.1 percent in Kenya, and 0.6 percent in Rwanda. Therefore, future climate variability and change may cause serious shortage of electricity and affect the entire economy of the region. Power rationing for both domestic and industrial use makes an economy more vulnerable to climate change–related disasters and leads to inefficiency in service provision to the public.

According to DFID, hydropower potential could decrease due to a reduction in rainfall in Uganda. The decline is estimated to be around 26 percent by 2050. The estimated additional capital investment in hydro, nuclear, and other electricity generation from 2015 to 2050 is around US$83 billion. Uganda is expected to invest around US$1 billion, or around US$200 million per year, equal to about 1 percent of GDP, in the first five years (DFID 2015).

Climate variability and change may have impacts on investment costs. Due to dependence on hydropower, drought years resulted in serious power supply shortages in the EAC Partner States. Some of those states may be forced to invest more on thermal generation (coal and gas) for future capacity increases. DFID projections for Tanzania show that thermal generation will lead to costs of $10 million (current prices) by 2030, which could rise further in future years to 2050 (DFID 2011).

Future socioeconomic development, coupled with population growth, will increase electricity demand. For example, increasing temperatures (1–3.5°C) and incomes will increase cooling demand, which will lead to increased electricity use and economic costs as follows:

- In Tanzania, DFID (2011) projections show that by the 2030s, climate change could have additional cooling costs of $60 million per year (current prices, no discounting). The continued temperature increases and per capita income growth would lead to much higher costs by the 2050s.
- In Kenya, cooling demand may increase by 300 percent in Mombasa by the 2050s (SEI 2009).
- Based on the national statistics for the five countries, the population of East Africa, currently about 148 million, will increase to 237 million by 2030 and to 278 million by 2050. Rwanda is the most densely populated country in the region—about 415 inhabitants per square kilometer, followed by Burundi (333 per square kilometer), Uganda (173 per square kilometer), Kenya (73 per square kilometer), and Tanzania 39 (per square kilometer) (United Nations 2009, Linard et al. 2012). Figure 18 shows the population projections for the five East Africa by 2100.

The population is predominantly rural—12 percent in Uganda, 20 percent in Kenya, and 23 percent in Tanzania. Hence, population increase will result in major demand for new, cheaper, and more environmentally friendly sources of energy.

4.2 Options Analysis

A broader mix and balance in generation options can improve energy security and supply stability. Among the possible options, as identified by the Asian Development Bank (ADB) are "decentralized renewable energy, decentralized planning and generation, integration of adaptation and mitigation planning, forecasting demand changes with warming and improving supply-side management, integrating power planning with that of other sectors, and rezoning land use so future energy infrastructure is in less vulnerable areas" (ADB 2012).

Table 3 summarizes the planned energy forecast and needs for 2030 and 2050 in East Africa (EAC 2016) and Figure 19 shows the existing and future transmission of electricity in East Africa.

Each of the five East African countries has short-term and long-term plans for energy (Table 4). However, most of those plans do not consider climate change. Hence, this report aims to raise awareness about the exposure and vulnerability of the energy sector in the EAC. It also identifies adaptation options available to each source of energy generation based on the Asian Development Bank study of the energy sector in Asia (ADB 2012; Table 5, Key climate change impacts and adaptation – hydropower; Table 6, Key climate change impacts and adaptation – Solar Photovoltaic Power; and Table 7, Impacts of Climate Change on Electricity Transmission and Distribution Networks). The report does not propose techniques and methodologies to assess and respond to exposure and vulnerability in specific settings. However, it is hoped that an increased awareness will be conducive to the development of such techniques and methodologies (see the section on further assessment and research needs for the region).

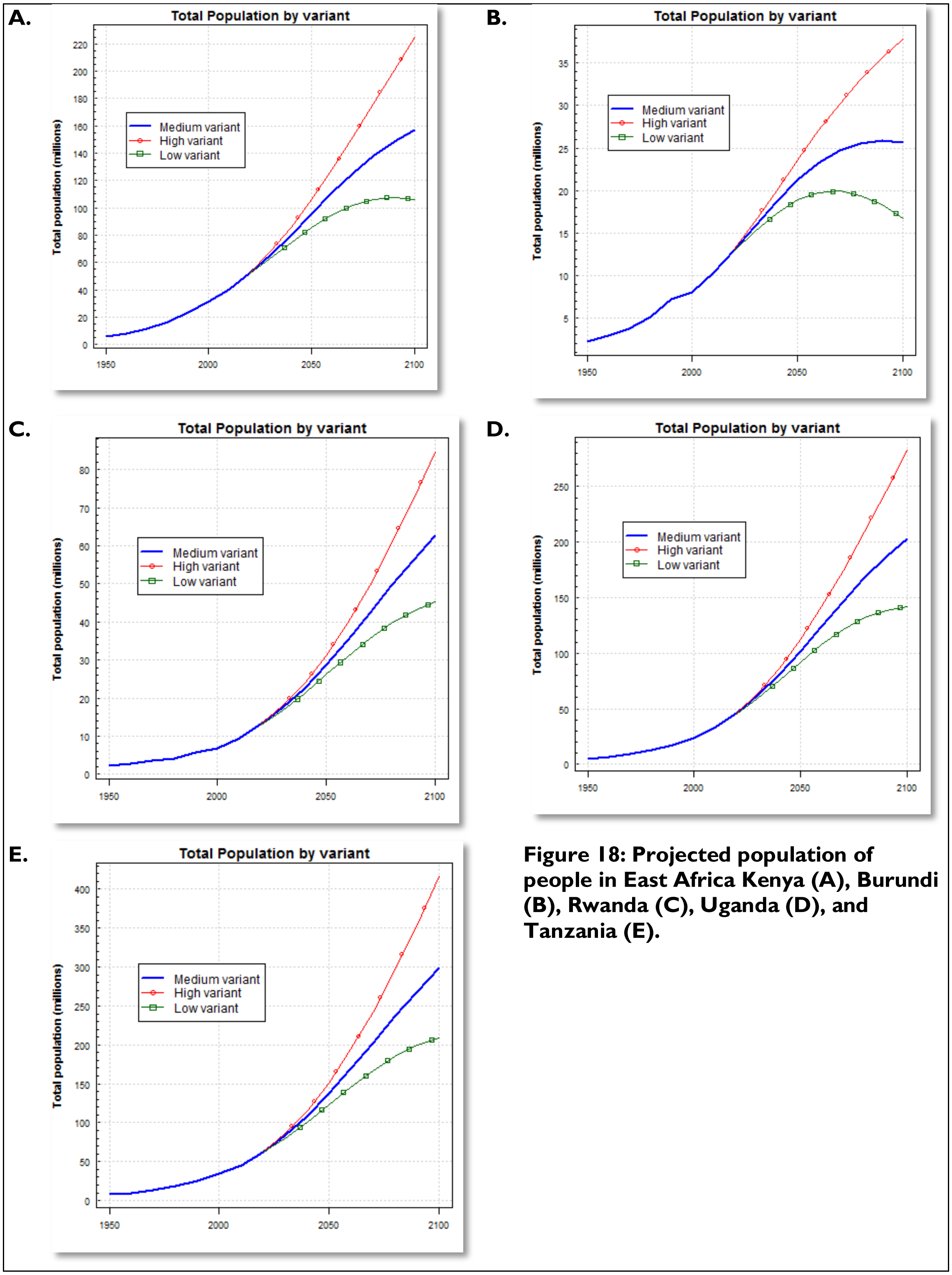


Figure 18: Projected population of people in East Africa Kenya (A), Burundi (B), Rwanda (C), Uganda (D), and Tanzania (E).

Table 3: EAC Vision 2050 socioeconomic and energy targets

Indicators		2014	2030	2050
Socioeconomic indicators				
	GDP per capita (US$)	1,014	3,000	10,000
	Average regional economic growth (%)	5.8	10	9.9
	People living below $1.25/day (%)	40	10	5
	Income distribution (Gini co-efficient)	0.35	0.3	0.2
	Unemployment rate (%)	14	10	5
	Gross capital formation (as % of total export)	24.3	32.2	40.5
	Raising local value addition (%)	8.2	40	60
Energy	**Energy production (megawatts)**	**3,965**	**70,570**	**122,569**
	Hydro	2,083	3,900	5,001
	Thermal	1,189	1,450	1,960
	Natural gas	431	2,600	5,640
	Geothermal	189	800	1,500
	Biomass and other (including wood fuel, wind, solar, etc.)	74	500	1,500
	Nuclear	0	1	2
	Electricity transmission grid			
	Electrification rate (%)	19.1	58	74
	Urban population with access to electricity (%)	28	63	94
	Rural population with access to electricity (%)	9.5	37	62
Regional refineries		1	5	12

Source: EAC 2016.

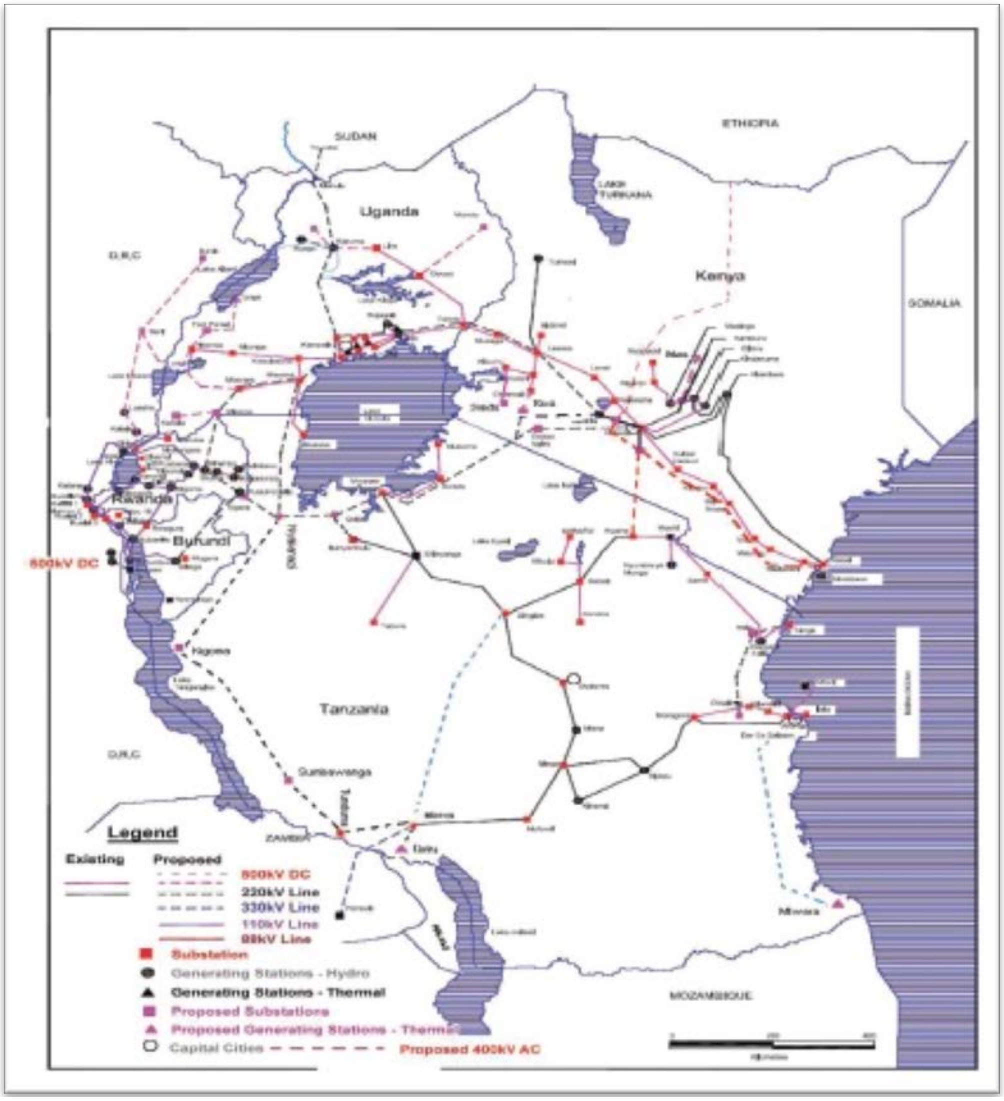


Figure 19: Existing and future transmission lines in the EAC (source: EAC 2016)

