The Republic of Uganda

MINISTRY OF WATER AND ENVIRONMENT

CLIMATE CHANGE DEPARTMENT

Economic Assessment of the Impacts of Climate Change in Uganda

Case study on water and energy sector impacts in the Mpanga river catchment

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LIST OF ACRONYMS

Acronym	Definition
AFD	Agence Française de Développement (French Development Agency)
AR5	Fifth Assessment Report of the Intergovernmental Panel on Climate Change
CDO	Community Development Officers
CGCMs	Coupled Global Climate Models
CPI	Consumer Price Index
EAIF	Emerging Africa Infrastructure Fund
ECMWF	European Centre for Medium-range Weather Forecasts
ERA	Electricity Regulatory Authority
FFEM	French Global Environment Facility
GPCC	Global Precipitation Climatology Centre
GDP	Gross Domestic Product
GW	Gigawatts
IPCC	Intergovernmental Panel on Climate Change
kWh	Kilowatt hours
KTOE	Kilo Tonnes of Oil Equivalent
MW	Megawatts
NCCP	National Climate Change Policy
NPV	Net Present Value
NWSC	National Water and Sewerage Corporation
RCP	Representative Concentration Pathways
SSP	Shared Socioeconomic Pathway
UBOS	Uganda Bureau Of Statistics
UETCL	Uganda Electricity Transmission Company Limited

EXECUTIVE SUMMARY

In Uganda, the potential exists for significant conflict between the energy and water supply sectors over the use of river water. This potential is likely to be exacerbated by socioeconomic development and climate change, both of which will place significant additional stresses onto systems in Uganda. This study attempts to value the impact of climate change on these two sectors, drawing on existing modelling of water supply and demand and potential future socioeconomic changes in the River Mpanga.

Potential impacts on renewable energy generation are likely to be significant, with potential annual welfare costs by 2035 to 2040 in the region of 62,733 to 246,795 million shillings (US$25 million to US$98 million). This value reflects the value consumers place on electricity shortages and draws on existing models of water availability at the AEMS-Mpanga hydro power plant.

Annual average economic losses in sectors other than energy (i.e. mining, industry, livestock and, to a lesser extent, irrigation for agriculture) in this area amount to between 114 and 198 million shillings per year by 2035 (US$45,400 to US$78,900). These costs may rise to 472 million shillings per year (US$188,000) if higher future willingness to pay values are used, drawing on potential scenarios of per capita GDP. It is unlikely that there will be significant impacts on domestic consumers, as their needs are given priority.

There are a number of national and local level adaptation options. This study does not estimate the benefits from each of the policy options, but the reductions in energy losses do not need to be that high to yield positive returns. Adaptation measures would need to offset between 2.8% and 32.8% of estimated losses in order to be justified (based on a 10% discount rate, which is commonly used in developing country contexts). A reduction in lost load of around 2% per million dollars of expenditure is required for a 5% rate of return to be attained. For a 10% rate of return the reduction is correspondingly higher at 8% per million dollars.

A number of barriers to effective policy on water have been identified, including the need for strong political will and sufficient funding for employing Community Development Officers to enforce existing laws. Enabling factors include better weather forecasting and early warning systems for water supply shortage and measures to reduce wood fuel demand.

There is a clear need for effective integrated river basin management in the Mpanga River Basin, to ensure that costs are minimised and that effective adaptation strategies are implemented. Further work is needed to improve the data on river flows to ensure appropriate policy action is taken.

The findings of this study are subject to a number of uncertainties. First, there is model uncertainty which has been partly addressed in this study using an "ensembles" approach- bringing together the downscaled results of different models and drawing out optimistic and pessimistic scenarios. Second, uncertainty exists over the values of water and energy losses. Values have been taken from other contexts, with appropriate adjustment to allow for this estimation. Third, there is also uncertainty over the cost of adaptation options. Appropriate factors have been applied to national level estimates to allow a first estimation of the needed levels of effectiveness of different adaptation options to be efficient.

We note there are a number of limitations in terms of data availability. Data on flows in the River Mpanga is limited – and effort needs to be placed on improving data quality in Uganda. Costing of adaptation options is limited for the water sector in Uganda, as is understanding the impact of extreme events. There is a clear need for further exploration of the costs of adaptation in the Ugandan context and for analysis of the costs and benefits to be updated once more reliable cost estimates are available. Improved understanding of the costs would aid decision making in this context.

SUMMARY

There is the potential for significant conflict between the energy and water supply sectors for the use of river water for hydroelectricity generation and supplying the needs of agriculture, households and industry. This potential is likely to be exacerbated by socioeconomic development and climate change, both of which are likely to place significant additional stresses to systems in Uganda. This study attempts to value the impact of climate change on these two sectors, drawing on existing modelling of water supply and demand, and potential future socioeconomic changes in the region.

The River Mpanga was selected as it faces a number of challenges, including pressures on both the quantity and quality of river water. There is an existing hydroelectric plant (AEMS-Mpanga hydro power plant) which has suffered significant outages in the past five years. There are also likely to be increases in non-energy demand for water supply for agricultural, industrial as well as domestic purposes.

This study has modelled the impact of climate change in the Mpanga River basin. The modelling shows that rainfall may decrease and that temperatures are likely to rise significantly. A number of different models have been estimated in a companion study by BRL ingénierie (2015), which shows that water resources are likely to come under increasing pressure, particularly in certain parts of the river basin. The BRL ingénierie study uses a range of existing models – including one generated as part of this particular study - to allow for the consideration of uncertainty across different models. Such an approach can be framed as an "ensembles" approach – i.e. one which clearly considers a range of different possible outcomes rather than taking point estimates as has been the case in the past[1]. Data on river flows in the region was sparse, and further efforts are needed to improve monitoring and analysis of river water flows. For the economic analysis of impacts, this study transferred values from existing studies in Uganda or neighbouring countries where necessary. The transfer of values from other contexts is a common practice, but adds a layer of possible errors to the estimates.

The study finds that the most significant impacts on water supply are likely to fall in the Rushango area of the catchment. Annual average economic losses from non-energy use in this area amount to between 114 and 198 million shillings per year by 2035 (US$45,400 to US$78,900). These costs may rise to 472 million shillings per year (US$188,000) if the higher willingness to pay and future scenarios of per capita GDP are taken into account.

The energy sector will face more significant challenges than the water sector. Building on existing models of water availability at the AEMS-Mpanga hydro power plant, and transferring economic values of lost electricity based on the value of lost load from a study in Kenya, adjusting for income differences and inflation, we find annual costs by 2035 to 2040 may be as high as 62,733 to 246,795 million shillings (US$25 million to US$98 million).

There are a number of adaptation options at both national and local level. The study drew on the scaling down of national level costs to the local level estimating scaling factors such as for example the length of river or electricity production relative to the national level. In order to refine the results obtained, more work would be needed to assess the particular costs of interventions in the Mpanga river area. This was not possible given the constraints of the current study. Particular attention was placed on those options that could be implemented more locally and have an impact on the management of the Mpanga River. Assuming the benefits occur in 2030 to 2035 (i.e. 20 years from the present) for discount rates of 5% and 10% the results are as shown in Table A-1.

[1] This differs from the other case studies in the Economic Assessment of the Impacts of Climate Change in Uganda study, for which downscaled estimates from other model runs were not available. Here it was felt that it was important this study gave the best estimates on impacts in the Mpanga river basin, rather than compromise for the sake of comparative analysis across sectors in other regions.

Table A-1: Effectiveness required for benefits to exceed costs for selected energy policies

Policy number (based on Energy Sector report)	Policy	Estimated Cost for Mpanga (US$m)	Reduction in energy losses needed for benefits to exceed costs 5% discount rate, high Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed costs 5% discount rate, low Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed 10% discount rate, high Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed costs 10% discount rate, low Value of Lost Load (%)
1	Promote and participate in water resource regulation to ensure the availability of water for hydropower production	1.40	0.92	3.61	2.78	10.94
2	Promote and participate in water catchment protection as part of hydroelectric power infrastructure development	4.20	2.75	10.81	8.34	32.81
3	Diversify energy sources by promoting the use of alternative renewable energy sources (such as solar, biomass, mini-hydro, geothermal and wind) that are less sensitive to climate change	1.92	1.26	4.94	3.81	14.99
5	Conduct research to determine the potential impacts of climate change elements on the country's power supply chain	1.47	0.96	3.78	2.92	11.47

Source: Own calculations.

Two discount rates and two values of lost load (the economic value of power outages) were used to test for sensitivity. While we cannot estimate the benefits likely from each of the policies (that would need more detailed analysis than was possible in this case study) we can see that the reductions in energy losses do not need to be that significant in some cases to yield positive returns. Table A-1 shows that actions would need to be offset between 2.8% and 32.8% of estimated losses in order to be justified (10% discount rate). A reduction in lost load of around 2% per million dollars of expenditure is required to achieve a 5% internal rate of return. For a 10% rate of return the reduction in lost load is correspondingly higher at 8%.

Based on the estimates derived above, the measures that appear to be most effective in the region would be "Better management of available water for hydropower production" (Policy 1) and "Promotion of water catchment protection" (Policy 2) of Table A-1. Diversification of energy sources (Policy 3) is not particularly suited to this catchment and may be more effective nearer large centres of demand. Further research on the impacts of climate change on the supply chain (Policy 5), while important, is unlikely to generate such benefits.

It is important to note, however, that the cost data used in the analysis is highly uncertain and further analysis of the costs of local level interventions and the likely extent of benefits is needed.

It is also important to note that that other policies identified in the national Energy Sector report (Baastel Consortium, 2015b) were not examined in this case study as they do not directly relate to river basin management – e.g. the targeting of energy efficiency and actions that reduce biomass demand. Analysis of these was beyond the scope of the current project, but clearly such strategies should be considered alongside those above in the development of integrated adaptation (and mitigation) strategies. Finally, it is important to note that these policies would likely have other benefits: water supply security and ecosystem services, including tourism. These benefits may occur in the shorter term; whereas the energy supply benefits arise later and hence need to be discounted to reflect social time preference. Hence, a project to improve energy supply may yield benefits in 20 years, but in the nearer term there may be other ecosystem service benefits from the project. More work would be needed to estimate the full benefits of these policies at local level. It is important to note that the benefits considered here only reflect the average variation and not an extreme event, therefore the benefits may be underestimated.

A number of barriers to effective policy, on water in particular, have been identified in this study through qualitative interviews. These include the need for strong political will and sufficient funding to employ Community Development Officers to enforce existing laws. Enabling factors include better weather forecasting, early warning systems for water supply shortage and measures to reduce wood fuel demand.

There is a clear need for effective integrated river basin management in the Mpanga River Basin, to ensure that costs are minimised and that effective adaptation strategies are implemented. Further work is needed to improve the data on river flows, to ensure appropriate policy action is taken.

1. INTRODUCTION

1.1. Rationale of the case study

Climate change is likely to affect the availability of water resources in Uganda, with impacts on a number of sectors especially the water sector and the energy sector. The impacts of climate change on both these sectors have been estimated at a national level as part of the current study. The economic assessment of impacts and strategies to assess them at national level is subject to a number of uncertainties. On the impacts side, values are based on transfer of estimates from previous studies in Uganda - where possible - and from neighbouring countries if not possible. Such "benefit transfer" adds a degree of uncertainty, though in the absence of adequate valuation studies this is a commonly used method to estimate values for cost-benefit analysis, to assess potential policy. For instance, these methods have been used for decades by the World Bank and others in evaluating water and energy projects (see Young, 1996). On the costs side, we are reliant on existing policy documents on the estimated costs of policies, which have themselves been based on limited data, leading to a further level of uncertainty.

To better understand the conflicts inherent in river basin management it is necessary to investigate these issues at a river basin scale. In this study we build on existing evidence of the impacts of climate change on water and hydroelectricity in the Mpanga River Basin.

The Mpanga River has been subject of a number of studies in recent years. One study on current and future potential water resources for the Mpanga river basin, under different climate scenarios, was launched in September 2014 by the Directorate of Water Resources Management of the Ministry of Water and Environment. The objective of the study was to assess the impact of different climate change scenarios on the water resources of the Mpanga River. The results of that study will be used as a basis for future Integrated Water Resources Management (IWRM) processes within Mpanga catchment area, hence supporting the sustainable management of the water resource. In particular, work will start soon on the re-drafting of the Catchment Management Plan for the Mpanga Basin. A better understanding of the basin's water resources under both present and future climatic conditions will provide essential information for this plan (BRL ingénierie, 2015[2]).

An Economic Assessment of the Impacts of Climate change is currently being realized in Uganda. Building on the above initiative, the Baastel consortium has attempted to assess the economic impacts of climate change in the Mpanga river catchment. The hydrological assessment (described above) provides an excellent input to the economic assessment. It has provided important links to key stakeholders mobilized in the area, including access to stakeholders at workshops.

1.2. Objectives

This case study aims to quantify the potential economic effects on the water and energy sectors due to climate change in the Mpanga River basin and to evaluate some adaptation options.