Table 1: Plans for power generation in the five East African countries

Country	Energy option	Plans and future generation of power
Burundi	Hydropower	Burundi's hydropower potential was evaluated in 1983 to be 1,700 MW of which approximately 300 MW was economically exploitable. The potential could be even greater today as the recent evaluation of certain sites has demonstrated a capacity higher than the 1983 calculations. According to a recent bibliography, 156 potential hydropower sites and 29 existing sites are about to be equipped. Currently, fewer than 30 sites have been explored.
	Solar	Burundi has very interesting solar potential. Average annual sunshine in Burundi is close to 2,000 kWh/m^2.year. The Ministry of Energy and Mines finds it desirable to carry out a more precise capacity study, taking topography and seasonal characteristics into account to address energy access through rural electrification by solar home systems, solar pumps, stand-alone photovoltaic generators, hybrid photovoltaic plants for remote areas, and grid-connected photovoltaic plants.
	Wind	According to the Solar and Wind Energy Resources Assessment Project the wind power potential of Burundi is less than 4.8 m/s. Consequently, more investigations are necessary to develop industrial wind turbines.
	Geothermal	Burundi is in the Great African Rift Valley, a geological area with significant geothermal potential. While there are approximately 15 hot springs in Burundi, the temperatures measured are at a maximum of approximately 70°C and there do not appear to be any sources with established fumaroles with higher temperatures. More investigations are necessary to conclude whether the geothermal potential should be exploited.
Kenya	Large hydropower	According to the Energy Policy 2014, Kenya has an estimated hydropower potential of about 6,000 MWe comprised of large hydro sites with capacity of more than 10 MW and small hydro. Of the large hydro, 807 MW has been exploited and accounts for about 50 percent of installed generation capacity as of 2013 while about 1,450 MW remains unexploited. A major challenge to hydropower generation has been variations in hydrology. Poor rains result in power and energy shortfalls, reducing the capacity of hydropower. Yet, during the rainy season, water is lost due to inadequate storage capacity in the existing reservoirs.
	Small hydro	Potential for small hydro is over 3,000 MW, of which only 35.1 MW have been installed from 16 power plants.
	Geothermal	According to the Least Cost Power Development Plan (LCPDP) 2011–2031, Kenya has a potential of about 10,000 MWe from its geothermal resources. Most future electricity is planned to be generated from geothermal. To actualize this plan, the government set up in 2006 a Geothermal Development Company to lead development of geothermal resources. From geothermal sources, Kenya expects to produce 700 MW by 2015, 1,400 MW by 2020, 2,340 MW by 2025, and 5,000 MW by 2030.

Country	Energy option	Plans and future generation of power
Kenya	Solar	Kenya receives daily insolation of 4-6 kWh/m^2. Solar energy use is mainly for photovoltaic (PV) systems, drying, and water heating. Solar PV systems are used mainly for telecommunication, lighting, and water pumping. The Energy Regulatory Commission has prepared a framework with the Energy (Solar Water Heating) Regulations 2012 and Energy (Solar Photovoltaic) Regulations 2012. A vibrant solar energy market has developed over the years. A 2005 survey found an annual market demand for PV panels of 500 kilowatt peak (kWp). It was also projected to grow at 15 percent per year. A 2005 program to provide basic electricity to boarding schools and health facilities in remote areas increased the annual demand for PV panels by 400 kWp. About 450 of about 3,000 eligible institutions have been equipped with systems and 400 more are expected to have the units installed. Together they will have a combined estimated capacity of 80 kWp.
	Wind	The draft National Energy Policy (2014) estimate that Kenya has a huge potential for wind electricity generation totaling more than 4,000 MWe. The potential is estimated as 346 watts per square meter and speeds of over 6m/s in parts of Marsabit, Kajiado, Laikipia, Meru, Nyandarua, Kilifi, Lamu, Isiolo Turkana, Samburu, Uasin Gishu Narok, and Kiambu Counties. The installed wind energy capacity to the grid was 5.45 MW as of November 2014. Numerous projects are at different stages of development and include the 300 MW Lake Turkana Wind Farm Project (the largest in Africa), 100 MW Kajiado-Kipeto Wind Farm, 50 MW Isiolo Wind Project, and 150 MW Marsabit Wind Project.
	Biomass – co-generation	In recent years, there has been increasing use of biomass for power generation in Kenya. A Feed-in-Tariffs (FiT) Policy was formulated in 2008, revised in 2010 and again in 2012, to promote the generation of electricity using renewable energy resources including wind, small hydro, and biomass for plants with capacities not exceeding 50 MW, 10 MW, and 40 MW, respectively. The FiT Policy elicited four expressions of interest from potential investors to develop biomass power plants with a combined installed capacity of 164 MW. The LCPDP 2011–2031, which is part of the country's Vision 2030 Medium-Term Plan, estimates that there is already 26 MW installed capacity of biomass co-generation from Mumias Sugar Factory, with a further 18 MW co-generation project using cane bagasse approved.
	Coal	Although Kenyan coal has not so far been exploited to feed the electricity grid, it is targeted as a potentially easily accessible source of energy. Explorations in Mui Basin in Kitui County have yielded positive results, with indications that >400 million tons are potentially exploitable. Kenya targets 1,900 MW of electricity from coal by 2016 and 4,500 MW by 2030 (GoK 2014). A coal-fired thermal electricity generation plant is planned in Lamu County, to be initially run with coal from South Africa and later from Mui Basin.
	Natural gas	In June 2016 Kenya dropped plans to construct a 700 megawatt (MW) natural gas power plant near Mombasa, fearing excess supply would lead to expensive electricity bills for homes and businesses. The gas-powered power plant was part of the government's plans to add 5,000 MWe to Kenya's existing generation capacity in the push to diversify sources of electricity. The Ministry of Energy and Power concluded that the plant could leave Kenya with excess power, forcing consumers to pay for capacity charges on idle plants and reversing the quest to deliver cheaper electricity.
	Power imports	It is estimated that Kenya will import 400 MW of electricity from Ethiopia.

Country	Energy option	Plans and future generation of power
	Nuclear	According to the Kenya Power Sector Medium-Term Plan 2015–2020, Kenya Nuclear Electricity Board has completed the pre-feasibility study for a nuclear power program and is expected to progress other preparatory activities toward full establishment of the program. The first nuclear plant is projected to be constructed within the Vision 2030 period to provide approximately 1,000 MW. In June 2016, Kenya signed Nuclear Power Cooperation Agreements with China and Russia under the oversight of the International Atomic Energy Agency. The legal and policy framework is also under development.
Rwanda	Hydropower	A recent study assessed the potential for a second phase of hydropower development carried out by the Ministry of Infrastructure with support from the Belgian Cooperation. The study identified 409 sites combining internal and shared resources totaling 612,331 KW that can exploited to mitigate the impact of climate change on energy installations.
	Solar	Rwanda has estimated capacity of 4.5–5 Kwh/m2/day and a total of 9.75 MW of installed capacity is connected to the grid. Moreover, other solar energy projects are being implemented to address increasing energy demand, particularly in remote areas. These include Ngoma Solar Power Station (2.4 MW) and the Kayonza Solar Power Station (10 MW to be completed by 2020).
	Wind	A wind resources assessment carried out by Rwanda Energy Group Ltd (2010) concluded that, due to its position close to the equator, distance from the sea, and moderate altitude, the country's wind resource is limited. However, recent studies have found there might be opportunity to generating wind energy in the Eastern Province. The report recommends that MININFRA should continue prospecting and evaluating wind resources.
	Geothermal	Geothermal investigations in Rwanda started in the 1980s, but the existence of geothermal resources still needs to be confirmed through drilling. Several reports indicate two areas as prospective zones for geothermal energy. The first of these zones (Gisenyi, Karisimbi, and Kinigi) is in the northwest and is associated with volcanoes. The second (Bugarama) is in the southern region and is associated with faults in the East African Rift. The development of Karisimbi is the most advanced, followed by Kinigi and Gisenyi. Bugarama is still at a reconnaissance stage to be followed by a geo-scientific survey to estimate the potential. So far, no tangible results despite efforts and investment of about US$20 millon dedicated to the project with support from countries where the exploitation of the geothermal resources is advanced (Germany, Kenya, and New Zealand firms).
	Methane	Lake Kivu, shared by Rwanda and the Democratic Republic of Congo, has a huge store of methane gas—60 billion cm with an estimated generation capacity of 700 MW. The first large-scale methane power plant in Africa (25 MW) was launched in 2016 and by 2020 is expected to generate about 100 MW of power. Extraction of the methane will contribute to its stability and prevent possible explosions, which would occur if the gas is not extracted.
Tanzania	Large hydropower	Tanzania has a potential to generate 4.7 GW, only 12 percent of this resource has been used. Four large hydro projects are under development: Rusumo (30 MW by 2018), Lower Kihansi (120 MW by 2020), Malagarasi (45 MW by 2020), and Kakono (87 MW by 2020).
	Solar	The average insolation is about 200 Wp/m^2 and about 6 MWp of off-grid solar PV systems are installed countrywide. The Ministry of Energy and Minerals envisages 120 MW of solar in the power generation mix plan by 2020.
	Wind	Several sites with wind speed ranging from 5 to 9 m/s have been observed. The expansion plan by Ministry of Energy expects that 50 MW will be added by 2017, 75 MW by 2018, 100 MW by 2019, and 125 MW by 2020.

Country	Energy option	Plans and future generation of power
Tanzania	Geothermal	Tanzania has identified more than 50 sites within the East African Rift System with potential for geothermal energy. The potential is estimated to be over 5,000 MW. Tanzania Geothermal Development Company Limited completed studies in three sites in the Lake Ngozi area (Mbeya). Borehole drilling is to be undertaken in 2016–17. Surface and feasibility studies will be conducted in other sites, including Kisaki (Morogoro), Luhoi (Pwani), Mbaka (Mbeya), Mount Meru, and Lake Natron (Manyara). Geothermal projects are expected to add 100 MW to the grid in 2020, 500 MW in 2022, and 800 MW in 2025.
	Biomass	Tanzania has considerable sources of biomass, including agricultural and forest bio-residues, which combined with woodlands, meet the majority of household energy and electricity needs. Excess bagasse from four sugar factories had estimated energy generation potential of about 99.42 GWh per year. Sisal wastes have potential to generate about 46 MW.
	Natural gas	Based on recent discoveries, the natural gas reserve is 57.25 TCF (May 2016). Several gas power generation projects (Kinyerezi I-IV, Mtwara, and Kilwa I-II) are being developed and will add about 3,466 MW to the grid by 2020.
	Small hydro	Tanzania has more than 300 small hydro sites with potential of generating 400 MW. Twelve existing plants have an installed capacity of 16.2 MW. Four small hydropower projects (representing a total of 6.6 MW installed capacity) were commissioned in 2015/16. Other projects with a combined capacity of 58.6 MW are in the final stage of development. The EAC expects that up to 140 new small hydropower plants with a total capacity of 190 MW could become operational by 2020.
	Coal	Coal reserves are estimated to be 1.9 billion tons, of which 25 percent is proven. Potential generation from the five sites is 1,700 MW. It is expected that about 100 MW will be added to the grid by 2019.
	Uranium	Tanzania has confirmed uranium deposits of about 200 million pounds. Availability of uranium in Ruvuma and Dodoma regions provides an opportunity for nuclear power generation to meet increasing demand. Development of nuclear power plants is still at infant stage and might be limited by high investment costs; concerns over the proliferation of nuclear weapons; high operation and maintenance costs; absence of requisite indigenous capacity; waste management; and decommissioning of nuclear plants.
	Imports	Tanzania imports power from Uganda (10 MW), Zambia (5 MW), and Kenya (1 MW). Power imports from Ethiopia are expected to be 200 MW by 2019 and 200 MW by 2020.
Uganda	Hydropower	The hydroelectric potential of Uganda is estimated at over 2,000 MW. This is mainly along the Nile. The government is currently fast-tracking construction of the Karuma and Isimba Hydropower Projects (600 MW and 183 MW respectively). A Memorandum of Understanding was signed between the Government of Uganda and China Gezhouba Group Company Limited to complete the feasibility study of the 600 MW Ayago Hydro power plant. More than 60 mini-hydropower sites with a total potential of over 200 MW have been identified. Some of the sites can be developed for isolated grids, others as energy supply to the grid, and the remining 42 sites were assessed to be less relevant to the energy supply for environmental and power market reasons.
	Solar	The mean solar radiation is 5.1 kWh/m^2 per day, on a horizontal surface. This level of insolation is favorable for some solar energy applications. An estimated 200 MW of potential electrical capacity are available in Uganda. Solar is used primarily for rural electrification, providing off-grid services, as well as for cooking, heating water, and powering public buildings. The total new installed photovoltaic capacity annually is estimated at 200 kWp for households, institutions, and commercial use.

Country	Energy option	Plans and future generation of power
	Wind	Wind speed is moderate in most areas of Uganda. The average wind speeds in low heights (less than 10 meters) generally range from 2 m/s to about 4 m/s. Recent studies also confirm that electricity generation through wind is feasible, especially for small industries or in rural areas where targets range from 2.5 kV to 10 kV.
	Geothermal	Geothermal resources were estimated at about 450 MW in the Ugandan Rift System and three areas—Katwe-Kikorongo (Katwe), Buranga, and Kibiro—identified as promising for geothermal exploration. To use the geothermal resources, the government and the German Federal Institute of Geosciences and Natural Resources have initiated a project on the rift system. According to the background to the budget 2016–2017, geothermal surface exploration is coming to an end at Kibiro and Buranga. The government is currently carrying out surveys to obtain a passive seismic model of the area.
	Biomass – co-generation	The total biomass-based co-generation capacity potential for Uganda is estimated to be 190 MW. To date only three co-generation facilities are producing biomass energy: Kakira Sugar Works Ltd, Kinyara Sugar Works Ltd, and Sugar Corporation of Uganda Ltd. Together they have total installed capacity of 30 MW mainly used for their own consumption with about 5 MW supplied to the grid.
	Peat	About 25 million tons of peat is potentially available for power generation and would provide 800 MW of capacity for 50 years.

Table 5: Climate change impacts and adaptation—hydropower

Climate variable	Physical components	Key impacts	Adaptation options
Precipitation • ***Temperature*** • ***Extreme events***	▪ Dam and other structures (intake, penstock) ▪ Power station (turbines and generators)	▪ Indicated below for specific climate changes	▪ Develop improved hydrological forecasting techniques and adaptive management operating rules ▪ Develop basin-wide management strategies that take into account the full range of downstream environmental and human water uses ▪ Restore and better manage upstream land, including afforestation to reduce floods, erosion, silting, and mudslides ▪ Analysis to estimate likely range of projected climate variations over hydro lifetime ▪ Identify cost-effective designs (new plants) and modifications (existing plants) to deal with specific risks identified for the site
Precipitation (including drought)	▪ Dam and other structures ▪ Power station	▪ Changing annual or seasonal patterns can affect river flows and water levels behind dams, either reducing or increasing power output ▪ Siltation can reduce reservoir storage capacity ▪ Increased uncertainty in water flows can affect power output and generation costs	▪ Increase dam height and/or build small dams upstream (if flow is expected to increase) ▪ Construct or augment water storage reservoirs ▪ Modify spillway capacities and install controllable spillway gates to flush silted reservoirs ▪ Modify number and type of turbines more suited to expected water flow rates ▪ Modify canals or tunnels to handle expected changes in water flows ▪ Optimize reservoir management and improve energy output by adapting to changes in rainfall or river flow patterns
Extreme events (glacier melting, floods)	▪ Dam and other structures ▪ Power station	▪ Floods and glacial lake outburst floods can damage or destroy infrastructure	▪ Design more robust dams and infrastructure for heavier flooding and extreme events ▪ Design for increased flows from glacier melting
Higher air temperature, wind speeds, and humidity	▪ Dam and other structures	▪ Can increase surface evaporation, reducing water storage and power output	▪ Construct or augment water storage reservoirs

Source: ADB 2012.

Table 6: Climate change impacts and adaptation—solar photovoltaic power

Climate variable	Physical components	Key impacts	Adaptation options
General	All	Those listed below	Develop meteorology-based weather/climate forecasting
Temperature increases	▪ Solar PV array ▪ Control system, inverters, cables	▪ Lowers cell efficiency and energy output ▪ Lowers capacity of underground conductors if high ambient temperature ▪ Increases soil temperature	▪ Improve airflow beneath mounting structure to reduce heat gain and increase outputs ▪ Specify heat-resistant PV cells and module components designed to withstand short peaks of very high temperature
Precipitation increases	▪ Solar PV array ▪ Control system, inverters, cables ▪ Mounting structure	▪ Can wash away dust (short term) but reduces panel efficiency (less solar radiation) ▪ Snow accumulation on panel reduces efficiency	▪ Select appropriate tilt panel angle to clean dust ▪ Select module surface conducive to self-cleaning ▪ Choose locations with lower probability of dust, grit, snow if practical
Wind speed; Turbidity	▪ Solar PV array ▪ Control system, inverters, cables ▪ Mounting structure	▪ Increased efficiency and output with cooling effect of wind ▪ Scouring of panel and lower output if air is gritty/dusty	▪ Design structures to withstand higher winds ▪ Assure free space (panels and mounting) so snow can slide off panel ▪ In dry areas, consider panel rinsing
Cloud cover	▪ Solar PV array ▪ Control system, inverters, cables ▪ Mounting structure	▪ Increase lowers efficiency/output ▪ Rapid fluctuations in cloud cover can destabilize grid	▪ Consider distributed systems (rather than feeding power into single part of the grid) to ameliorate cloud impact ▪ Site PV systems where expected changes in cloud cover are relatively low ▪ Consider micro-inverters for each panel (in place of small numbers of large centralized inverters) to improve stability and increase power output
Extreme events (flood, typhoons, drought)	▪ Solar PV array control system, inverters, cables ▪ Mounting structure	▪ Can damage systems (e.g., lightning strikes)	▪ Specify stronger mounting structure ▪ Specify cabling and components that can deal with high moisture content and flooding

Source: ADB 2012.

Table 7: Impacts of climate change on electricity transmission and distribution networks

Climate variable	Physical components	Key impacts	Adaptation options	Level of impact
Wind speed and storms	Wind and storm damage	Overhead lines Pylons	Variable	Variable from moderate to high
	Increasing heat convection	Overhead lines	Continuous	Up to 20% capacity increase for each m/s rise in wind speed
Increasing temperature	De-rating	Transformers	Continuous	–1% load per 1°C rise
	Decreased conductivity	Overhead lines Underground cables	Continuous	Resistance rises ~0.4% per 1°C degree rise –0.5 to –1% line load capacity per1°C rise
	Sag	Overhead lines	50°C	4.5 cm per 1°C rise*
	Thawing permafrost	Substations Pylons	Varies with local conditions	Potential total loss of supply locally
Increasing drought	Moisture migration	Underground cables	>55°C at cable surface	Reduces cable capacity by 29%
	Dry soil movement	Underground cables	Variable	Repair cost roughly $4,200 per fault
Flooding	Inundation	Substations	Varies with local conditions	Up to 100% loss of supply locally
	Cable breakage	Underground cables	As above	As above

4.3 Sector Policy Framework

4.3.1 Regional Policies

The focus of the energy sector in the EAC has been on electricity generation and transmission and the East Africa Power Master Plan (EAPMP) of 2003 is the key policy document. The plan seeks to address the technical requirements and economic viability for interconnection of the Partner States' power systems as electricity demand grows. The EAC also works closely with regional organizations such as the Nile Basin Initiative (NBI) and the Economic Cooperation of the Great Lakes Countries in promoting regional projects and programs in common geographical areas. Examples include the Nile Equatorial Lakes Subsidiary Action Plan and Regional Power Trade Project of the NBI. In its efforts to increase access in a cost-effective manner, the EAC has developed an electrification program that enables border centers to access electricity from the nearest grid.