The objectives of this case study are to:

[2] BRL Ingénierie is the consultancy contracted by Adetef (with funds from the French AFD) to conduct this study, which started in July 2014 and was finalised in February 2015. This case study built on the results of the final report (BRL Ingénierie, 2015).

- Predict climate change scenarios for the Mpanga River basin, specifically temperature and rainfall patterns over the next 50 to 80 years;
- Estimate the likely impacts of climate change and development on the water and energy sectors, in the River Mpanga;
- Assess the current economic cost of extreme climatic events and the likely future economic cost of climate change, according to the scenarios of changes in water availability; and
- Evaluate and recommend a range of possible adaptation strategies.

Most of these objectives were achieved. However, we were unable to quantify the economic cost of extreme climatic events in the Mpanga River basin. We attempted to collect information on historic analogues of drought and flood, through both secondary document analysis and interviews, but insufficient information was available to support this level of analysis.

This constitutes one of five case studies of the national study (Economic Assessment of the Impacts of Climate Change in Uganda), the other four being:

- Infrastructure: Economic assessment of the impacts of climate change in the Kampala urban area, in close collaboration with the Kampala City Council Authority (KCCA);
- Export/agriculture sector: Economic assessment of the impacts of climate change on the coffee sector in Bududa district in the region of Mt. Elgon;
- Health sector: Economic assessment of the impacts of climate change on malaria prevalence in the districts of Tororo and Kabale;
- Agriculture / livestock: Economic assessment of the impacts of climate change in three villages of the Karamoja region (agricultural sector) chosen from three different agro-ecological zones.

Case studies provide an opportunity to assess the impacts of climate change at the local level, through consultation with various stakeholders, including: local authorities, development partners, private sector operators and local communities. In particular, stakeholders' perceptions of the impacts of climate change have been given due consideration, as well as the adaptation strategies they implement as a reaction to extreme events or new climatic patterns. This bottom-up approach will feed into the final assessment report of the Economic Assessment study - providing concrete examples of the cost of climate change at the local level and possible benefits of a range of adaptation strategies implemented locally.

1.3. Report structure

This report is structured as follows. Section 1.4 presents an overview of the interlinkages between climate change, energy and water. Section 1.5 presents an overview of the Mpanga catchment. Section 2 presents an overview of the methodology, including discussion of the application of climate scenarios, the methods used in estimating the impacts on water and consequent impacts on energy generation, and a brief discussion of the techniques used in adaptation policy analysis. Section 3 outlines the baseline data for water supply and demand, and the energy supply. Section 4 presents an assessment of the likely future scenarios for precipitation and rainfall in the Mpanga river basin, before Sections 5 and 6 present estimates of the economic impacts on water and energy respectively. Section 7 presents an analysis of adaptation options, with Section 8 discussing the policy conclusions and recommendations.

1.4. Climate change, energy and water: an overview

Uganda's energy sector is dominated by biomass that contributes over 90% of the total energy consumption, with charcoal and firewood supplying about 5.6% and 78.6% respectively (MEMD, 2012). Fuel wood and charcoal are principal cooking fuels in Uganda, in addition to being a major fuel source for small and medium scale industries and rural cottage industries. The use of electricity is still very low. The energy mix developed by the Ministry of Energy and Mineral Development shows that in 2013, biomass contribution to the national energy balance was 88.9%, while fossil fuels share was 11.1%. The contribution of electricity to total energy consumed in Uganda is only about 1.4% currently. The current installed capacity is 882.84 MW out of which 630 MW is large hydropower (Nalubaale, Kiira and Bujagali) 65.84MW [3] is mini-hydropower, 51MW is cogeneration[4] and 136 MW is from Oil fired plants[5] (GoU, 2014).

The sectoral level study on energy conducted as part of the present study showed that there would be a need to move from biomass to alternative energy sources, particularly renewables. Hydropower offers a significant potential source of energy, but it is highly climate dependent. This study is important in assessing future risks to hydropower from climate change.

Hydropower potential for Uganda is about 2,000 MW, most of which is along the River Nile. The potential for small hydropower generation plants is about 300 MW. In the short to medium term, construction of Karuma Hydropower project (600MW), Isimba (188MW) and Ayago (600 MW) are on track. The government also plans several small scale power generation capacities (from mini-hydropower and co-generation) (GoU, 2014).

Electrification in the rural areas is still very low. The overall national access to grid electricity is about 18.2%, which is low compared to, for example, Kenya where 23% have access to grid electricity (World Bank, 2015a). The energy use of the household sector is 65.5% of the total energy. It is followed by the industrial sector which is 20.2%. Transport sector and agricultural energy consumption was 6.9% and 0.4% respectively, while other remaining sectors were 6.9% of the total energy consumption. Electricity is very important for national development and the government has a major expansion plan to double generation, from 2.5 tWh in 2010 to around 5 tWh by 2030, from the development of both large, medium and small hydropower (see Energy Sector Report, Baastel Consortium 2015b). The industrial sector consumption is 65%, while residential and other sectors consumption was 22% and 12% respectively of the total electricity consumption. The Government is planning to transform rural communities by encouraging the private sector to develop small scale hydropower systems in rural areas.

Closely linked to hydropower are water resources, which are subject to pressures from the fast growing population, industry and agriculture.

1.5. The Mpanga River Catchment

The Mpanga River is the eighth biggest river in Uganda. It starts in the Rwenzori Mountains, in western Uganda, and flows successively through the towns of Fort Portal (Kabarole district) and near Kamwenge (Kamwenge district) down to Lake George. The city of Ibanda is also part of the Mpanga river basin. A map of the river basin is presented in Figure 1. The Mpanga region is mostly covered by protected areas (Rwenzori Mountains, Kibale

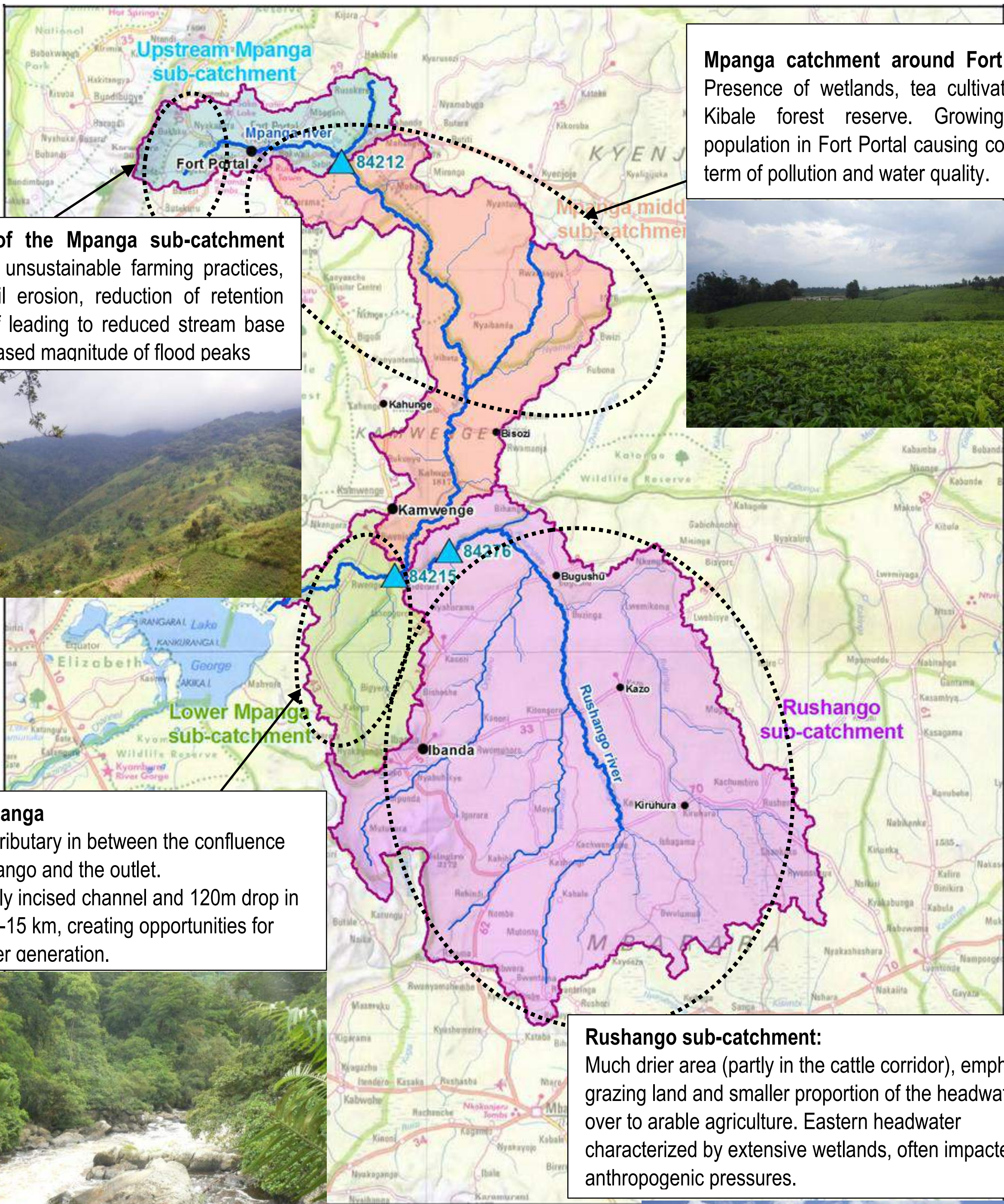
[3] Mini-hydro power plants include Mpanga (18MW), Buseruka (9MW), Kilembe Mines/Mobuku I, (5MW), Kasese Cobalt/Mobuku II (10MW), Bugoya/Mobuku III (13MW), Ishasha (6.4MW), Kisizi (0.26MW), Kagando (0.06MW), Kaluva (0.12MW), Nyagak (3.5MW).
[4] Cogeneration power plants include Kakira 32MW, Kaliro 12 MW and Kinyara 7MW.
[5] Oil fired Plants include Jacobsen (56MW) and Electromaxx (80MW).

Forest and Queen Elisabeth National Park around Lake George) and rural areas dominated by small holder subsistence farming and tea estates.

The River Mpanga has been the subject of a significant study on water availability (BRL ingénierie, 2015). The BRL ingénierie study was a pilot study which was intended to be replicated in other river catchments in Uganda. The hydrological modelling included in that study is crucial to the estimation of potential damages due to climate change. The synergies between the Baastel and BRL ingénierie studies and the importance of the River to the region played a significant role in the selection of the River Mpanga for investigation.

Figure 1: Location and map of the Mpanga river catchment, in yellow

Source: own compilation



Mpanga catchment around Fort Portal: Presence of wetlands, tea cultivation and Kibale forest reserve. Growing urban population in Fort Portal causing concern in term of pollution and water quality.

Upper part of the Mpanga sub-catchment
Deforestation, unsustainable farming practices, leading to soil erosion, reduction of retention capacity, itself leading to reduced stream base flow and increased magnitude of flood peaks

Lower Mpanga
No major tributary in between the confluence with Rushango and the outlet.
Increasingly incised channel and 120m drop in the last 12-15 km, creating opportunities for hydropower generation.

Rushango sub-catchment:
Much drier area (partly in the cattle corridor), emphasis on grazing land and smaller proportion of the headwater put over to arable agriculture. Eastern headwater characterized by extensive wetlands, often impacted by anthropogenic pressures.

Figure 2: photos of the Mpanga river catchment

Upstream part of the Mpanga sub-catchment; the Rwenzori mountains

Degraded slopes around Fort Portal

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Tea estates in Mpanga River sub-catchment

.

Mpanga river at Kam gauging station (84212, Fort Portal – Kampala road) (extracted from BRLi mission report)

River Mpanga power station

Lake George and Queen Elisabeth National Park

Source: BRL ingénierie and O.Beucher.

The Mpanga River basin is in a critical situation in terms of both the quality and quantity of water resources. This situation is due to the combined effects of existing climatic variability and tensions on the use of water resources. According to the local community consultations, led for the baseline study that fed into the BRL ingénierie work (Protos, 2012), the local climate appears to be changing in the Mpanga catchment area. Dry seasons are reported to be longer and harsher than 30 years ago (fewer, lighter rains and higher temperatures), leading to more frequent crop failure and increasing food insecurity. In addition, global reduction of Mpanga River flows combined with extreme events (stronger floods and destructive storms) are also reported (Rwenzori Regional Think Tank, 2011). This climatic variability heightens the tension surrounding water use. With respect to quantity, the water balance is described as limited during the dry season - as agricultural, industrial and energy users compete for scarce resources. There is a marked increase in water demand, notably due to the growing needs in the urban areas of Fort Portal (2011 population estimate: 47,100 inhabitants, UBOS), Kamwenge (2011 population estimate: 16,300 inhabitants, UBOS) and Ibanda (2011 population estimate: 28,500 inhabitants, UBOS). A recent World Bank study highlighted the rapid population growth in urban areas in Uganda (World Bank, 2015). The expectation is that the urban population will increase across Uganda from 6.1 million at present to 32 million by 2050.The possible development of irrigation projects on top of this could lead to a critical situation. In addition, the recent building and start of operations (2012) of the AEMS-Mpanga hydro power plant near Kamwenge, towards the end of the Mpanga River, places an additional pressure on the need to maintain a high water flow for electricity production purposes.