The Eastern Africa Power Pool, a milestone in regional policy, was established in 2005 with the signing of an Inter-Governmental Memorandum of Understanding by Burundi, Democratic Republic of Congo, Egypt, Ethiopia, Kenya, Rwanda, and Sudan. The heads of states of the Common Market for Eastern and Southern Africa (COMESA) later adopted EAPP to foster power system interconnectivity. Tanzania, Libya, and Uganda joined the EAPP in March 2010, February 2011, and December 2012 respectively. The EAC, jointly with the EAPP is developing a Regional Power Master Plan and Interconnection Code (2013–2038) that is an expansion of the existing East African Power Master Plan (2003–2024) that includes Rwanda and Burundi, which joined the EAC after the EAPMP had been developed.

In addition, the EAC Regional Strategy on Scaling-up Access to Modern Energy Services is supporting access to energy as part of achieving the Millennium Development Goals. However, these policy initiatives have not given adequate attention to potential future climate change impacts. The EAC Climate Change Strategy (2011) and Master Plan (2011–2031) recognize energy as a priority issue that is vulnerable to climate change. These strategic documents call for climate change mitigation measures among EAC Partner States to increase availability and accessibility of sustainable, reliable, and affordable renewable energy resources.

4.3.2 National Policies and Strategies

EAC energy policies related to climate change are summarized in Table 8 with an analysis of gaps, inconsistencies, and weaknesses.

Table 8: Analysis of national policies and strategies relevant to the energy sector in East Africa

Policy/act	*Key mandate*	*Issues*	*Adoption*
BURUNDI			
Environment Act, 2000	• Outlines procedures for environment assessment and stresses that construction (including public infrastructure) should undergo environmental assessment	• Necessity of review for harmonization with Forestry Code, Land Code	Operational
Energy sector Strategy, 2011	• Objective is to increase access to electricity to support agricultural production and other non-farming income-generation activities. • Reduce stress on forestry resources and CO_2 emission	• The strategy recognizes lack of coordination of various entities involved in energy sector and recommends the overall coordination of entities by the Ministry of Energy and Mines, clear definition of roles assigned to each entity, improvement of legal and regulatory framework	Operational since 2011
Sector Strategy (MEEATU), May 2013	• Objectives of promotion of coordinated environment management (land and infrastructure, forests, water, and air quality)	• The strategy recognizes lack of harmonization of different codes, of population participation in the implementation of environment programs, absence of public awareness of international conventions	Draft published on 7 May 2013
KENYA			
Energy Policy, 2014	• A sessional paper that sets out the national policies and strategies for the energy sector that are aligned to the new constitution pf 2010 and are in tandem with the country's Vision 2030 • Formally recognizes the role of renewable energy	• Although it promotes the use of biomass as part of the renewable energy mix, there are no specific strategies for achieving this	Yet to be fully enacted
Energy Act, 2006	• The primary legislation on energy in Kenya • Following the promulgation of the Constitution of Kenya in 2010 and the adoption of Kenya's Vision 2030, the Energy Act is currently being reviewed to align it with the constitution and vision	• Emphasis on petroleum and electricity at the expense of renewable energy	Operational
Rural Electrification Master Plan	• Created to accelerate the pace of rural electrification in Kenya • 80% financing from internal resources	• Inadequate funding • Skewed population distribution making some regions uneconomical to connect	Established in 2006 through Energy Act

Policy/act	***Key mandate***	***Issues***	***Adoption***
	• Stakeholder involvement	• High connection fees which discourages application from target population	No. 12 of 2006 and operationalized in July 2007
Least Cost Power Development Plan (LCPDP), 2011–2031	• Per the Vision 2030 Medium-Term Plan, the LCPDP aims to enhance national power generation and supply by identifying new generation and supply sources to ensure that the national electric power supply exceeds 3,000 MW by 2018 • Has an elaborate implementation plan	• Inadequate funding	Updated and Launched in March 2011
Kenya National Climate Change Response Strategy (NCCRS, 2010)	• The NCCRS was the first national policy document to fully acknowledge the reality of climate change in Kenya • Advocates the use of renewable and clean energy as a mitigation and adaptation option	• Inadequate funding	April 2010
Bioenergy Policy and Strategy, 2011	• A sessional paper that provides a national bioenergy policy framework to promote and harmonize the development of sustainable bioenergy in Kenya • It provides bioenergy policy recommendations and an implementation strategy and plan	• Inadequate funding	August 2011
Forests Act, 2005	• Provides for the establishment, development, and sustainable management, including conservation and rational use of forest resources for socioeconomic development • The act applies to all forests and woodlands on state, local authority, and private land • It provides for rational and efficient use of biomass energy	• Needs to be aligned fully with the new constitution • Provisions on private forest ownership discourage private investment in forestry development	2005
Forests (Charcoal) Regulations, 2009	• Regulations on sustainable charcoal production, transportation, and marketing • The rules are undergoing review	• Several ambiguities in the statutes need to be addressed • Requirement of charcoal production and transport licenses is a major impediment	Under piloting in select districts

Policy/act	Key mandate	Issues	Adoption
RWANDA			
Biomass Energy Strategy, June 2009	• Objective of integrating biomass resources into the economic development of the country with actions to be done, appropriate costs, and benefits for sustainable use	• Necessity of elaboration of new taxation system to avoid bureaucratic practices, limited financial resources	Operational
National Energy Policy, March 2015	• Objective of advancing Rwanda's targets by insuring sufficient, reliable, affordable, and sustainable energy services to all residents with promotion of environment conservation and climate change concerns into energy planning and development	• The policy recognizes that use of other energy resources such as solar, biogas, and liquified petroleum gas (LPG) is limited despite various promotional efforts • More efforts still to be done on the improvement of a legal and regulatory framework to attract private investors for off-grid solutions and Public Private Partnerships. Gender equity in energy use still to be addressed	Operational
Electricity Act, 2011	• Governs electricity power licensing for production, transmission, distribution, and trade inside and outside of the territory of Rwanda	• More efforts to be done on legal and regulatory framework to attract investment for off-grid solutions	Operational
Green growth and Climate Change resilience strategy, 2012	• Focus on all sectors including energy and transport to address in general climate change impacts	• Climate change is well addressed	Pending adoption
Law 04/2005 of 08/04/2005	• Establishes modes of protection, conservation, and promotion of environment (environmental impact assessments (EIA) mandatory for all the projects)	• It emphasizes environmental assessment, little focus on climate change issues	Operational
Law 16/2006 of 03/04/2006	• Establishing Rwanda Environment Management Authority for coordination and integration of environmental management functions in relation to cross-cutting issues (monitoring, evaluation of environmental policy, implementation of legislation)	• It emphasizes environmental assessment, little focus on climate change issues	Operational
TANZANIA			

Policy/act	*Key mandate*	*Issues*	*Adoption*
Energy Policy – 2003	• Objectives are to ensure availability of reliable and affordable energy supplies and their rational and sustainable use to support national development goals	• Seeks to promote renewable energy technologies to minimize threats of climate change, but no mention on anticipated impacts of climate change or related measures	Under review
Energy Policy 2015(draft)	• Objective is to ensure availability of sufficient, reliable, and affordable modern energy supplies and their rational and sustainable use	• New Energy Policy 2015 (draft) recognizes that one challenge in developing hydro systems is vulnerability to hydrology and climate change. It has objective to improve reliability of hydropower	Still in draft form
National Climate Change Strategy, 2012	• Seeks to address climate change and improve energy availability, reduce deforestation, and improve energy diversification and efficiency	• Sets goals and objectives for energy, but no mention of anticipated impacts of climate change or related measures	Has been in operation since 2012
The Environment Management Act, 2004	• Stresses EIAs	• No mention of anticipated impacts of climate change or related measures	Adoption limited by impacts of older acts
Rural Energy Act, 2005	• Promotes access to modern energy services in rural areas. It also directs the provision of grants and subsidies to developers of rural energy projects	• No mention of anticipated impacts of climate change or related measures	Has been in operation since 2005
Electricity Act, 2008	• Facilitate and regulate generation, transmission, transformation, distribution, supply, and use of electric energy, to provide for cross-border trade in electricity and planning and regulation of rural electrification and to provide for related matters	• It stresses on assessment of social and environmental impacts, but no mention of anticipated impacts of climate change or related measures	Operational
Tanzania National Adaptation Programme of Action, 2007	• Biomass and hydropower are vulnerable due to reduced rainfall and high temperatures • Explore and invest in alternative clean energy sources	• Ineffective implementation of proposed activities that address urgent and immediate needs for adapting to the adverse impacts of climate change	Limited adoption
Biomass Energy Strategy (BEST), 2014	• BEST identifies means of ensuring a more sustainable supply of biomass energy to raise the efficiency with which biomass energy is used, to promote access to alternative energy sources where appropriate and affordable	• BEST has not critically assessed the impact of climate change on the future availability of biomass	Not adopted, finalized in 2014

Policy/act	***Key mandate***	***Issues***	***Adoption***
Energy Water and Utilities Regulatory Authority Act, 2012	• Regulates electricity, petroleum, and natural gas and water sectors	• No mention of anticipated impacts of climate change or related measures	Operational
Power Sector Master Plan 2012	• Gives demand and generation forecast. Sources are hydro, gas, coal, wind, geothermal, etc.	• No analysis of anticipated impacts of climate change on energy generation or related measures	Operational
UGANDA			
National development plan, 2010	• It acknowledges that forest cover has declined over the years and set targets to reverse the trend	• Climate change is not well addressed	Operational
Disaster preparedness and Management, 2010	• Mentions climate change as an issue that needs to be addressed; calls for proactive efforts to reduce the causes and the negative impacts of climate change; and proposes that government develop climate change adaptation and mitigation measures	• Policy actions for addressing the challenges of climate change do not have specific strategies	Operational
Renewable Energy Policy, 2007	• Promote and increase the use of modern renewable energy	• Increased hydro and biomass use, but no mention on anticipated impacts of climate change or related measures	Operational
Energy Policy, 2002	• Government commitment to the development and use of renewable energy resources and technologies such as solar, wind, geothermal and hydropower	• The policy does not include any comprehensive provisions for addressing climate change and disaster risk reduction, mitigation, or adaptation	Operational
Forest Policy, 2001	• Initiatives on sustainable forest management—collaborative forest management	• Does not elaborate how people can practice climate change mitigation	Operational
National water policy, 1997	• Recognizes that water is a key strategic resource, vital for sustaining life, promoting development, and maintaining the environment. It mentions agriculture, energy, and forestry as water-related sectors	• No specific measures to address challenges with water resources resulting from climate change. No mention on the role of energy or forests in protecting water catchments	Operational
Environment policy, 1995	• Recognizes the importance of conservation and restoration of ecosystems, biodiversity, and ecological processes. It recommends strategies for achieving environmental sustainability	• No climate change mitigation and adaptation strategies	Operational

Policy/act	***Key mandate***	***Issues***	***Adoption***
Climate change policy, 2012	• Recognizes the need to act upon sector-specific priorities to increase the resilience of the country's development path to the impacts of climate change and to contribute to the reduction of greenhouse gas emissions	-	Operational
National Adaptation Programme, 2007	• Lists climate change impacts in the context of trends such as rapid population growth, agricultural production, water availability, food security, health, education, infrastructure development, energy, deforestation/forestry, wildlife	• Energy and deforestation were not included as priority areas in the National Adaptation Plans of Action, despite evidence that forests and energy are highly affected by climate change	Operational
Biomass Energy Strategy, 2013	• Recognizes overdependency and unsustainable use of tree biomass. Strategic objectives proposed as plausible intervention to the biomass sector	• No analysis of future scenario on biomass supply. No mention of anticipated impacts of climate change or related measures	??
National Forestry and Tree Planting Act of 2003	• Sets target to increase forest cover. It recognizes agricultural expansion as a threat to forest cover	• Silent on strategies to combat anticipated impacts of climate change and related measures	Operational

4.4 Suggestions for Further Assessment and Research Needs

The energy and transport sectors are major contributors to causes of climate change. At the same time, they are affected by variability and change in climate. It is critical that the EAC Partner States plan for adaptation of the sectors.