Conflicts could arise in the future due to different uses of water, notably: domestic consumption, agricultural use, industrial use and use of the river for energy production. The hydro plant was constructed by Africa EMS Mpanga Ltd, starting in 2009. It is a mini hydro hydropower plant along Mpanga River with installed capacity of 18MW. The completed power station came online in 2011. A new 33kV transmission line connects the power station to the national electrical grid. Construction of the power station was undertaken by a Sri Lankan hydropower construction company called VSHydro (Private) Limited, at an estimated cost of US$26 million. It was financed by the Emerging Africa Infrastructure Fund (EAIF), which provided long term financing of US$14 million and then an additional US$6 million. The power generated by the plant is purchased by the Ugandan Electricity Transmission Company Limited (UETCL) and fed into the national grid, under long-term power purchase agreements.

The plant operates six turbines, each with capacity of 3MW. The head[6] is 163m and the designed flow rate is $16m^3s^{-1}$. **Currently the plant operates at full load for only three months in the year.** For the rest of the year it operates at partial loads, due to the decreasing water level available for energy generation. **At times the level of water drops so low that the company is forced to shut down the hydropower power plant, as in February/ March 2015.** Low flow is caused by both drought and extraction – climate change and socioeconomic change may increase these pressures.

[6] The head refers to the vertical distance between the intake and the turbine. This together with the flow is important in determining the amount of electricity that can be produced (Energypedia, 2015).

2. METHODOLOGY

2.1. Overview of methodology

The study involved the following steps:

- Downscaling climate change scenarios to the Mpanga river basin, in order to provide an updated evidence of temperature and rainfall patterns over the next 50 to 80 years. Full details on the downscaling approach applied are available in Rautenbach (2014). These downscaled data sets have been used in the BRL Ingénierie (2015) study together with other climate scenarios, and then in this case study;
- Assessment of the likely impacts of climate change on power generation, and on the domestic water supply and access;
- Assessment of the economic cost of the impacts of climate change, as well as the cost of possible adaptation options. The study aims to estimate current impacts of variability and likely future damages to the domestic water sector in the area and evaluate a range of possible adaptation options in terms of the amount by which they reduce damages and the costs they impose.

In section 2.2 climate scenarios are discussed, before Sections 2.3 and 2.4 discuss particular methods for assessing losses for water and energy respectively. Section 2.5 gives an overview of the method for adaptation policy analysis.

2.2. Climate Scenarios

An initial analysis of climate change scenarios based on downscaling of model projections was conducted as part of this project. This fed in to an analysis by the BRL Ingénierie study (2015) of the outcomes of a number of modelling exercises, which used an "ensembles" type approach – allowing for consideration of model uncertainty in the assessment.

As part of this study historical (1951 to 2005: 55 years) climate model simulations, as well as future (2006 to 2095: 90 years) climate model simulated projections for rainfall and near-surface temperatures were carried out for the Mpanga domain of Uganda. For the purpose of climate scenarios, the larger Mpanga River Catchment area was divided into two domains, namely (1) the Mpanga-south domain (30.36°E to 30.80°E; 0.88°S to 0.00°) and (2) the Mpanga-north domain (30.36°E to 30.80°E ; 0.00° to 0.88°N). These domains were selected according to the position of grid points that are located within the larger Mpanga area. Spatial averaged values of rainfall and near-surface temperatures, calculated across six grid points in each one of the two Mpanga domains, were regarded as the *dynamical downscaled* climate for the domain.

Projections were made under conditions of a high Carbon Dioxide (CO_2) Representative Concentration Pathway (RCP 8.5)[7] and a medium-to-low CO_2 Representative Concentration Pathway (RCP 4.5) (Meinhausen, et al., 2011; Riahi et al., 2011).

For rainfall, monthly total data from the Global Precipitation Climatology Centre (GPCC) were downloaded for the period 1951 to 2005 (55 years). This data product is based on quality-controlled data from 67 200 stations

[7] The Representative Concentration Pathways show the potential cumulative measure of anthropogenic emissions of greenhouse gases. In the Intergovernmental Panel on Climate Change's AR5 report four RCPs were used, two of which have been selected for this case study.

worldwide that feature record durations of 10-years or longer. The GPCC Full Data Reanalyses product used in this report is regarded as having a high accuracy and is regarded as suitable for use in the verification of models (Schneider et al., 2011; 2013).

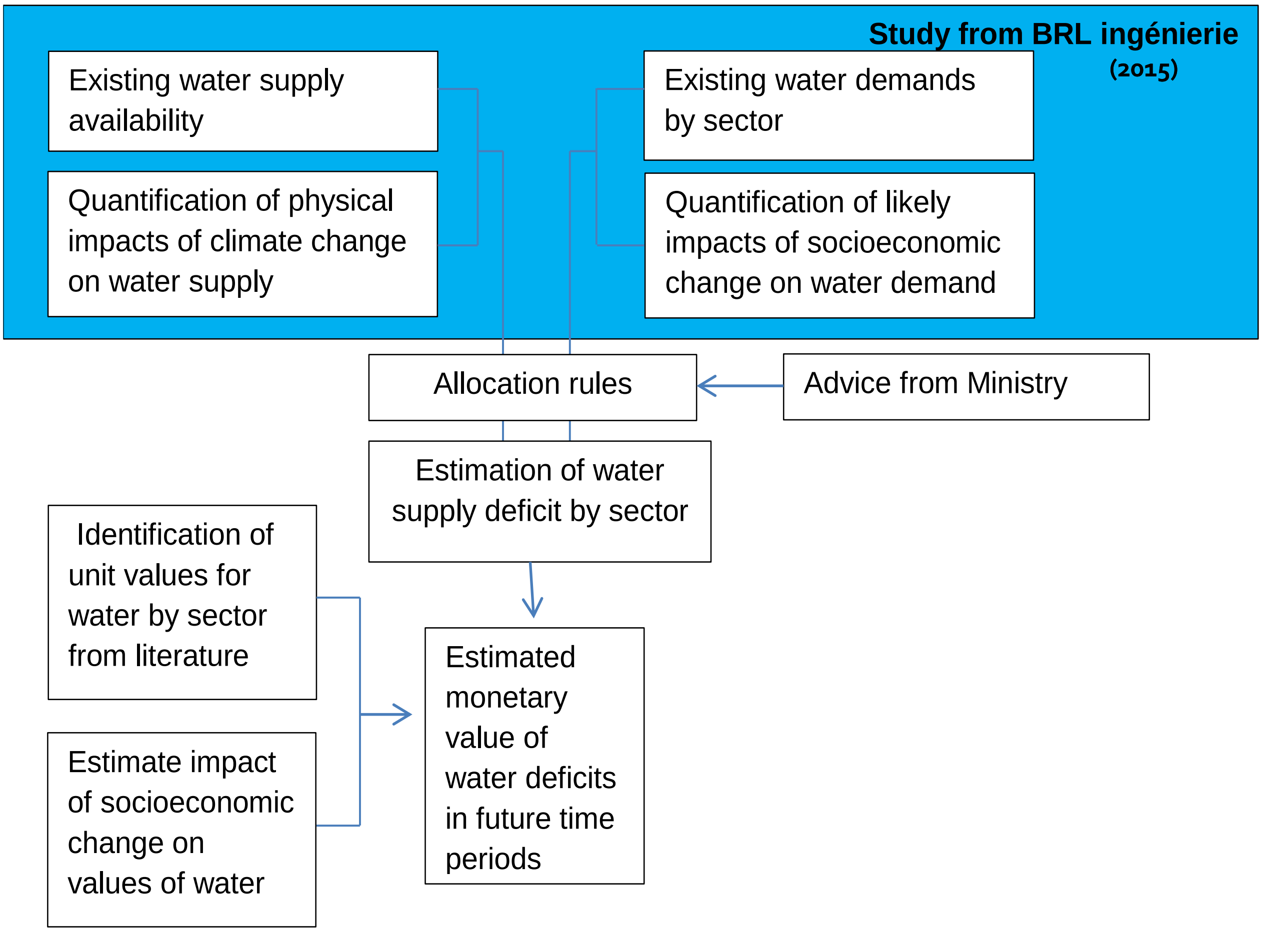
For near-surface temperature, monthly averaged data from the European Centre for Medium-range Weather Forecasts (ECMWF) Reanalysis (ERA-Interim) data products were downloaded for the period 1979 to 2005 (27 years).

Systematic errors (also known as biases) often occur in model simulations. These biases might create uncertainties and will have an influence on model simulated projections, which will make these projections less suitable for application in climate change impact studies. For this study a *bias correction* technique was applied to calibrate or to make model simulated output more representative of observations. For details see Rautenbach (2015).

2.3. Climate change and water

In order to assess the cost of climate change impacts on the water sector, we use a similar approach to that taken in the water sector study realised at the national level (Baastel consortium, 2015). Figure 3 gives an overview of the core methodology. We draw heavily on the outputs of BRL ingénierie (2015) to estimate the demand and supply of water in the different catchments. An allocation rule is then used to allocate water to the different sectors with demand – and helps identify those sectors likely to be most impacted by shortages. The shortages are then valued using existing estimates of willingness to pay based on previous studies in Uganda, with future changes in willingness to pay being accounted for by adjusting the values to show the sensitivity of expected damages to these variables.

Figure 3: Overview of methodology to estimate costs of climate change to water in Mpanga



Based on discussions with the Ministry of Water and Environment, we assume a hierarchy of allocation, with the following demands being met sequentially:

- Consumption demand – urban and rural;
- Irrigation water demand;
- Industry water demand; and
- Livestock consumption demand.

The hierarchy above is generally reflected in policy documents of the Ministry of Water and Environment – e.g. the Joint Water and Environment Sector Support Programme (JWESSP, 2013-18) (Government of Uganda, 2013). In terms of the costs of the recent 2010-2011 drought, costs were more significant on the agriculture, livestock and agro-industry than on the water supply sector. This distribution of costs possibly reflected the priority placed on the protection of domestic supplies in times of shortage (Department of Disaster Management, 2012).

For the case study in Mpanga information was also available on demand for water by institutions (e.g hospitals and schools) and mining and mineral extraction sectors. The study assumes that institutional water demand is considered as consumption demand, given the critical role of services provided by institutions. This study also assumes that mining and mineral extraction sector is considered as an industry in terms of water demand.

2.4. Climate change and energy

A mixed method approach was taken to assess the impacts of climate change on energy generation in the Mpanga River Basin. This consisted of both quantitative modelling approaches and qualitative semi-structured interviews in four districts within the Mpanga River Basin.

In terms of quantitative modelling, projected data for each month of water flow rates in the river near the dam for 30 years were provided on request by the BRL ingénierie team for the pessimistic scenario. Using a model that relates flow to generation, the potential energy generation was calculated for every year for 30 years and compared to a baseline to assess the potential fall in energy generation attributable to climate change and future water demand from the river.

The modelling work involved the following technical assumptions about the AEMS-Mpanga hydro power plant (see details below) and its operation:

- Efficiency of the turbine is estimated to be 92% when in normal operation, but it will decrease to 88% for lower water flow rates[8]. The available head will be maintained constant at about 136m. It is assumed there will not be significant drop in the head in case of drought. If any drop occurred it was assumed that energy production ceases until a suitable head is reached.
- The efficiency of the generator (conversion of hydro energy into electrical energy) is approximately 98% and the power availability is about 99%. This means that power is available almost at all times, except when the plant has to stop).
- In the first 22 years of operation, the low flow rates of the river will be compensated with increased flow rates at different intervals. As an example, decreased flow from year 1 to year 4 will be compensated with increasing flow from year 5 to year 8. A similar assumption can be made for the years 12 to 22. The design flow is 16m^3 per second. It is assumed that in the long term, average flow rate will be about 8 m^3 per second. It can be seen from the data that 16m3 per second can be achieved only for about three months per year, whilst in other months the flow rates drop. Hence the average 8m^3 per second is obtained over the entire period.

2.5. Adaptation policy analysis

An assessment was made of adaptation options based on the sectoral reports. Costs were scaled from the national level to the local using appropriate factors, and compared to potential benefits to give an idea of how effective a measure would have to be to give a positive net present value (NPV[9]). This approach was chosen due to a lack of data on the costs of measures that could be applied in the Mpanga River catchment. There are a number of significant limitations:

1. It is assumed that the costs of adaptation options at national level are accurate – whereas there may be local factors that cause deviations from the national estimates these are not accounted for;
2. It is assumed that the options chosen are perfectly separable and that national costs will be equally borne across all regions – which is not likely to be the case; and

[8] Francis turbines have high efficiencies when compared to other turbines, but assume that the head and flow rates are kept constant. When flow rates decrease, the efficiency also decreases. Manufactures catalogues were not available however.