All the EAC Partner States rely heavily on hydro for electricity generation and biomass for cooking. The countries need to understand the risk posed by future climate change to this sensitive option of electricity generation and cooking. Diversification of generation sources is essential to avoid the risk of supply disruptions and price increases, particularly in the face of increasingly unpredictable hydroelectric power resulting from changing weather patterns. Kenya has led the way in seeking and promoting alternative sources of electricity to reduce vulnerability of hydropower from weather variability. The gradual shift to geothermal is providing triple-win results—it provides power while also protecting against the need for load shedding when hydropower generation is affected, reducing the cost of electricity as dependence on thermal generation, and reducing carbon emissions from thermal generation. In Tanzania, the government expects that significant thermal capacity will need to be added, much of it from natural gas. It is projected that by 2025, most of its electricity will be derived from natural gas, followed by coal, hydro, and renewable energy sources.

Some important interventions would include:

- Diversification of energy sources to include:
    - Alternative sources, such as renewable energies (hydro, geothermal, solar, and wind) and natural gas.
    - Hybridation through combining different energy sources within one power plant to insure a reliable and sustainable supply of electricity to end-users (residential, commercial, and industrial).
- Large-scale energy efficiency programs to adopt modern technologies. This might include improved household energy efficiency through the use of newer cooking technologies such as improved cook stoves and solar cookers; solar water heaters; inverters in commercial buildings; domestic and industrial biogas; and co-generation supported by an intensive public awareness campaign. Such an effort would require strong support from political decision makers who could model adoption of these technologies.
- Reforestation of the catchment areas of hyropower plants to help ensure retention of underground water, mitigation of erosion, and reduction of landslides and related siltation that can damage hyropower plant equipment.
- Agro-forestry and reforestation for sustainability of biomass resources (for firewood and charcoal).
- Recycling waste to produce usable products, such as briquettes (using rice and coffee husks, bagasse, etc.).
- Regional interconnectivity of electrical networks through regional power pools and tariff harmonization.

However, additional research is needed to enhance the understanding of climate risks and inform adaptation responses in the energy sector. Some of the necessary efforts are as follows:

- Assess observed climate change, its impacts, and current and future vulnerabilities to assist in prioritizing adaptation options.
- Conduct impact assessments combining energy models and sector impact models with downscaled climate information through integrated assessment modeling.

- Evaluate the potential effects of climate change on energy installations to inform energy sector planners, designers, and practitioners.
- Update university engineering curricula (at both graduate and diploma levels) to factor in the impacts of climate change. Increase the intake for engineering course and introduce courses in wind engineering, solar, nuclear science, and others.[2]
- Develop climate risk atlases at the national and regional levels using geographic information systems to identify vulnerable energy assets and develop adaptive responses.
- Assess the costs and benefits of various adaptation options and energy strategies.
- Introduce and foster the smart grids[3] concept aiming at improving environmental sustainability, efficiency, quality, and stability of energy supply in the EAC countries. Aspects of smart grids—such as distributed energy, energy storage, transmission and distribution automation, micro-grids, demand response, data analytics, and cyber security—are relevant and important for grid modernization in the EAC.

[2] Kenya has 1,323 registered engineers and 5,000 graduate engineers for a total of 6,323 engineers serving a population of 40 million. This is a ratio of 1:6,328 or one engineer serves 6,328 people, nearly three times the recommended ratio of one engineer serving 2,000 people by the United Nations Educational, Scientific, and Cultural Organisation (UNESCO). It also means that Kenya needs to triple the number of its engineers to meet the recommended ratio, but that effort is lowered by the fact that only about 700 engineers graduate from universities every year (EAC 2016).

[3] The European Union Commission Task Force for Smart Grids defines "smart grid" as an electricity network that can cost-efficiently integrate the behavior and actions of all users connected to it in a manner that ensures an economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety.

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ANNEX I: DETAILS OF ANALYSIS USING VARMAX

The VARMAX model can be represented in various forms, including in state space and dynamic simultaneous equation or dynamic structural equations forms. The model allows representation of distributed lags in the explanatory variables. For example, power generation in year *t* can be related to power generation in year *t*-1, *t*-2 plus to annual rainfall in year *t*, *t*-1, *t*-2, minimum and maximum temperatures in years *t*, *t*-1, *t*-2, etc., simultaneously.

Univariate autoregressive moving average models with power generation were used as the response variable and rainfall, minimum and maximum temperature as the explanatory variables. Various lags in rainfall, minimum and maximum temperature were tested and allowed for so that most of the models can be characterized as autoregressive and moving average multiple regression with distributed lags. Also included in the models and tested for was the significance of seasonal deterministic terms for monthly time series data. For some response variables dead-start models that do not allow for present (current) values of the explanatory variables were used. Heteroscedasticity was tested for in residuals and, where appropriate, GARCH-type (generalized autoregressive conditional heteroscedasticity) conditional heteroscedasticity of residuals was allowed for. Several Information-theoretic model selection criteria were used to automatically determine the AR (autoregressive) and MA (moving average) orders of the models. The specific criteria used were the Akaike information criterion (AIC), the corrected AIC (AICC), Hannan-Quinn (HQ) criterion, Schwarz Bayesian criterion (SBC), also known as Bayesian information criterion, and the final prediction error (FPE). As additional AR order identification aids, partial cross-correlations were used for the response variable, Yule-Walker estimates, partial autoregressive coefficients, and partial canonical correlations. Parameters of the selected full models were estimated using the maximum likelihood (ML) method. Roots of the characteristic functions for both the AR and MA parts (eigenvalues) were evaluated for the proximity of the roots to the unit circle to infer evidence for stationarity of the AR process and inevitability of MA process in the response series.

The adequacy of the selected models was assessed using various diagnostic tools. The specific diagnostic tools used are the following. 1) Durbin-Watson test for first-order autocorrelation in the residuals. 2) Jarque-Bera normality test for determining whether the model residuals represent a white noise process by testing the null hypothesis that the residuals are normally distributed. 3) F tests for autoregressive conditional heteroscedastic (ARCH) disturbances in the residuals. This F statistic tests the null hypothesis that the residuals have equal covariances. 4) F tests for AR disturbance computed from the residuals of the univariate AR(1), AR(1,2), AR(1,2,3), and AR(1,2,3,4) models to test the null hypothesis that the residuals are uncorrelated. 5) Portmanteau test for cross-correlations of residuals at various lags. Final forecasts and their 95 percent confidence intervals were then produced for the response series for lead times running up to 2100.

The VARMAX (*p,q,s*) model with autoregressive process of order *p*, moving average process of order *q* and seasonal component of length *s* was used to model trends in historic observations and to forecast future power generation data for Mkungwa 1, Ntaruka, and Tana Hydro power plants. The models for Mkungwa 1 and Ntaruka power plants used power generation / 1000000 as the response variable. The predictor variable for both plants was the total annual rainfall divided by its mean computed over 1998–2014. The models included lags 0, 1, and 2 in the total annual rainfall each divided by the long-term mean as predictors. The specific model used for the Mkungwa 1 plant is VARMAX (2,2,0) whereas that for the Ntaruka plant is VARMAX (1,2,0). The model for Mkungwa 1 plant means that power generated in the current year is a function of power generated in the preceding two years and annual rainfall in the current year and in each of the two preceding years. The model for Mkungwa 1 differs from that for Ntaruka only in that for Ntaruka power generated in the current year depends only power generated last year instead of in the preceding two years. The two models were fitted to historic power generation observations spanning 1998–2014 and used to forecast power generation from 2015 to 2100, separately for the two power plants.

Historic power generation data for the Tana hydropower plant were available for the period 1990–2009. The data were summarized on a monthly basis instead of annually as was the case for Mkungwa 1 and Ntaruka. The power generation data were log transformed for analysis. The predictor variable was the total monthly rainfall divided by its mean calculated over 1990–2009. Rainfall was represented in terms of five variables corresponding to lags 0, 1, 2, 3, and 4. Seasonal fluctuations in power generation were accounted by including a seasonal component of length=s=12 (corresponding to January to December). This model can be summarized compactly as VARMAX (1,2,12). This model means that power generation in the current month was a function of power generated in the previous month and monthly rainfall in the current month and the contributions of rainfall in the preceding four months. The model was used to project monthly power generation from 2010 to 2100.

The dependence of power generation on prior rainfall was nonlinear for both Kidatu and Mtera hydropower plants. Accordingly, to properly account for this curvilinearity, the Unobserved Components Model (UCM) was used instead of the VARMAX (*p,q,s*) model for both power plants. The UCM is a univariate State Space Model. The response variable was the logarithm of power generated per month. The explanatory or predictor variable was the total monthly rainfall divided by the mean computed over 1990–2014. The curvilinear relationship between power generation and rainfall was modelled using a third-order penalized cubic basis spline with 10 equally spaced interior knots placed on the rainfall values. Additional features of the model were a stochastic irregular component, a time- varying intercept (level) and trend and two cyclical components.

APPENDIX I

The parameter estimates and univariate model diagnostics for assessing how well the selected VARMAX(*p*,*q*,*s*) models fitted the data.

Table 9: Model Parameter estimates for power generation and river discharge S1_t-S11_t model seasonality with 12 levels

Station/Basin	Equation	Parameter	Estimate	Standard Error	t Value	Pr > |t|	Variable
Ntaruka	Generation2	CONST1	-28.59889	9.22704	-3.1	0.0073	1
Ntaruka	Generation2	XL0_1_1	-50.50089	17.56505	-2.88	0.0116	rain_dev(t)
Ntaruka	Generation2	XL1_1_1	90.71989	37.4009	2.43	0.0284	rain_dev(t-1)
Ntaruka	Generation2	XL2_1_1	1.1003	30.88823	0.04	0.9721	rain_dev(t-2)
Ntaruka	Generation2	AR1_1_1	0.94165	0.15452	6.09	0.0001	Generation2(t-1)
Ntaruka	Generation2	AR2_1_1	-0.42665	0.10222	-4.17	0.0008	Generation2(t-2)
Ntaruka	Generation2	MA1_1_1	1.93029	0.23121	8.35	0.0001	e1(t-1)
Ntaruka	Generation2	MA2_1_1	-1	0.22455	-4.45	0.0005	e1(t-2)
Mukungwa 1	Generation2	CONST1	-79.52718	11.30972	-7.03	0.0001	1
Mukungwa 1	Generation2	XL0_1_1	-8.33441	18.13498	-0.46	0.6524	rain_dev(t)
Mukungwa 1	Generation2	XL1_1_1	45.08638	22.87069	1.97	0.0674	rain_dev(t-1)
Mukungwa 1	Generation2	XL2_1_1	73.84845	19.89769	3.71	0.0021	rain_dev(t-2)
Mukungwa 1	Generation2	AR1_1_1	0.45779	0.11088	4.13	0.0009	Generation2(t-1)
Mukungwa 1	Generation2	MA1_1_1	-0.00001	0.30506	0	1	e1(t-1)
Mukungwa 1	Generation2	MA2_1_1	1	0.30506	3.28	0.0051	e1(t-2)
Tana River	log_discharge	CONST1	0.90351	0.3581	2.52	0.0123	1
Tana River	log_discharge	SD_1_1	0.07307	0.13871	0.53	0.5989	S_1t
Tana River	log_discharge	SD_1_2	-0.8347	0.2139	-3.9	0.0001	S_2t
Tana River	log_discharge	SD_1_3	-0.96464	0.33641	-2.87	0.0045	S_3t
Tana River	log_discharge	SD_1_4	0.01584	0.32706	0.05	0.9614	S_4t
Tana River	log_discharge	SD_1_5	-0.26535	0.16196	-1.64	0.1027	S_5t
Tana River	log_discharge	SD_1_6	-0.27069	0.17869	-1.51	0.1312	S_6t
Tana River	log_discharge	SD_1_7	-0.04205	0.20706	-0.2	0.8392	S_7t
Tana River	log_discharge	SD_1_8	0.27753	0.19467	1.43	0.1553	S_8t
Tana River	log_discharge	SD_1_9	0.17036	0.17935	0.95	0.3432	S_9t

Station/Basin	Equation	Parameter	Estimate	Standard Error	t Value	Pr > |t|	Variable
Tana River	log_discharge	SD_1_10	-0.12356	0.15601	-0.79	0.4292	S_10t
Tana River	log_discharge	SD_1_11	0.07548	0.13647	0.55	0.5808	S_11t
Tana River	log_discharge	XL0_1_1	0.55756	0.04794	11.63	0.0001	rain_dev(t)
Tana River	log_discharge	XL1_1_1	0.33281	0.14324	2.32	0.021	rain_dev(t-1)
Tana River	log_discharge	XL2_1_1	-0.09471	0.07451	-1.27	0.205	rain_dev(t-2)
Tana River	log_discharge	AR1_1_1	0.39058	0.23673	1.65	0.1003	log_discharge(t-1)
Tana River	log_discharge	AR2_1_1	0.19658	0.14376	1.37	0.1728	log_discharge(t-2)
Tana River	log_discharge	MA1_1_1	-0.17747	0.24304	-0.73	0.466	e1(t-1)
Tana River	log_discharge	MA2_1_1	-0.04769	0.0912	-0.52	0.6016	e1(t-2)
Tana River	log_gen	CONST1	0.29097	0.18679	1.56	0.1207	1
Tana River	log_gen	SD_1_1	0.13791	0.20029	0.69	0.4918	S_1t
Tana River	log_gen	SD_1_2	-0.26938	0.24152	-1.12	0.2659	S_2t
Tana River	log_gen	SD_1_3	-0.4895	0.22921	-2.14	0.0338	S_3t
Tana River	log_gen	SD_1_4	-0.12988	0.20554	-0.63	0.5281	S_4t
Tana River	log_gen	SD_1_5	-0.18656	0.12435	-1.5	0.1349	S_5t
Tana River	log_gen	SD_1_6	-0.40098	0.17433	-2.3	0.0223	S_6t
Tana River	log_gen	SD_1_7	-0.17643	0.21987	-0.8	0.4231	S_7t
Tana River	log_gen	SD_1_8	-0.37177	0.21143	-1.76	0.08	S_8t
Tana River	log_gen	SD_1_9	-0.1422	0.20238	-0.7	0.483	S_9t
Tana River	log_gen	SD_1_10	-0.10447	0.18309	-0.57	0.5688	S_10t
Tana River	log_gen	SD_1_11	-0.02616	0.14683	-0.18	0.8587	S_11t
Tana River	log_gen	XL0_1_1	-0.07771	0.04144	-1.88	0.062	rain_dev(t)
Tana River	log_gen	XL1_1_1	0.01255	0.04354	0.29	0.7735	rain_dev(t-1)
Tana River	log_gen	XL2_1_1	0.13358	0.04461	2.99	0.003	rain_dev(t-2)
Tana River	log_gen	XL3_1_1	0.07988	0.04417	1.81	0.0718	rain_dev(t-3)
Tana River	log_gen	XL4_1_1	0.02994	0.04364	0.69	0.4933	rain_dev(t-4)
Tana River	log_gen	AR1_1_1	0.88698	0.04091	21.68	0.0001	log_gen(t-1)
Tana River	log_gen	MA1_1_1	0.0607	0.07953	0.76	0.4461	e1(t-1)
Tana River	log_gen	MA2_1_1	0.15197	0.08761	1.73	0.0841	e1(t-2)

Table 10: Component significance for Unobserved Components Model fitted to power generation and river discharge

Station/ basin	Component	Degrees of Freedom	Chi-Square	Approx Pr > Chi-Square
Kidatu	Irregular	1	0.42	0.5187
Kidatu	Level	1	19297.5	<.0001
Kidatu	Slope	1	0.06	0.7995
Kidatu	Cycle_1	2	40.88	<.0001
Kidatu	Cycle_2	2	11.18	0.0037
Kidatu	rain_dev	13	50.64	<0.0001
Mtera	Irregular	1	0.08	0.782
Mtera	Level	1	4581.9	<0.0001
Mtera	Slope	1	0.15	0.6977
Mtera	Cycle_1	2	23.16	<0.0001
Mtera	Cycle_2	2	29.36	<0.0001
Mtera	rain_dev	13	71.53	<0.0001
Tana River	Irregular	1	0.04	0.8411
Tana River	Season	11	30.34	0.0014
Tana River	Mavrain2	13	103.19	<0.0001

Table 11: Parameter estimates for power generation and river discharge for the UCM model

Station/Basin	Component	Parameter	Estimate	Standard Error	t Value	Approx Pr > |t|
Kidatu	Irregular	Error Variance	0.00679	0.0085343	0.8	0.4265
Kidatu	Level	Error Variance	0.00304	0.00551625	0.55	0.582
Kidatu	Slope	Error Variance	5.04E-13	1.06E-08	0	1
Kidatu	Cycle_1	Damping Factor	1	0.00019779	5055.86	<0.0001
Kidatu	Cycle_1	Period	7.48224	0.30619481	24.44	<0.0001
Kidatu	Cycle_1	Error Variance	2.73E-07	2.90E-07	0.94	0.3458
Kidatu	Cycle_2	Damping Factor	1	0.00028331	3529.71	<0.0001
Kidatu	Cycle_2	Period	5.63593	0.20135365	27.99	<0.0001
Kidatu	Cycle_2	Error Variance	1.23E-07	1.53E-07	0.81	0.4205
Kidatu	rain_dev	Error Variance	1.67E-11	3.47E-07	0	1
Mtera	Irregular	Error Variance	0.0295	0.01737943	1.7	0.0896
Mtera	Level	Error Variance	1.21E-11	3.06E-07	0	1
Mtera	Slope	Error Variance	3.01E-13	7.47E-09	0	1
Mtera	Cycle_1	Damping Factor	1	0.00010271	9735.88	<0.0001
Mtera	Cycle_1	Period	13.63693	0.58033657	23.5	<0.0001
Mtera	Cycle_1	Error Variance	3.99E-07	4.40E-07	0.9	0.3656
Mtera	Cycle_2	Damping Factor	1	0.00014256	7014.54	<.0001
Mtera	Cycle_2	Period	7.81623	0.2660979	29.37	<0.0001
Mtera	Cycle_2	Error Variance	3.43E-07	3.68E-07	0.93	0.352
Mtera	rain_dev	Error Variance	1.62E-11	4.17E-07	0	1
Tana River	Irregular	Error Variance	2313.08134	209.48807	11.04	<0.0001
Tana River	Season	Error Variance	0.3607	.	.	.
Tana River	Mavrain2	Error Variance	2.31309	.	.	.
Tana River	DepLag	Phi_1	0.50119	0.05522178	9.08	<0.0001

Table 12: Portmanteau Test for Cross-Correlations of Residuals. The results show tests for white noise residuals based on the cross-correlations of the residuals. Insignificant test results show that we cannot reject the null hypothesis that the residuals are uncorrelated.