[9] The NPV of an investment is determined by calculating the present value (PV) of the total benefits and costs which is achieved by discounting the future value of each cash flow. NPV is a useful tool to determine whether a project or investment will result in a net profit or a loss. A positive NPV results in profit, while a negative NPV results in a loss.

3. The benefits are based on transfers of values from previous studies in different locations in Uganda and neighbouring countries.

For these reasons the approach has a number of approximations, but provides at least an indicative assessment of the likely necessary effectiveness of a selection of measures. A more complete analysis would be needed to facilitate policy choice at local level.

This analysis was supplemented by interviews with key stakeholders in the Mpanga River Basin. Particular focus was put on the identification of the barriers and enabling factors in the districts. Thematic analysis, which is the examination of themes within qualitative data, was conducted on the interview transcripts.

3. BASELINE

3.1. Water demand and supply in the Mpanga catchment

The current demand for water in the Mpanga catchment is largely from domestic consumers, with the three main cities (Fort Portal, Kamwenge and Ibanda) dependent on water from the Mpanga river catchment. The urban populations are rapidly expanding, implying increased demand for domestic water. Problems of water quality already exist, in particular in Fort Portal where costs for de-siltation are increasing. After heavy rains, water pumping has to be stopped due to excessive silt in water, leading to high treatment costs..

The level of rural water supply is difficult to quantify, with many smaller rural communities dependent on groundwater. Stakeholders interviewed as part of this study suggest that there is significant pressure on springs in particular. They reported that the majority of the springs are now drying up and also note issues with shallow wells, where there are high chances of contamination due to water stagnation. In terms of water quality, there have been issues with water borne diseases. For example, in 2003 there was an outbreak of Bilharzia in the shores of Lake George and the Ministry of Health had to take action. Stakeholders also reported issues with boreholes. These are in some places up to 80 metres deep and subject to frequent breakdown of pumps. All the boreholes are manual, hence the deeper they are the more labour required to pump the water.

Apart from the tea estates located between Fort Portal and the Kibale forest, agriculture in the Mpanga sub-catchment is mainly rainfed subsistence farming. The main crops grown are bananas, vegetables, as well as cereals (maize, millet, sorghum). A few perennial cash crops such as coffee and fruit trees are also grown in some parts (upper part of Mpanga sub-catchment, between Kibale forest and Kamwenge) (BRL ingénierie, 2015. This part of western Uganda generally benefits from elevated and balanced rainfall throughout the year, strongly limiting the need for irrigation in the agriculture sector.

Cattle farming is another source of demand for water, which also has consequences for the environmental quality of the river with impacts on the river banks and river water quality as cattle frequently benefit from free access to rivers.

BRL ingénierie (2015) estimated current water demand at 9,870m^3/day for Mpanga and 13,191m^3/day for Rushango.

The data on availability of water in the River Mpanga catchment were reviewed by BRL ingénerie (2015). The main findings were:

i. That the availability of data on flows in the River Mpanga were limited due to problems with gauging stations. At the time of the BRL ingénierie study, none of the gauging stations were functioning correctly;
ii. Estimates for two stations give a reasonably long time series (Kampala-Fort Portal road and Fort Portal-Ibanda road), but data since 2011 is unreliable for the former and not available from 2012 for the latter – due to the impact of road works on the gauging stations;
iii. Estimates for the Rushango River are only available for a few years and with no common period with the other stations – hence estimates for the Rushango subcatchment are subject to significant uncertainty.

There is a clear need to enable effective monitoring and analysis of river flows in the Mpanga region.

3.2. Energy supply in the Mpanga catchment

The Africa EMS Mpanga Hydro Power Station operating since 2011 is located on River Mpanga downstream of the confluence with Rushango, about 8 km upstream of its outlet in Lake George. The plant has a maximum capacity of 18MW. The Electricity Regulatory Authority (ERA) in Kampala has estimates of the lost load since 2011 (Table 1). The time loadshed shows the duration of outages, energy lost reflects the extent of the losses in MWh and the value reflects the value of the electricity lost. This shows that lost load at the plant is highly variable – but that performance in 2014 was better than in previous years.

The operations manager is concerned with the encroachment of farmers on the river banks (deforestation, cattle rearing) and related high levels of erosion and would support a joint agreement on water uses for the whole Mpanga river catchment, as lower water levels have a direct impact on the company's revenues and return on investment.

Table 1: Lost load at AEMS-Mpanga hydroelectric plant 2011-2014

AEMS-MPANGA				
Year	Quarter	Time loadshed (hrs)	Energy lost (MWh)	Value lost (UGX Mill)
2014	Q4	5	162	17
2014	Q3	6	292	19
2014	Q2	6	28	19
2014	Q1	-	50	-
2013	Q4	41	807	365
2013	Q3	71	70	698
2013	Q2	65	73	969
2013	Q1	20	420	-
2012	Q4	26	1,843	-
2012	Q3	89	210	-
2012	Q2	146	115	-
2012	Q1	-	-	-
2011	Q4	177	1,979	482
2011	Q3	177	850	191
2011	Q2	154	2,549	552
2011	Q1	129	479	101

Source: ERA, 2015

4. CLIMATE CHANGE AND THE MPANGA CATCHMENT

4.1. Climate Change Scenarios

4.1.1. Mpanga South Domain

Figure 4 depicts the historically observed monthly rainfall totals (in blue) in relation to the future projections (orange), as calculated for the Mpanga-south domain for RCP4.5 (left) and RCP8.5 (right) - developed as part of this study.

Figure 4: Historic and Future Projected Rainfall under different climate change scenarios for the Mpanga South region

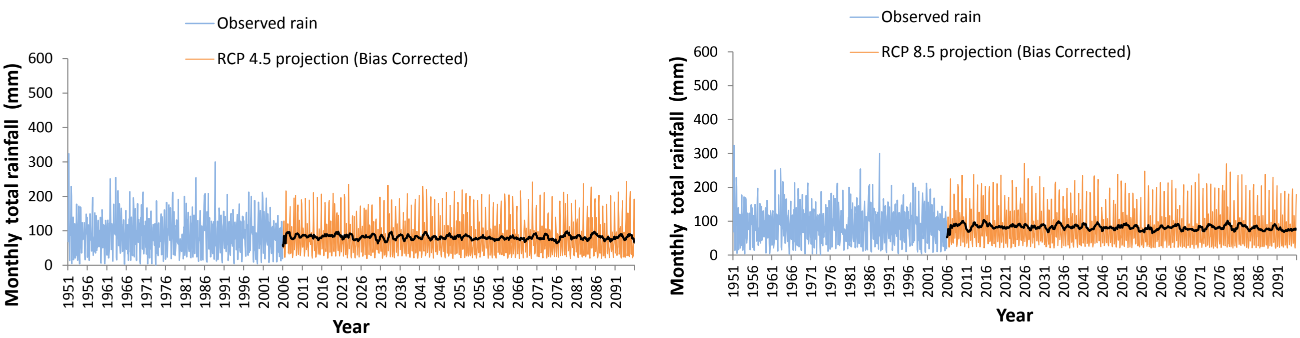
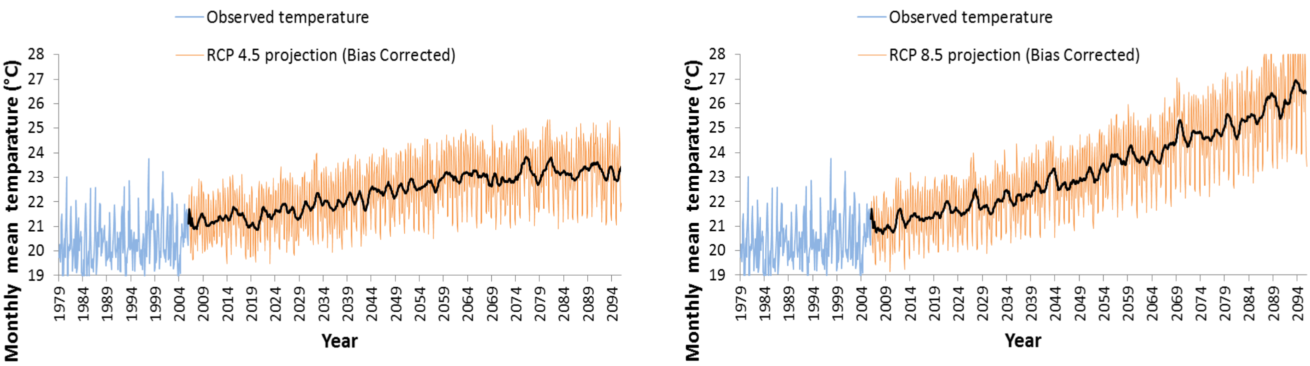


Figure 5 depicts historically observed monthly near surface temperature averages (blue) in relation to the future projections (orange) for two climate change scenarios - RCP 4.5 and RCP8.5. It can be seen that temperature is likely to increase far more rapidly under RCP 8.5.

Figure 5: Observed and Projected Near Surface Temperatures in Mpanga South under different climate change scenarios



4.1.2. Mpanga-North Domain

As above, Figure 6 depicts observed monthly rainfall totals (blue) in relation to the future projections (right, orange) as calculated for the Mpanga-north domain.

Figure 6: Historic and Future Projected Rainfall under different climate change scenarios in Mpanga North, with bias correction

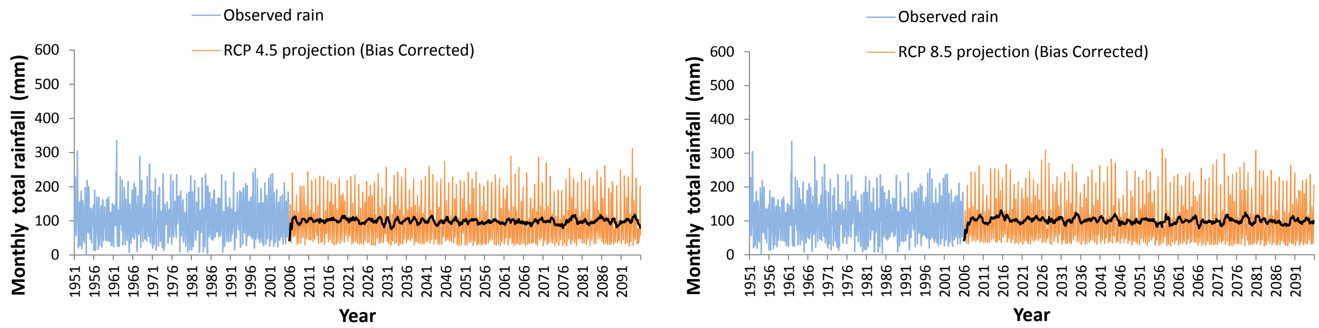


Figure 7 depicts historically observed monthly near surface temperature averages (blue) in relation to the future projections (right, orange). In both figures significant changes in temperatures can be seen, though they are more pronounced under RCP 8.5.

Figure 7: Historic and Projected Near Surface Temperatures in Mpanga North under different climate change scenarios, with bias correction

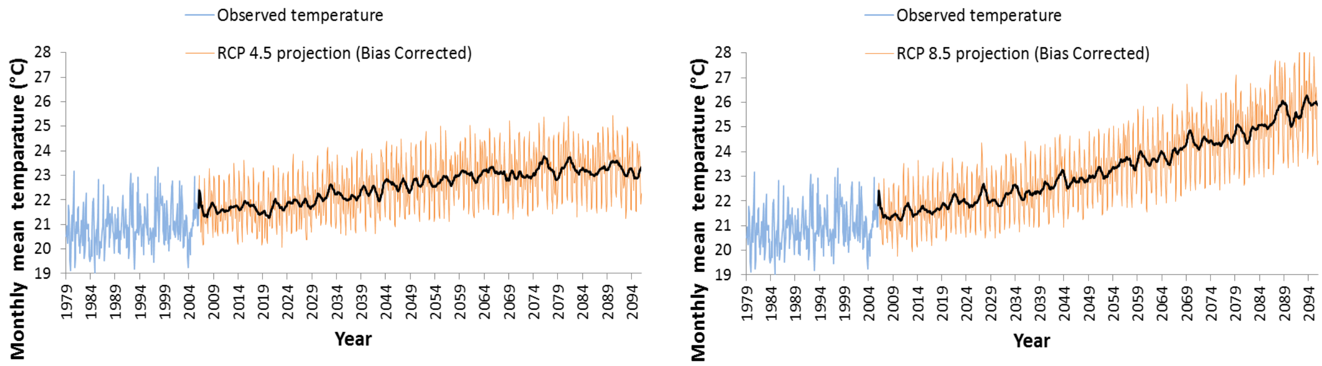


Table 2 summarises the 20-year averaged bias corrected projections of annual rainfall totals and near-surface temperatures across the Mpanga-south and Mpanga-north District domains under RCP 4.5 and RCP 8.5 conditions. Rainfall declines to 2060, then rises slightly under both scenarios. Temperature increases across the period. Interestingly rainfall declines more under RCP 4.5 than RCP 8.5, whereas temperature increases more under RCP 8.5.

Table 2.Average monthly projections of annual rainfall totals and near-surface temperatures across the Mpanga-south (top) and Mpanga-north (bottom) District domains under RCP 4.5 and RCP 8.5 conditions. 20 year averages.

Mpanga-south		≈1995 (1985-2005) current	≈2020 (2010-2030)	≈2040 (2030-2050)	≈2060 (2050-2070)	≈2080 (2070-2090)
RCP 4.5	Rainfall (mm)	87.7	83.4	81.5	79.4	80.7
	Temperature (ºC)	20.4	21.4	22.1	22.8	23.1
RCP 8.5	Rainfall (mm)	87.7	84.6	83.1	79.7	81.2
	Temperature (ºC)	20.4	21.5	22.4	23.8	25.1

Mpanga-north		≈1995 (1985-2005) current	≈2020 (2010-2030)	≈2040 (2030-2050)	≈2060 (2050-2070)	≈2080 (2070-2090)
RCP 4.5	Rainfall (mm)	107.2	101.8	98.9	97.6	98.1
	Temperature (ºC)	20.9	21.7	22.3	22.9	23.2
RCP 8.5	Rainfall (mm)	107.2	104.2	101.6	98.8	100.0
	Temperature (ºC)	20.9	21.8	22.5	23.7	24.8

4.2. Climate change scenarios in other studies

BRL ingénierie (2015) uses a range of climate change scenarios, including the one mentioned above for RCP 4.5, to derive future possible scenarios for the Mpanga River Basin. A summary of the scenarios used and the models in question is given in Table 3. Table 4 gives an overview of the findings of the modelling under these different scenarios for the Mpanga region for rainfall. It can be seen that the change in rainfall varies from 0% to -8% annually, which is relatively modest. For temperature, BRL ingénierie (2015) uses the temperature trends as shown in Table 5. From these scenarios BRL ingénierie develops "optimistic" and "pessimistic" composite climate change scenarios. We apply the same scenarios in this case-study – noting that the RCP 4.5 scenario is towards the "pessimistic" end of these for most months.

Table 3: Concentrations Scenarios used in BRL ingénierie study

Name given	Source of data	Emission scenario considered	Global circulation model	Reference used for downscaling / bias correction
RCP 4.5	Baastel study	RCP 4.5	Ensemble mean of 4 different GCM	GPCC
A1b-ECHAM	NELSAB/NBI study	A1b	ECHAM5[10]	
A2-ECHAM		A2		
B1-ECHAM		B1		
A1b-HadCM3		A1b	HadCM3[11]	
A2-HadCM3		A2		
B1-HadCM3		B1		

Source: BRL ingénierie (2015)

Table 4: Evolution of Rainfall under different climate change scenarios

	Mpanga basin												
	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Annual**
RCP 4.5	-24%	-24%	-30%	-29%	-1%	-15%	-21%	-35%	-23%	15%	36%	24%	-7%
A1b-ECHAM	-4%	-7%	-8%	-16%	-17%	-36%	-4%	-18%	-23%	-4%	12%	23%	-8%
A1b-HadCM3	9%	37%	12%	-14%	-12%	-48%	-15%	-10%	-7%	8%	-5%	8%	-2%
A2-ECHAM	3%	10%	-2%	-12%	-13%	-30%	2%	-14%	-17%	0%	5%	10%	-5%
A2-HadCM3	16%	12%	28%	-13%	-8%	-27%	-4%	2%	-4%	5%	-5%	-6%	0%
B1-ECHAM	11%	8%	-9%	-17%	-9%	-33%	-11%	-19%	-16%	-3%	2%	37%	-5%
B1-HadCM3	33%	2%	13%	-5%	1%	-48%	-13%	9%	-12%	6%	-9%	-2%	-1%
Average of all scenario	**6%**	**5%**	**1%**	**-15%**	**-9%**	**-34%**	**-9%**	**-12%**	**-15%**	**4%**	**5%**	**13%**	**-4%**
Range	-24% to +33%	-24% to +37%	-30% to +28%	-29% to 5%	-17% to +1%	-48% to 15%	-21% tp 2%	-35% to +9%	-23% to 4%	-4% to +15%	-9% to +36%	-6% to +37%	-8% to 0%

Source: BRL ingénierie (2015)

Table 5: Future temperature increases n the Nile Equatorial Lake area, as used in BRL ingénierie (2015)

Months	Scenario 1	Scenario 2
December-January-February (DJF)	2.5	4.1
March-April-May (MAM)	3.1	4.9
June-July-August (JJA)	3.5	5.8
September-October-November (SON)	2.8	4.5
Annual	**3**	**4.8**

This section has shown that the climate in the Mpanga River Basin is likely to experience higher temperatures in the future, with rises of average annual temperatures between 3 and 4.8 degrees Celsius depending on the scenario. The picture for rainfall is rather mixed depending on the scenario. In the following sections, we build on this analysis to assess the likely impacts on the water and energy sectors, noting this uncertainty.

[10] ECHAM5 is the 5th generation of the ECHAM general circulation model developed at the Max Planck Institute for Meteorology in Hamburg evolving originally from the spectral weather prediction model of the European Centre for Medium Range Weather Forecasts (ECMWF) - http://www.mpimet.mpg.de/en/wissenschaft/modelle/echam.html

[11] HadCM3 is a Met Office climate prediction model that has been used extensively for climate prediction, detection and attribution, and other climate sensitivity studies. HadCM3 stands for the Hadley Centre Coupled Model version 3. HadCM3 was one of the major models used in the IPCC Third and Fourth Assessments, and also contributed to the Fifth Assessment. http://www.metoffice.gov.uk/research/modelling-systems/unified-model/climate-models/hadcm3

5. Water

5.1. Future demand for water in Mpanga River Catchment

Future water demand by **domestic consumers** and by institutions was estimated in the BRL ingénierie study (2015). Demand for water is likely to increase, with population growth being a significant driver. The estimated water demand projections for Mpanga and Rushango are given in Table 6.

Table 6: Water demand projection (m³/day)

		2015	2020	2025	2030	2035
Mpanga	Domestic water demand	4,685	5,734	6,970	8,417	10,098
	Water demand for institution	982	1,014	1,045	1,076	1,108
	Total	**5,667**	**6,748**	**8,015**	**9,493**	**11,206**
Rushango	Domestic water demand	11,943	14,616	17,767	21,455	25,742
	Water demand for institution	976	1,007	1,036	1,067	976
	Total	**12,919**	**15,623**	**18,803**	**22,522**	**26,718**

Source: BRL ingénierie (2015) based on "Consultancy services to determine and map water use and demands in Lake George, Lake Edward and Kafu basin" Draft Report, December 2014.

Demand for water for irrigation purposes is likely to increase in future as well. BRL ingénierie (2015) presents potential irrigable areas in different regions and the quantity of water needed for irrigation to meet these needs (Table 7).

Table 7: Potential irrigation water demand per subcatchment

	Potentially irrigable area (ha)	Potential amount of water needed for irrigation (m3/day)
Upper Mpanga	56	1,543
Middle Mpanga	824	22,562
Lower Mpanga	23	629
Rushango	944	25,861

Source: BRL ingénierie (2015)

Demands by industry and mining and mineral extraction sectors were also estimated in the same study. It can be seen that demand by the commercial sector is expected to increase greatly by 2035. However caution should be expressed in terms of these estimates as they simply take a multiplier of domestic demand for industrial demand – which results in industrial demands being equivalent to domestic demand by 2035. This may under or overestimate demand for industry, which is at quite low levels currently.

Table 8: Commercial sector demands

Area	Sector	2015	2020	2025	2030	2035
Mpanga	Industrial water demand	1406	2294	4182	6733	10098
	Mining and minerals extraction	703	1147	1742	2525	3534
	Commercial Total	**2109**	**3441**	**5924**	**9258**	**13632**
Rushango	Industrial water demand	3583	5846	10660	17164	25742
	Mining and minerals extraction	1792	2923	4442	6436	9010
	Commercial Total	**5375**	**8769**	**15102**	**23600**	**34742**

Source: BRL ingénierie (2015)

BRL ingénierie (2015) also quantified the **water demand for livestock** based on water consumption estimates by different types of livestock and projected populations (Table 9). Livestock demand is anticipated to increase significantly in both Mpanga and Rushango.

Table 9: Water demand for Livestock (2015-2035 projections)

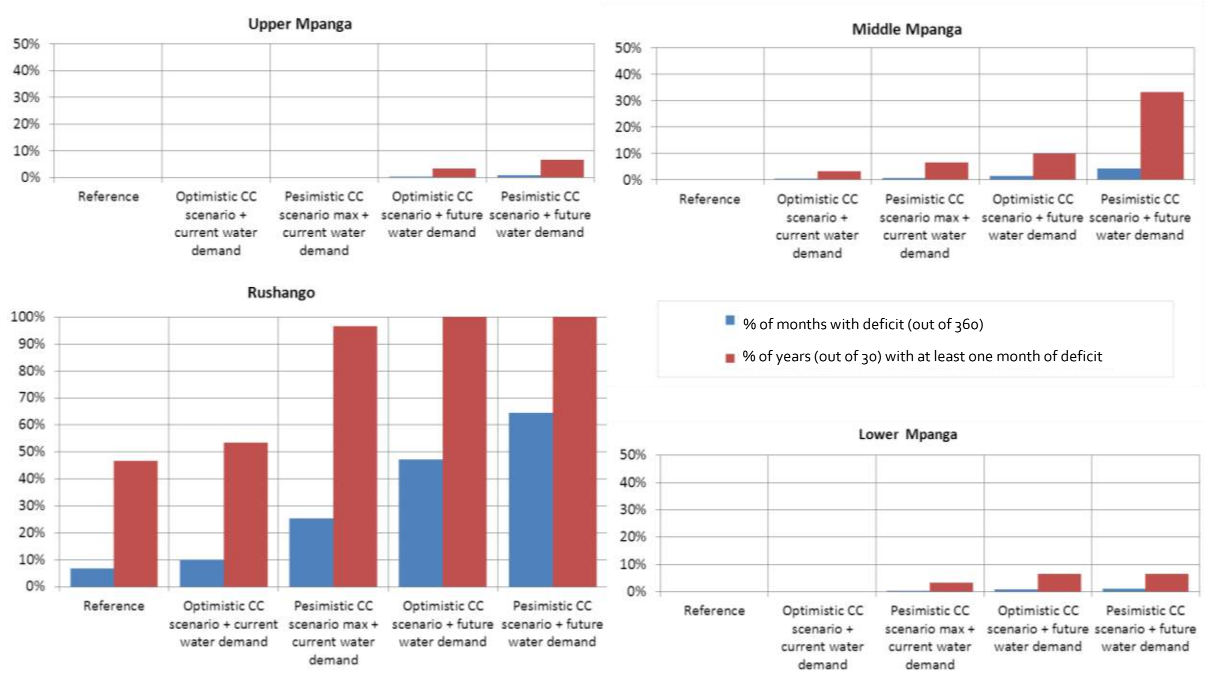
M3/day	2015	2020	2025	2030	2035
Mpanga	9,870	10,849	11,857	12,446	13,064
Rushango	13,191	14,479	15,875	16,653	17,470

Source: BRL ingénierie (2015) based on "Consultancy services to determine and map water use and demands in Lake George, Lake Edward and Kafu basin" draft report, December 2014.

5.2. Impacts of climate change on water supply and demand in the Mpanga River catchment

The estimated impact of climate change on the frequency of deficits was estimated by BRL ingénierie (2015), taking into account both climate change and future water demand scenarios. The results are shown in Figure 8. This shows that for the Upper and Lower Mpanga areas even under the most pessimistic climate change scenarios there is likely to be very little unmet demand. However, for Middle Mpanga there is likely to be more months with water deficits (less than 5% of months will experience deficits), with just over 30% of years having one month of deficit. In Rushango there are more significant impacts. In this area, under all climate change scenarios there is likely to be more significant impact – with every year experiencing one month of shortage under future demand scenarios.