Station/basin	Up to lag	Degrees of freedom	Chi-Square	Pr > ChiSq
Ntaruka	5	1	3.19	0.0743
Ntaruka	6	2	3.51	0.1726
Ntaruka	7	3	3.63	0.3048
Ntaruka	8	4	3.64	0.4574
Ntaruka	9	5	4.75	0.4469
Ntaruka	10	6	6.42	0.378
Ntaruka	11	7	6.91	0.4386
Ntaruka	12	8	7.14	0.5212
Mukungwa 1	4	1	3.29	0.0695
Mukungwa 1	5	2	3.31	0.1913
Mukungwa 1	6	3	4.36	0.2254
Mukungwa 1	7	4	5.18	0.2694
Mukungwa 1	8	5	5.19	0.3927
Mukungwa 1	9	6	5.22	0.5162
Mukungwa 1	10	7	5.23	0.6323
Mukungwa 1	11	8	7	0.537
Mukungwa 1	12	9	7.53	0.5817
Tana River	5	1	3.21	0.0731
Tana River	6	2	12.19	0.0023
Tana River	7	3	14.62	0.0022
Tana River	8	4	18.61	0.0009
Tana River	9	5	18.64	0.0022
Tana River	10	6	18.66	0.0048
Tana River	11	7	18.76	0.009
Tana River	12	8	19.13	0.0142
Tana River	4	1	1.57	0.2096
Tana River	5	2	2.25	0.3243
Tana River	6	3	2.33	0.5072
Tana River	7	4	2.33	0.6757
Tana River	8	5	3.45	0.6312
Tana River	9	6	3.9	0.6897
Tana River	10	7	6.47	0.4866
Tana River	11	8	10.94	0.205
Tana River	12	9	12.47	0.1882

Table 13: Univariate model ANOVA diagnostics for power generation and river discharge The results show that each model is significant

Station/Basin	Variable	R-Square	Standard Deviation	F Value	Pr > F
Ntaruka Station	Generation	0.9098	3.50439	10.08	0.0034
Mukungwa 1 Station	Generation	0.8882	4.70994	10.59	0.0019
Tana River Basin	log_discharge	0.8396	0.39463	61.95	<0.0001
Tana River Station	log_gen	0.764	0.3421	35.78	<0.0001

Table 14: Univariate Model White Noise Diagnostics for power generation and river discharge. The results test whether the residuals are correlated and heteroscedastic. The Durbin-Watson test statistics to test the null hypothesis that the residuals are uncorrelated. The Jarque-Bera normality test tests the null hypothesis that the residuals are normally distributed. The F statistics and their p-values for ARCH(1) disturbances test the null hypothesis that the residuals have equal covariances.

			Jarque-Bera normality test		ARCH(1) test	
Station/basin	**Variable**	**Durbin-Watson Statistics**	**Chi-Square**	**Pr > ChiSq**	**F Value**	**Pr > F**
Ntaruka	Generation2	2.23984	1.64	0.4411	10.51	0.0071
Mukungwa 1	Generation2	1.50775	21.9	<0.0001	0	0.9592
Tana River Basin	log_discharge	2.00404	32.89	<0.0001	5.63	0.0185
Tana River Station	log_gen	1.99794	398.99	<0.0001	7.75	0.0058

Table 15: Univariate AR Model Diagnostics for power generation and river discharge The F statistics and their p-values for AR(1), AR(1,2), AR(1,2,3) and AR(1,2,3,4) models of residuals test the null hypothesis that the residuals are uncorrelated.

		AR(1)		AR(1,2)		AR(1,2,3)		AR(1,2,34)	
Station/Basin	**Variable**	**F Value**	**Pr > F**	**F Value**	**Pr > F**	**F Value**	**Pr > F**	**F Value**	**Pr > F**
Ntaruka	Generation	1.06	0.3245	2.47	0.1347	4.99	0.0308	3.33	0.0919
Mukungwa 1	Generation	0.45	0.5159	0.78	0.4845	0.9	0.4804	2.02	0.2108
Tana River Basin	log_discharge	0	0.963	0.02	0.9805	0.52	0.668	0.38	0.8213
Tana River Station	log_gen	0	0.992	0.02	0.9842	0.04	0.9897	0.4	0.8092

Table 16: Roots of AR and MA characteristic polynomials
The modulus of the roots of its AR polynomial should be less than 1 for a time series to be stationary.

Station/Basin	Process	Index	Real Part	Imaginary Part	Modulus	Arctangent	Degree
Mukungwa 1	AR	1	0.45779	0	0.4578	0	0
Mukungwa 1	MA	1	1	0	1	0	0
Mukungwa 1	MA	2	-1	0	1	3.1416	180
Ntaruka	AR	1	0.47083	0.45274	0.6532	0.7658	43.8778
Ntaruka	AR	2	0.47083	-0.45274	0.6532	-0.7658	-43.8778
Ntaruka	MA	1	0.96515	0.26171	1	0.2648	15.1717
Ntaruka	MA	2	0.96515	-0.26171	1	-0.2648	-15.1717
Tana River	AR	1	0.67976	0	0.6798	0	0
Tana River	AR	1	0.88698	0	0.887	0	0
Tana River	AR	2	-0.28919	0	0.2892	3.1416	180
Tana River	MA	1	-0.08874	0.19953	0.2184	1.9893	113.9765
Tana River	MA	1	0.42136	0	0.4214	0	0
Tana River	MA	2	-0.08874	-0.19953	0.2184	-1.9893	-113.9765
Tana River	MA	2	-0.36066	0	0.3607	3.1416	180

APPENDIX II

Table 17: Summary of observed and forecast power generation in GWh x 1000000 for Mukungwa and Ntaruka

Station	Period	Scenario	Generation mean	Forecast mean	Generation median	Forecast median	Generation CV (%)	Forecast CV (%)
Mukungwa 1	1998-2014	MPI-26-2006-2100	57.7	56.9	63.3	65.7	30.8	30.6
Mukungwa 1	1998-2014	MPI-45-2006-2100	57.7	56.9	63.3	65.7	30.8	30.6
Mukungwa 1	1998-2014	MPI-85-2006-2100	57.7	56.9	63.3	65.7	30.8	30.6
Mukungwa 1	2015-2030	MPI-26-2006-2100	.	63.3	.	65.2	.	16.2
Mukungwa 1	2015-2030	MPI-45-2006-2100	.	65.8	.	73.1	.	29.0
Mukungwa 1	2015-2030	MPI-85-2006-2100	.	56.2	.	56.6	.	14.8
Mukungwa 1	2031-2050	MPI-26-2006-2100	.	52.6	.	54.0	.	17.6
Mukungwa 1	2031-2050	MPI-45-2006-2100	.	62.9	.	59.3	.	22.5
Mukungwa 1	2031-2050	MPI-85-2006-2100	.	56.1	.	54.1	.	25.3
Mukungwa 1	2051-2070	MPI-26-2006-2100	.	62.9	.	62.0	.	22.3
Mukungwa 1	2051-2070	MPI-45-2006-2100	.	51.1	.	50.2	.	24.4
Mukungwa 1	2051-2070	MPI-85-2006-2100	.	55.8	.	58.1	.	27.4
Mukungwa 1	2071-2100	MPI-26-2006-2100	.	54.0	.	48.8	.	40.7
Mukungwa 1	2071-2100	MPI-45-2006-2100	.	60.0	.	61.0	.	24.6
Mukungwa 1	2071-2100	MPI-85-2006-2100	.	61.2	.	61.3	.	25.0
Ntaruka	1998-2014	MPI-26-2006-2100	27.6	26.7	29.4	31.6	48.9	49.4
Ntaruka	1998-2014	MPI-45-2006-2100	27.6	26.7	29.4	31.6	48.9	49.4
Ntaruka	1998-2014	MPI-85-2006-2100	27.6	26.7	29.4	31.6	48.9	49.4
Ntaruka	2015-2030	MPI-26-2006-2100	.	28.5	.	28.1	.	31.4
Ntaruka	2015-2030	MPI-45-2006-2100	.	30.4	.	30.9	.	57.4
Ntaruka	2015-2030	MPI-85-2006-2100	.	25.3	.	27.3	.	29.3
Ntaruka	2031-2050	MPI-26-2006-2100	.	24.2	.	25.2	.	44.2
Ntaruka	2031-2050	MPI-45-2006-2100	.	29.0	.	26.1	.	42.3
Ntaruka	2031-2050	MPI-85-2006-2100	.	26.5	.	27.0	.	56.3
Ntaruka	2051-2070	MPI-26-2006-2100	.	28.9	.	28.7	.	52.6
Ntaruka	2051-2070	MPI-45-2006-2100	.	22.6	.	22.0	.	60.5
Ntaruka	2051-2070	MPI-85-2006-2100	.	25.0	.	30.8	.	55.7
Ntaruka	2071-2100	MPI-26-2006-2100	.	25.2	.	24.9	.	80.4
Ntaruka	2071-2100	MPI-45-2006-2100	.	27.5	.	26.6	.	44.3
Ntaruka	2071-2100	MPI-85-2006-2100	.	27.9	.	30.5	.	58.3

APPENDIX III

Table 18: Summary of observed and forecast power generation in GWh x 1000000 for Kidatu and Mtera

Station	Period	Scenario	Generation mean	Forecast mean	Generation median	Forecast median	Generation CV (%)	Forecast CV (%)
Kidatu	1990-2014	MPI-26-2006-2100	931.9	930.2	988.4	969.2	21.0	20.4
Kidatu	1990-2014	MPI-45-2006-2100	931.9	930.2	988.4	969.2	21.0	20.4
Kidatu	1990-2014	MPI-85-2006-2100	931.9	930.2	988.4	969.2	21.0	20.4
Kidatu	2015-2030	MPI-26-2006-2100	.	852.7	.	900.3	.	23.6
Kidatu	2015-2030	MPI-45-2006-2100	.	970.6	.	931.2	.	35.4
Kidatu	2015-2030	MPI-85-2006-2100	.	945.3	.	793.9	.	38.4
Kidatu	2031-2050	MPI-26-2006-2100	.	830.1	.	762.7	.	29.2
Kidatu	2031-2050	MPI-45-2006-2100	.	840.4	.	801.9	.	30.7
Kidatu	2031-2050	MPI-85-2006-2100	.	882.9	.	820.4	.	26.1
Kidatu	2051-2070	MPI-26-2006-2100	.	880.7	.	908.1	.	26.9
Kidatu	2051-2070	MPI-45-2006-2100	.	848.0	.	761.3	.	28.7
Kidatu	2051-2070	MPI-85-2006-2100	.	784.1	.	744.5	.	28.1
Kidatu	2071-2100	MPI-26-2006-2100	.	730.6	.	729.0	.	28.9
Kidatu	2071-2100	MPI-45-2006-2100	.	738.3	.	712.9	.	31.2
Kidatu	2071-2100	MPI-85-2006-2100	.	757.5	.	718.4	.	29.5
Mtera	1990-2014	MPI-26-2006-2100	349.4	347.2	374.1	359.6	33.1	31.8
Mtera	1990-2014	MPI-45-2006-2100	349.4	347.2	374.1	359.6	33.1	31.8
Mtera	1990-2014	MPI-85-2006-2100	349.4	347.2	374.1	359.6	33.1	31.8
Mtera	2015-2030	MPI-26-2006-2100	.	374.1	.	293.5	.	80.4
Mtera	2015-2030	MPI-45-2006-2100	.	496.1	.	347.2	.	66.9
Mtera	2015-2030	MPI-85-2006-2100	.	393.0	.	308.3	.	77.0
Mtera	2031-2050	MPI-26-2006-2100	.	306.2	.	231.7	.	63.0
Mtera	2031-2050	MPI-45-2006-2100	.	396.8	.	312.6	.	70.7
Mtera	2031-2050	MPI-85-2006-2100	.	359.2	.	276.9	.	83.2
Mtera	2051-2070	MPI-26-2006-2100	.	313.4	.	258.8	.	74.7
Mtera	2051-2070	MPI-45-2006-2100	.	267.8	.	236.6	.	68.9
Mtera	2051-2070	MPI-85-2006-2100	.	355.2	.	216.8	.	113.6
Mtera	2071-2100	MPI-26-2006-2100	.	353.8	.	269.6	.	93.5
Mtera	2071-2100	MPI-45-2006-2100	.	294.0	.	186.1	.	98.3
Mtera	2071-2100	MPI-85-2006-2100	.	265.8	.	204.5	.	95.3