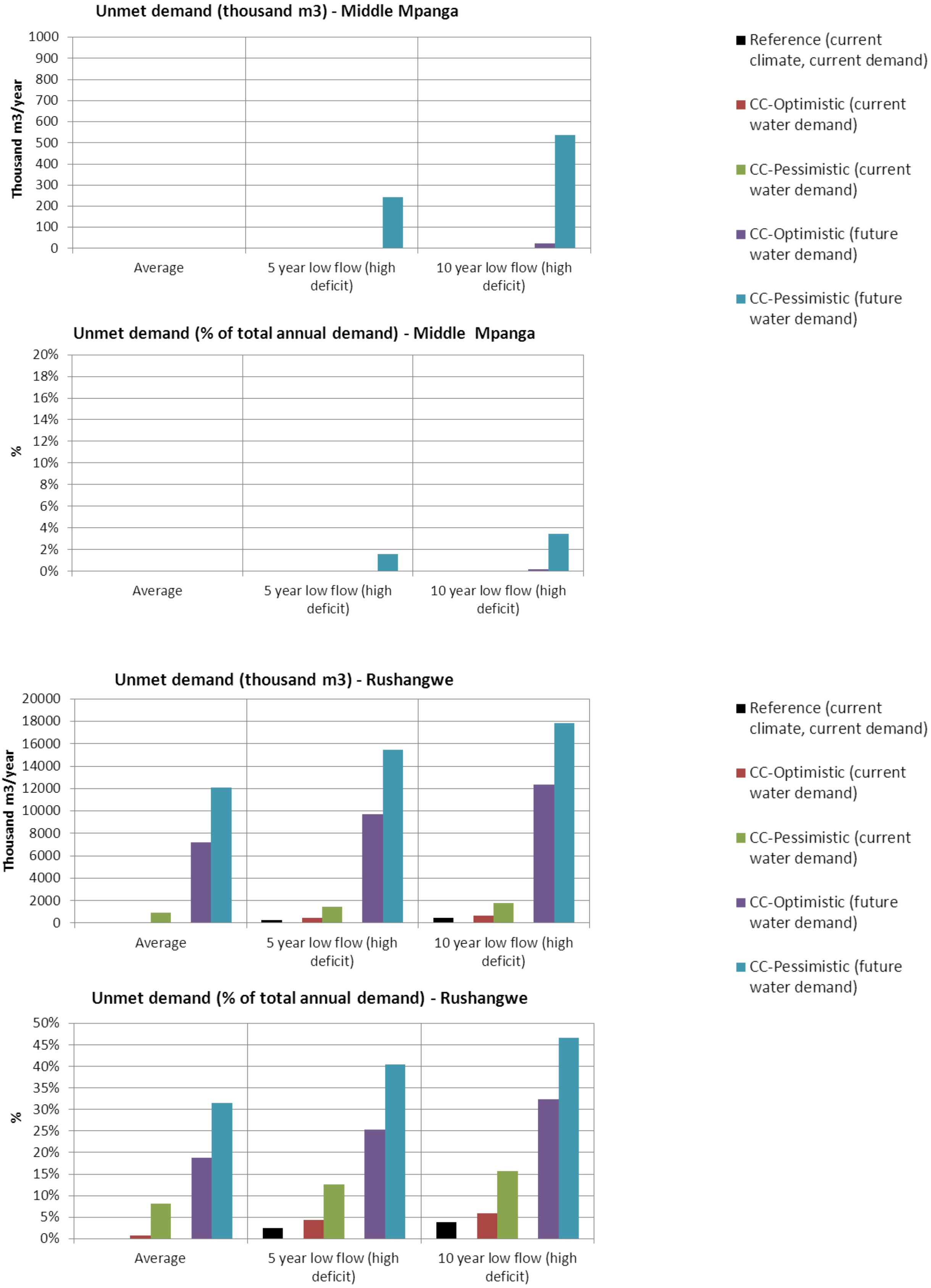
Figure 8: Frequency of deficits (water demand>water resources) under different climate and water demand scenarios



Source: BRL ingénierie, 2015)

The unmet demand under the different scenarios is shown for Middle Mpanga and Rushango in Figure 9. This shows that the impacts are rather limited in Middle Mpanga– with only a few of the scenarios having any unmet demand at all. For Middle Mpanga there is very little unmet demand during an average year; though under the most pessimistic climate scenario there are unmet demands - of just over 200 thousand cubic metres of water under a 5 year low flow event and just over 500 thousand cubic metres of water under a 10 year low flow event. For Rushango, the picture is starker. Average annual unmet demand in Rushango is between 7 million cubic metres of water and 12 million cubic metres of water depending on the climate scenario considered. Under a 10 year low flow event the unmet demand ranges from 12 million to just under 18 million metres of water depending on the climate scenario when future demand is taken into account. We note that here the scenarios being used differ slightly from those used elsewhere in the Baastel study (e.g. Baastel Consortium, 2015a,b) – the findings of RCP 4.5 are more towards the pessimistic outcomes identified above. As we note elsewhere, the approach taken by BRL Ingénierie (2015) is based on an "ensembles" type analysis, which may be considered more robust than estimates from any one modelling framework. The "ensembles" type modelling was not available at regional level for the other case studies. Further work on downscaling using "ensembles" type analysis is needed in Uganda to allow for further sensitivity testing on the basis of model uncertainty.

Figure 9: Unmet demand for different subcatchments under different climate change scenarios



Source: BRL ingénierie, 2015

5.3. Economic valuation of impacts

To evaluate the costs of the impacts of climate change, we first need to assess how different user groups are likely to be impacted. From the above one can see that shortages occur over 7.4 months, but we do not know the distribution of losses over the different months. We have therefore estimated losses by assuming that shortages occurred equally over the period of shortage. This is very much a simplifying assumption. In reality, certain months may be more impacted by shortage than others. If this is the case, then shortages will be more acute and more likely to impact on user groups higher up the priority list and have higher associated economic costs.

For the valuation of water supply shortages we draw on the review of literature conducted as part of the water sector study of the national-level economic assessment (Baastel consortium, 2015). Table 10 presents an overview of the estimates from existing studies of willingness to pay by different users. These studies used contingent valuation, a survey based method that is commonly used – essentially respondents are asked questions regarding their water use, socioeconomic characteristics and their willingness to pay for water resources (e.g. they may be asked "Are you willing to pay X shillings for a jerrican of water?"). Statistical analysis tests the validity of responses.

Table 10: Unit value estimates for water

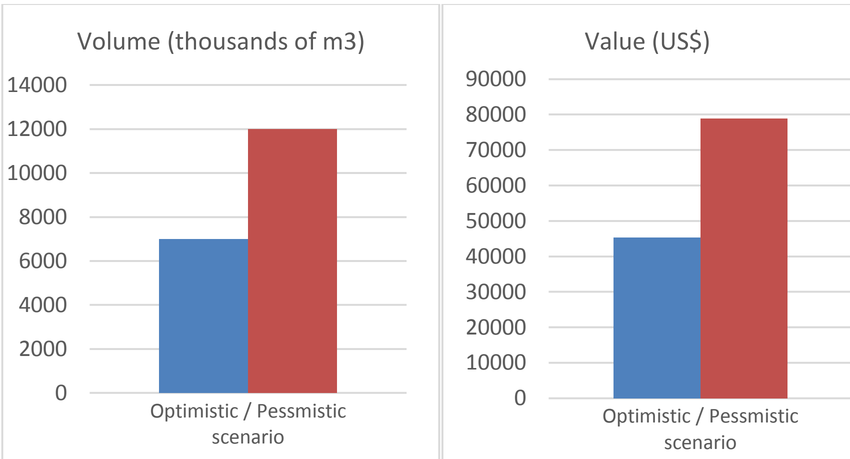
User category	Willingness to pay (shillings/litre, 2013 prices)	Source
Urban domestic	17.97	Based on Whittington et al (1998), updated for inflation
Rural domestic	15.08	Based on Wright (2012), updated for inflation
Industry	17.18	Based on Davis et al (2001), updated for inflation
Irrigation	15.15	Based on Angella et al (2014), updated for inflation
Livestock	15.15	Used same value as for irrigation

We hence estimated the annual average losses for Rushango as shown in Table 11. This shows the sectors (or user groups) impacted under the different scenarios and the values. Annual average losses by 2035 may be between 114 million shillings and 198 million shillings (US$45,400 to US$78,900). Similar estimates are not possible for Middle Mpanga as there is no unmet demand in an average year under any scenario.

Table 11: Unmet demand by sector and value in Rushango – average year with 2035 demand, current prices, no discounting[12]

	Volume (thousand m^3)		Value (UGX millions)	
Sector	Optimistic climate change scenario (future water demand)	Pessimistic climate change Scenario (future water demand)	Optimistic climate change scenario (future water demand)	Pessimistic Climate Change Scenario (future water demand)
Domestic	0	0	0	0
Institutions	0	0	0	0
Industrial water demand	2554	5794	44	100
Mining and mineral extraction	1513	2028	26	35
Irrigation	0	246	0	4
Livestock	2933	3932	44	60
Total	**7000**	**12000**	**114**	**198**

Figure 10.Unmet demand estimated in volume and value in Rushango – average year with 2035 demand, current prices, no discounting



For sensitivity, we tested for the effect of income elasticity of willingness to pay based on the shared socioeconomic pathway scenarios (SSPs[13]) for per capita GDP. Future incomes in Uganda will rise. The question of the extent to which this will lead to increases in willingness to pay is uncertain. We do not know well how willingness to pay varies across time. Studies are just starting to emerge on transfer of values from old studies to the current period, so it is hard to assess what the likely value would be. What we can do is use the same approach as we use for transferring values from different contexts, adjust for likely income changes and relate

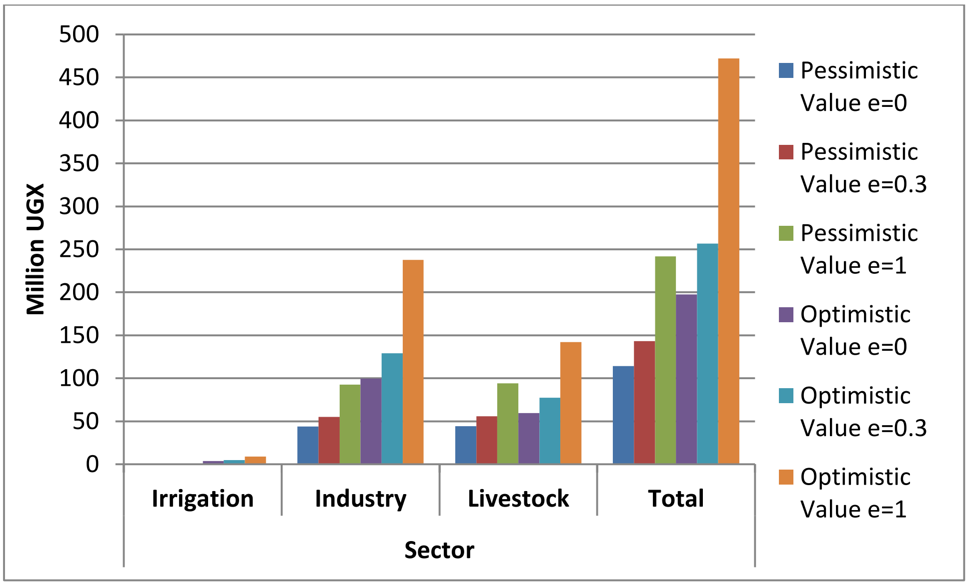
[12] Discounting is not included here as it could lead to confusion as to the future value – this is the value as in 2035 with current prices. Discounting would be needed in assessing the relative costs and benefits of policies over time.
[13] Narratives of SSP1 and SSP2 on the IASA website (http://www.iiasa.ac.at) are:
SSP1 (Sustainability). A world making relatively good progress toward sustainability, with ongoing efforts to achieve development goals while reducing resource intensity and fossil fuel dependency. It is an environmentally aware world with rapid technology development, and strong economic growth, even in low-income countries.
SSP5 (Conventional Development). A world in which conventional development oriented toward economic growth as the solution to social and economic problems. Rapid conventional development leads to an energy system dominated by fossil fuels, resulting in high greenhouse gas emissions and challenges to mitigation.

that to willingness to pay using the "income elasticity of willingness to pay" for different potential values. Table 12 shows testing for e=0 (i.e. no change in willingness to pay with income), e=0.3 (a 1% increase in income leads to a 0.3% increase in willingness to pay) and e=1 (a 1% increase in income leads to a 1% increase in willingness to pay). Adjusting for differences in incomes under the shared socioeconomic pathways, we related the pessimistic scenario with SSP5, and the optimistic scenario with SSP1. This leads to the results as shown in Table 12. It can be seen that the cost could be as high as 472 million shillings (US$188,000) in 2035 under the most pessimistic climate change scenario in the case where willingness to pay is most sensitive to income (e=1). The table shows how assumptions on the responsiveness of willingness to pay to income affects the value placed on water shortages to different user groups or sectors. For instance, under the optimistic scenario the shortage of 2.5 million litres of water in the industry sector is valued at between 44 million shillings and 92.8 million shillings depending on the assumptions. The results are also shown in Figure 11.

Table 12: Sensitivity analysis – including income elasticity of willingness to pay under different climate and socioeconomic scenarios

	Optimistic = SSP1				Pessimistic = SSP5			
Annual losses	Volume - shortage	Value (million UGX)			Volume - shortage	Value (million UGX)		
	thousand m^3	e=0	e=0.3	e=1	thousand m^3	e=0	e=0.3	e=1
Irrigation	-	-	-	-	245.70	3.7	4.8	8.9
Industry	2,554.01	44	54.94	92.79	5,794.10	99.6	129.3	237.7
Mining	1,512.78	26	32.54	54.96	2,028.00	34.9	45.2	83.2
Livestock	2,933.21	44	55.64	93.97	3,932.21	59.6	77.4	142.2
Total	**7,000.00**	**114**	**143.12**	**241.72**	**12,000.00**	**197.7**	**256.7**	**472.0**

Figure 11: Sensitivity analysis: Damages by scenario and income elasticity by user group



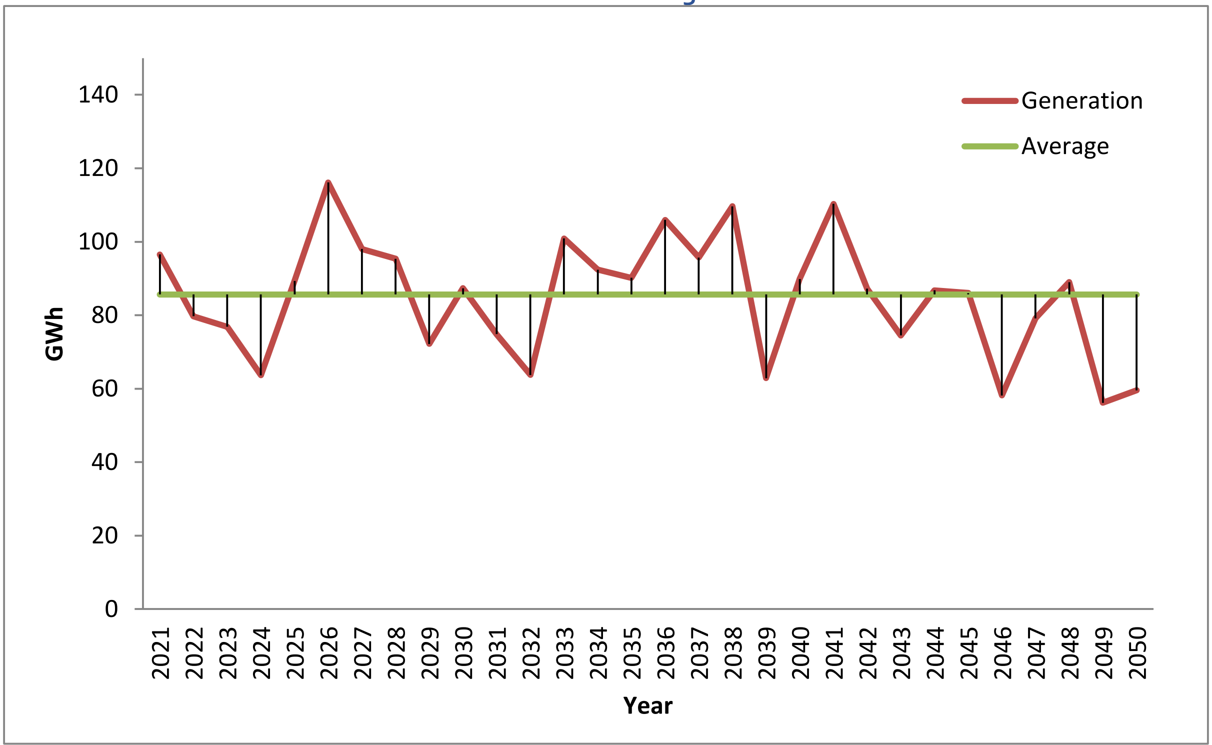
This section has shown there are potential costs of unmet demand for water. The scale is perhaps not as significant in other sectors, in part because of the availability of water in the basin at present and because these costs reflect the costs in Rushango. **We have not been able to assess the costs of extreme events such as drought due to a lack of available data on such events. These costs may be significant.** The next section investigates the case for the energy sector.

6. ENERGY

6.1. Impacts of climate change on energy production

Based on the estimated river flow at the site of the AEMS-Mpanga hydro power plant (under the pessimistic climate change scenario and with future water demand), we are able to model the expected future energy production (Figure 12). It can be seen that the estimated energy generated per year will be about 88.4 GWh in the longer term (average green line, to compare to the average 82.1 GWh over the period 2011-2013[14]). From 2041, estimates show a likely gradual reduction in river flow rates, with a consequent reduction in the level of energy generated. The estimated reduction would be about 115 GWh over the last 5 years of the period considered (2046 – 2050). Estimated generation will be 442 GWh over the same period. The estimated loss is about 115 GWh and represents about 26% of average production. The likely margin of error is about ±4%.

Figure 12: Modelled energy generation at the AEMS-Mpanga hydro power plant in future years – Pessimistic Climate Change Scenario



[14] This average hides a growing capacity over that period since the plant started in 2011 (production sold 65.1 GWh), and increased progressively to 78.8 GWh in 2012 and 102.4 GWh in 2013)

6.2. Economic Valuation

To value the lost load, we have to make a number of assumptions. First, we assume no spare capacity in the system – i.e. that the losses identified in the section above cannot be covered by bringing online alternative sources. This implicitly assumes that demand equals supply, as Uganda develops over the next 30 years there is likely to be increasing demand for energy putting pressure on the system, but there are likely to be increases in generation capacity as well, so this is a simplifying assumption.

Oseni and Pellit (2013) provide estimates of the economic costs of unsupplied electricity in a range of African countries, based on a 2007 survey of 6,854 firms in 12 African states. This study calculated losses using three methods – the marginal cost, incomplete back-up and subjective evaluation techniques. The marginal cost method looks at the cost of investments in own generation by energy users (e.g. spending on back-up generators); the incomplete back-up method considers potential losses a firm may suffer as a result of incomplete back-up (i.e. considering investment in own generation and losses due to failure to cover all of the load lost); and the subjective evaluation involves surveys of firms as to their actual losses.

In the context of the current study, we take the estimates for Kenya based on both the incomplete back-up and subjective evaluation techniques to give an estimate of the cost of lost electricity in the Mpanga region. We adjust for a number of factors – including per capita GDP, income elasticity of willingness to pay, exchange rates and inflation. We choose a broad range of income elasticities from 0.3 to 1, to show how sensitive the values can be to this assumption – a recent review of energy demand elasticities suggests the value is broadly in this range (Charap et al, 2013). This leads to an estimate of the costs of between 2,728 shillings to 4,609 shillings per kWh under the incomplete back-up method (US$1.09-US$1.84) and 6,349 shillings to 10,730 shillings (US$2.53-US$4.27) per kWh under the subjective evaluation method. Using these methods, we can estimate the losses annually in the period to 2035 of between 62,733 to 246,795 million shillings (approx. US$25 million to US$98 million).

Table 13: Estimated Annual Losses due to Energy Shortages (Uganda shillings, million, 2013 prices)

	Income elasticity	
	0.3	1
Incomplete back-up method	106,022	62,733
Subjective evaluation	246,795	146,029

Therefore significant losses in electricity generation are to be expected in the next 30 years, as a direct consequence of the gradual reduction in river flow rates. This will not only impact the dam operator, but also the overall electricity supply of the Ugandan people as this dam is connected to the national power grid. The next section identifies and assesses the costs and benefits of a number of adaptation actions and strategies that are likely to mitigate the impacts of climate change.

7. IDENTIFICATION OF ADAPTATION OPTIONS

7.1. Identification of adaptation options: lessons from previous studies

The previous studies on climate change adaptation in East Africa have identified a number of options for adaptation to climate change in the water and energy sectors. A review of the previous studies was conducted as part of the current study – see Baastel Consortium (2014). Measures identified in the previous studies in Kenya, Rwanda, Tanzania and Burundi included those on the demand side and supply side and institutional measures.

Demand side management

- Water/energy pricing;
- Permits for abstraction for irrigation;
- Permits for abstraction for other purposes;
- Leak/loss reduction;
- Energy efficiency programmes – including adoption of biomass energy efficient stoves;
- Improved regulation/control of illegal connections.

Supply side

- Increased storage or supply capacity through improved infrastructure;
- Promotion of good agricultural practices and soil conservation;
- Development of new energy plants and alternative sources (e.g. wind, solar, geothermal);
- Rural areas: Development of groundwater wells;
- Rural areas: Shifting from surface water to deep borewells;
- Increase in rainwater harvesting structures.

Institutional

- Catchment management planning;
- Land use planning (e.g. afforestation/reforestation).

7.2. Identification of adaptation options: national policy

Options for adapting to the effects of climate change for both water and energy supply were discussed in the sectoral reports realised at the national level in this Economic Assessment study. For the case of the water sector, the Sectoral Study reviewed the National Climate Change Policy Costed Implementation Strategy of the Government of Uganda. This identified eight programs to address water problems in the next 15 years (i.e. to about 2030). These have a total cost of US$203 million, with US$36 million in the short term (1-5 years), US$67 million in the medium term (6-10 years) and US$99 million in the long term (10-15 years). The following were given particular attention in the water sectoral study:

A. Promote and encourage water harvesting and efficient water utilisation among individuals, households, institutions and sectors (US$11.8 million over the next 15 years).
B. Ensure availability of water for production in water dependent sectors in order to increase their resilience to climate change impacts (US$69.5 million over the next 15 years).
C. Promote integrated Water Resources Management (including underground water resources) including contingency planning for extreme events such as floods and droughts (US$105.9 million over the next 15 years).

Table 14 reproduces the costings for the different relevant national level strategies for energy in the period 2015 to 2030. It is particularly worth noting that these would all directly or indirectly impact on the case of the hydroelectric dam in the Mpanga River, with some having more impact than others. Actions to reduce biomass demand, for instance, will improve the quality of water in the river. Measures to reduce energy consumption would reduce the losses due to climate change in the energy sector in the Mpanga River Basin. Direct measures including actions to promote efficient management of resources – particularly by those sectors with significant consumption - will likely reduce the impact of the lost load.

Table 14: National Level Policy Interventions for Energy Sector

	Intervention	Outcome	Additional Cost (US$m)	Timing and Critical Decisions	Comment
1	Promote and participate in water resource regulation so as to ensure the availability of water for hydropower production	Better management and protection of water resources for hydropower	54.0	Short term priority that needs urgent action	Not evaluated quantitatively except to note that current power shortages indicate the seriousness of the problem
2	Promote and participate in water catchment protection as part of hydroelectric power infrastructure development	Protection of water resources should make more available for hydropower	60.3	Start now but has a longer term horizon with major outlays after 2020.	The problem of power deficits is noted and this will contribute over the medium term
3	Diversify energy sources by promoting the use of alternative renewable energy sources (such as solar, biomass, mini-hydro, geothermal and wind) that are less sensitive to climate change	Ensures that power generation is not so affected by reductions in hydropower	74.0	Medium to long term strategy.	Present projections for hydro are uncertain so it is desirable to keep options open for more information (see Item 5). Some renewables are cost effective and should be developed right away
4	Promote energy-efficient firewood cook stoves, solar and liquefied petroleum gas (LPG) cookers	Reduced demand for biomass	128.2	Programme is absolutely critical and needs highest priority. Needs to be coordinated with item 8.	Efficiency increases in use of wood fuel are critical even without climate change and more so with it. If well implemented benefits will be very high relative to costs but problems arise with take up
5	Conduct research to determine the potential impacts of climate change elements on the country's power supply chain	Makes planning for future energy supply more effective	71.8	Programme is a high priority	This is a key requirement, given the lack of knowledge and the importance of information on likely future impacts on supply of energy

	Intervention	Outcome	Additional Cost (US$m)	Timing and Critical Decisions	Comment
6	Promote the development of energy conservation and efficiency projects in all sectors; for example, to promote the use of stabilised bricks and efficient brick kilns in the building sector	Decreased demand for biomass	29.2	Program justified under present conditions and should be a high priority	Efficiency increases in use of wood fuel are critical even without climate change and more so with it. If well implemented benefits will be very high relative to costs
7	Enforce building codes to reduce energy consumption	Reduced consumption of energy	71.8	Effects will take time to be realised but needs to start now	In other countries enforcement of building codes is a cost effective way to reduce energy use if implementation can be assured (Markandya et al., 2014)
8	Promote the use of energy-efficient technologies such as compact fluorescent and other high energy lamps	Reduced consumption of energy	1.9	Program justified at present and can be promoted	Benefits of adopted are high relative to costs but the problem here is take up. Some programs make little impact on this and others involving subsidies are not cost-effective. Care needs to be taken in selecting the right promotional measures
9	Promote efficient firewood/charcoal stoves and solar and LPG cookers, and address the high upfront costs of acquiring these technologies through household subsidies or tax waivers	Reduced demand for biomass	5.3	Needs to be coordinated with item 4 as a high priority item	Success depends on high take up rates at modest subsidy payments

Source: Government of Uganda, 2012, Own Calculations

7.3. Identification of adaptation options: local stakeholders

Interviews with local stakeholders identified a range of adaptation options for water and energy. These were conducted by the study team using an interview guide. Local stakeholders were identified in part through contact at a workshop as part of the BRL ingénierie study where the case-study's scope and objectives have been presented by our local team. The list of people interviewed is given in Appendix 1.

The key adaptation options identified by stakeholders are summarised in Table 15.