APPENDIX IV

Table 19: Summary of observed and forecast power generation in GWh x 1000000 for Tana River

Basin	Period	Scenario	Generation mean	Forecast mean	Generation median	Forecast median	Generation CV (%)	Forecast CV (%)
Tana River	1990-2009	MPI-26-2006-2100	14.6	14.3	15.9	15.1	40.5	41.6
Tana River	1990-2009	MPI-45-2006-2100	14.6	14.3	15.9	15.1	40.5	41.6
Tana River	1990-2009	MPI-85-2006-2100	14.6	14.3	15.9	15.1	40.5	41.6
Tana River	2010-2030	MPI-26-2006-2100	.	12.0	.	10.5	.	49.5
Tana River	2010-2030	MPI-45-2006-2100	.	12.5	.	11.2	.	49.7
Tana River	2010-2030	MPI-85-2006-2100	.	10.8	.	9.6	.	44.8
Tana River	2031-2050	MPI-26-2006-2100	.	12.4	.	11.1	.	43.2
Tana River	2031-2050	MPI-45-2006-2100	.	12.8	.	11.4	.	45.1
Tana River	2031-2050	MPI-85-2006-2100	.	11.6	.	10.3	.	55.5
Tana River	2051-2070	MPI-26-2006-2100	.	12.7	.	10.7	.	57.8
Tana River	2051-2070	MPI-45-2006-2100	.	13.2	.	10.8	.	56.9
Tana River	2051-2070	MPI-85-2006-2100	.	14.5	.	11.4	.	77.2
Tana River	2071-2100	MPI-26-2006-2100	.	14.7	.	12.7	.	51.2
Tana River	2071-2100	MPI-45-2006-2100	.	13.6	.	11.6	.	55.3
Tana River	2071-2100	MPI-85-2006-2100	.	15.9	.	13.0	.	63.6

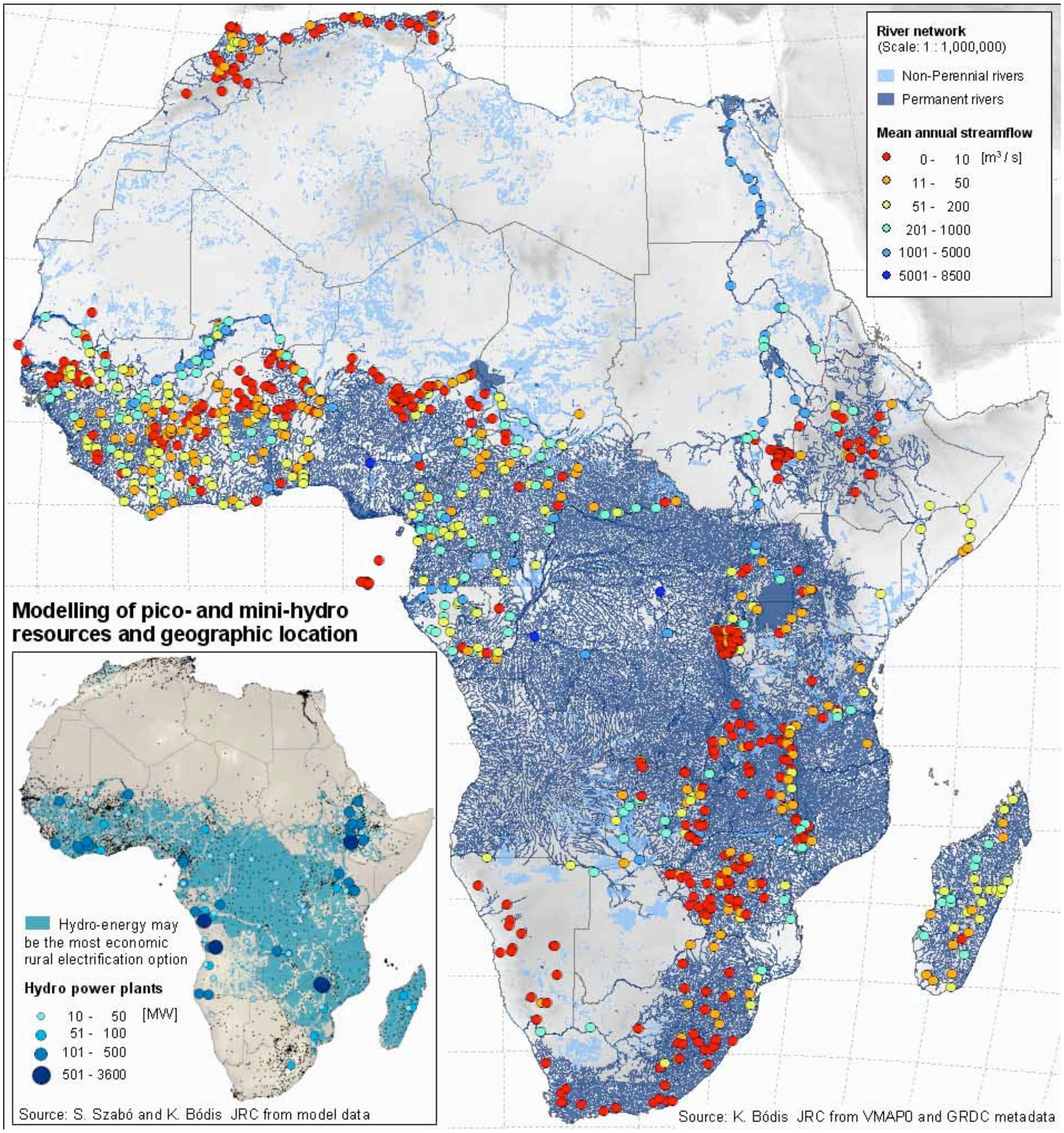

Figure 20: Permanent (dark blue) and non-permanent (light blue) river networks on the African continent with annual mean discharge data [m^2/s] and areas where mini-hydro is the most convenient rural electrification option (detail). Discharge refers to annual discharge, which can be directly correlated to changes in precipitation. (source Belward et al. 2011)

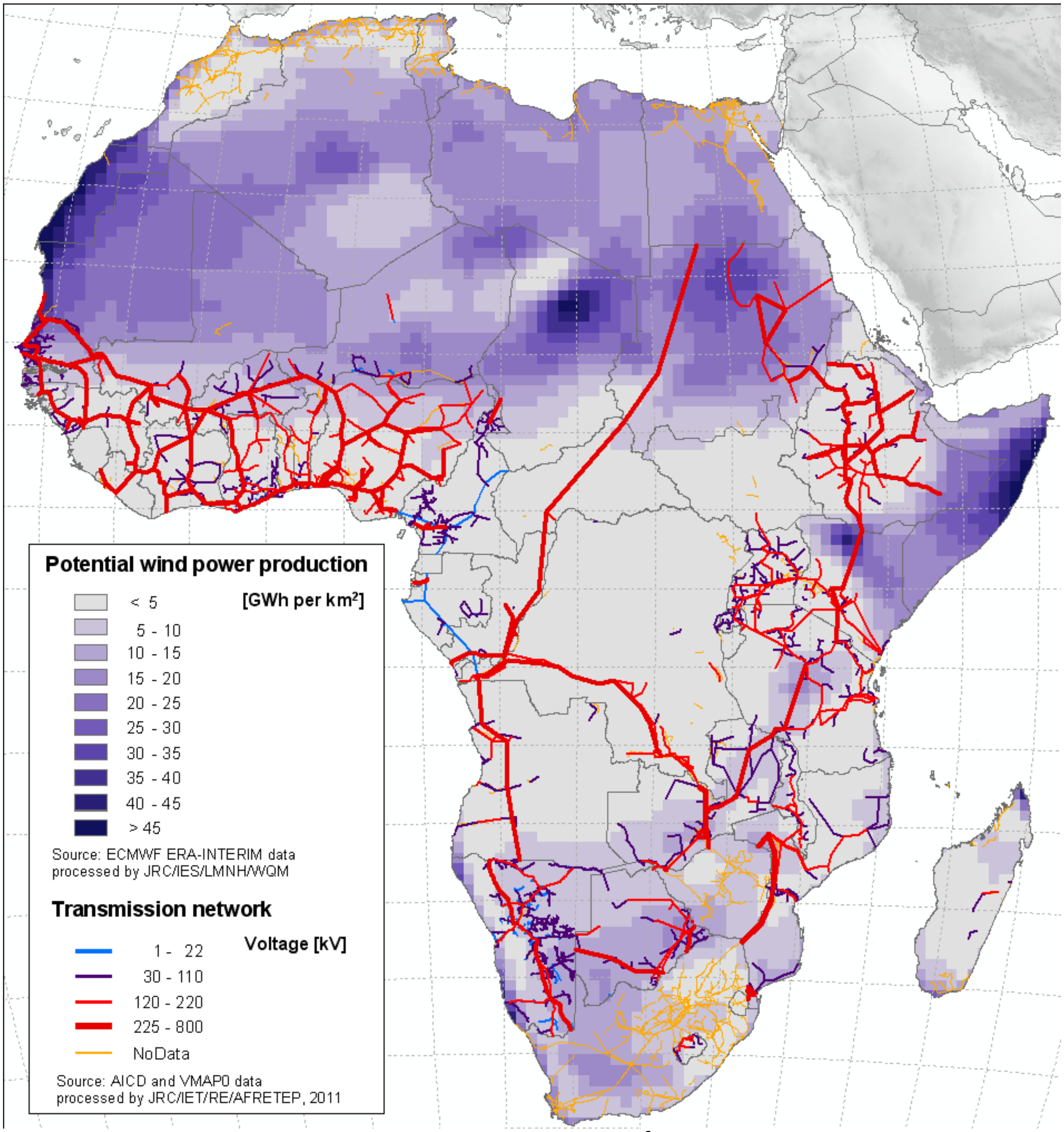

Figure 21: Potential wind power production in GWh per km^2 excluding regions with water bodies, forest, cities, and protected areas and assuming five turbines per km^2. Overlaid is the position of the available data on the existing power grid with capacity in kVolts. (source Belward et al. 2011)

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