Table 15: Selected Adaptation Options identified by Local Stakeholders

Adaptation option	Description
Awareness raising of climate change and appropriate management of the river.	The majority of the district officials identified the potential use of mass media to sensitize the public to climate change and adaptation needs. Important to take a community approach. Education on appropriate removal of stone and sand from the river.
Tree planting	Almost all the respondents identified tree planting as an adaptation option. Kabarole district council recently passed a resolution to plant trees on hills. The district has promised to provide seedlings to those who want to plant the trees. TAMTECO tea company grows a lot of eucalyptus trees extensively, some of which are used as fuel wood.
Planning – enforcement of restriction on building within 100 metres of the river bank	The majority of district officials identified enforcement of planning as an option. Appropriate enforcement action of existing regulations. Recruitment of more Community Development Officers.
Wetland preservation	Over half the respondents mentioned the discouraging of encroachment on the wetlands, including restoration orders and warnings. In December 2014, the Kabarole district forest officer issued a radio warning to encourage preservation of natural resources especially the protection of trees.
River management	Over half the respondents identified the need to clean the river regularly, including maintenance of river banks and removal of rubbish.
Improve farming management	About 30% of respondents mentioned the need to encourage farmers to use modern farming methods. Encourage small scale irrigation for drought prone areas.
Improved coordination between concerned parties	Over half the respondents called for improved coordination. This would involve engagement at all levels – local leaders, village committees, Ministry of Water and Environment/AMZ and NEMA need to be strong and clear.
Increased rainwater harvesting	Over half the respondents mentioned the potential to construct rainwater harvesting tanks at institutions including schools and hospitals.
Extension of supply network	Over half mentioned the possibly to extend the supply network. There are ongoing discussions with the National Water and

	Sewerage Corporation (NWSC) regarding the possibility of supplying water to the North.
Creating valley dams	The majority of respondents, particularly those from the dry areas, identified this option, noting that valley dams can be useful for animals and irrigation.

7.4. Costing of adaptation options

There is limited data on the costing of adaptation at river catchment level. However, we can draw on the national level analysis of costing of measures for both the water and energy sectors and use appropriate scaling factors to try to evaluate such measures at a more localized level. It is important to note that this is an estimation method based on appropriate scaling of estimates for the national level options. The cost data for adaptation options is hence subject to a degree of uncertainty – as the costs presented are based on rather limited data. However, we were unable to identify any other data on costs – so this is the best available approach. This was done for the policies that are likely to have a direct impact on hydroelectric power and which can be applied at local level, as shown in Table 16.

Table 16: Estimated Adaptation Costs of National Level Policies for energy in Mpanga

Policy number (based on Energy Sector report)	Policy	Cost (US$m)	Adjustment factor	Proportion of cost in Mpanga	Estimated Cost for Mpanga (US$m)
1	Promote and participate in water resource regulation so as to ensure the availability of water for hydropower production.	54	Proportion of hydropower capacity in Mpanga	0.0259	1.40
2	Promote and participate in water catchment protection as part of hydroelectric power infrastructure development	60.3	Area	0.0696	4.20
3	Diversify energy sources by promoting the use of alternative renewable energy sources (such as solar, biomass, mini-hydro, geothermal and wind) that are less sensitive to climate change	74	Proportion of hydropower capacity in Mpanga	0.0259	1.92
5	Conduct research to determine the potential impacts of climate change elements on the country's power supply chain	71.8	Proportion of electricity produced	0.0204	1.47

Source: Own calculations

For water, we use the relative level of water demand in the catchments compared to the national level to allow an estimation of the costs, as shown inTable 17. Water demand in Mpanga is 1.5% of the national total, compared to 3% for Rushango – hence the differences in cost levels between the two. In reality, the costs will not be equally distributed on this basis because the impacts of climate change, as shown in this study, will be spatially differentiated so more effort will be needed in some areas than others.

Table 17: Estimation Adaptation Costs of National Level Policies in Mpanga and Rushango for the Water Sector

Programme	National Present Value of Costs @ 10% Discount Rate (US$m)	Mpanga equivalent cost based on water demand ($m)	Rushango equivalent cost based on water demand (US$m)
Efficient water utilisation among households	4.7	0.07	0.13
Increased water availability for agriculture and industry	32.7	0.51	0.91
Integrated water resource management to deal with extreme events	42.8	0.66	1.19

7.5. Evaluation of benefits of adaptation – effectiveness of interventions

Based on the costs presented above, it is possible to do a simple analysis of the potential extent of benefits needed in terms of reduced lost load in the future to make the policy viable in the Mpanga case. It should be noted that this analysis is based on indicative costings only, and so the results presented here can only be suggested to be indicative. There is a clear need for further exploration of the costs of adaptation in the Ugandan context, and for analysis of the costs and benefits to be updated once more reliable cost estimates are available. Improved understanding of the costs would aid decision making in this context.

Following the analysis of losses to energy in Section 6.1, we assume the benefits occur over the period 2030 to 2035 (i.e. 20 years from the present) applies. The results are shown in Table 18. The estimates are made for two different levels of the value of lost load (the economic value of energy shortages) and for two different discount rates (5% and 10%). This reflects the uncertainty in the calculation. These results show that actions would need to offset between 2.8% and 32.8% of estimated losses in order to be justified (10% discount rate). It should be noted that the policies would be likely to have other benefits in terms of water supply security and ecosystem services, including tourism. These benefits may occur in the shorter term; whereas the energy supply benefits arise later and hence need to be discounted to reflect time preference. Nonetheless, these benefits would make the case for investment in adaptation measures even stronger. More work would be needed to estimate the full benefits of these policies at local level. It is important to note that the benefits considered here only reflect the average variation and not an extreme event, hence the benefits may be underestimated. Note that other policies identified in the national Energy Sector report (Baastel Consortium, 2015b) were not felt to be appropriate to this case study as they do not directly relate to river basin management – e.g. the targeting of energy efficiency and actions that reduce biomass demand.

Table 18: Effectiveness required for benefits to exceed costs for selected energy policies

Policy number (based on Energy Sector report)	Policy	Estimated Cost for Mpanga (US$m)	Reduction in energy losses needed for benefits to exceed costs 5% discount rate, high Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed costs 5% discount rate, low Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed 10% discount rate, high Value of Lost Load (%)	Reduction in energy losses needed for benefits to exceed costs 10% discount rate, low Value of Lost Load (%)
1	Promote and participate in water resource regulation so as to ensure the availability of water for hydropower production.	1.40	0.92	3.61	2.78	10.94
2	Promote and participate in water catchment protection as part of hydroelectric power infrastructure development	4.20	2.75	10.81	8.34	32.81
3	Diversify energy sources by promoting the use of alternative renewable energy sources (such as solar, biomass, mini-hydro, geothermal and wind) that are less sensitive to climate change	1.92	1.26	4.94	3.81	14.99
5	Conduct research to determine the potential impacts of climate change elements on the country's power supply chain	1.47	0.96	3.78	2.92	11.47

Source: Own calculations

While we cannot estimate the benefits likely from each of the policies (that would need more detailed analysis than was possible in this exercise) we can see that a reduction in lost load of around 2 percent per million dollars of expenditure is required to achieve a 5% internal rate of return[15]. For a 10% rate of return the reduction in lost load is correspondingly higher at 2 to 8%. Based on the evidence, the measures most likely to be effective in the region would be better management of available water for hydropower production and promotion of water catchment protection. Diversification of energy sources is not particularly suited to this catchment and may be more effective nearer large centres of demand.

For the water sector, it is not possible for us to do a similar analysis based on the above estimates of the benefits. For Rushango we have been able to quantify some values of water shortages for an average year with 2035

[15]The **internal rate of return** provides an estimate of the discount rate that would need to be applied to make the net present value equal to zero – so the higher this rate is the more desirable the option.

demands – but it is clear that the distribution of effort in responding to such shortages will need to be spatially differentiated as the benefits are not equally spread over Uganda. This means that simple allocation on the basis of factors such as those used for energy would not be appropriate, so it is likely that the adaptation costs represented above are a significant underestimate for Rushango. However, the sheer scale of the value of reduced water shortage suggests that adaptation action is more than merited in Rushango. The costs of adaptation are a small fraction of the benefits of adaptation, even if the adaptation measures themselves were not very effective.

It is important to note that if adaptation were included at an early stage in project development and design then some costs may be avoided. This may need the consideration of climate change in strategic environmental assessment of infrastructure projects for energy or water. The National Environment Management Authority (NEMA) could include further assessment of the likely impacts of climate change in the environmental impact assessments conducted. In addition, improved data on the hydrometeorological system would aid adaptation at an early stage and hence lead to improved risk management.

7.6. Barriers and enabling factors for adaptation

The qualitative interviews yielded some interesting results as to the barriers and enabling factors for adaptation in the Mpanga River catchment. Barriers included institutional, educational, social and technological factors.

Key institutional barriers include:

- **Involvement of leaders in the community in activities relating to the river, including farming along the river banks.** Some stakeholders reported that technical staff have been reluctant to implement resolutions due to this;
- **Funding constraints** – there is a lack of financing to deal with environmental issues, including a lack of staff (notably Community Development Officers) to enforce the laws;
- **Lack of clear policy and will to enforce the existing law.** Some stakeholders suggest that a lack of a clear legislative framework will make adaptation measures more difficult. Some report there has been political interference in the enforcement process. It was noted that the Department of Natural Resources is not among the law enforcement agencies.

Educational barriers include:

- **Low educational levels of communities along the river**. Stakeholders report that this will make the changing of mindsets difficult, and so hamper adaptation strategies.
- **Lack of awareness and/or willingness to act –** this is a general problem with climate change not being taken seriously.

Social barriers include:

- **The difficulties involved in relocation of those who are living in areas that require protection.** Stakeholders noted that these groups are difficult to relocate and are likely vulnerable due to poverty. There is also the issue of the sheer scale of the issue in the Mpanga River catchment and the shortage of land due to increasing population levels.
- **The need to meet immediate needs** which affects decision making, e.g. between planting food crops or planting trees. With trees taking time to mature, such options may not be viable for more disadvantaged groups.
- **Cultural factors may restrict adaptation.** For example, people say they have been burning bushes for a long time and they have never seen it as a problem, and that even their grandparents used to burn the bushes and they would germinate again. This cultural aspect may make adaptation more difficult.

Technological barriers include:

- **The significant cost of technology for piped water.**

- The need for water treatment was also noted.

Facilitating factors include:

- **Improved data collection on river flows and water use.** Stakeholders noted the current issues with data collection and that policy is based on estimates rather than necessarily real data. Improving data collection would improve decision making.
- **Measures to reduce fuel wood demand**. Stakeholders discussed issues relating to the cutting of trees for fuel wood and that the demand for charcoal and fire wood is high. Measures to reduce such demand could help adaptation.
- **Effective warning systems, including better weather forecasting.** These were noted by some stakeholders as being important, with the important factor being having enough time to alert the affected population so that they could take action.

This section demonstrates that the costs of adaptation are a small fraction of the benefits of adaptation in the Mpanga river catchment, even if the adaptation measures themselves were not very effective. A number of key barriers and facilitating factors to adaptation have been identified. The policy implications of those finding are discussed in the next section.

8. CONCLUSIONS & POLICY RECOMMENDATIONS

8.1. Key sectoral findings

From the above analysis, it can be seen that there will be significant losses by 2035 in the Rushango district in terms of water supply. **Hydroelectric losses are shown to dominate the losses in the water sector.** There are a number of policies that could help better balance demands, including better catchment management and interaction of stakeholders in decision making processes.

There will be significant lost load on average due to lack of water to feed the existing dam on the Mpanga River, and damages to energy hence outstrip the losses for water supply. **There is clear need for integrated river basin management in the catchment**. Assessment of existing policies suggest that, even if only changes to the average level of water available for energy is considered then the policies would only have to marginally reduce the lost load for the benefits to exceed the costs. Other unquantified near term benefits may include improved ecosystem services from the river.

A number of adaptation actions in the energy sector and water sector would all either directly or indirectly impact on the case of the hydroelectric dam in the Mpanga River – with some having more impact than others. Actions to reduce biomass demand, for instance, will improve the quality of water in the river and measures to improve energy efficiency and promote demand management would reduce pressure on the system. These would reduce the losses due to climate change in the energy sector in the Mpanga River Basin. Direct measures including actions to promote efficient management of resources – particularly by those sectors with significant consumption - will likely reduce the impact of the lost load. This shows the **importance of considering cross-sectoral effects**. Such cross-sectoral impacts may lead to the need for more complex analysis of strategies – **simple sectoral analysis may miss key impacts on other sectors (or opportunities for win-win solutions).**

Most adaptation options are shown to only need to marginally impact on water or energy supply shortages to be cost-effective.

8.2. Barriers and Enabling Factors

A number of barriers to effective policy on water in particular have been identified, including the need for strong political will and, in particular, **sufficient funding for employing Community Development Officers to enforce existing laws**.

There is a need for improving data availability on river flows to facilitate better policy making. Data on the catchment is rather limited, in part due to damage to equipment caused by road construction – highlighting again the need for integration of efforts to adapt to climate change.

Enabling factors include better weather forecasting and early warning systems for water supply shortage and measures to reduce wood fuel demand. **Improving weather forecasting will require significant investment in data collection and in analysis**, and also education about weather forecasts for communities. Forecasts for water supply shortage are in their relative infancy internationally, and the background data would need to be significantly improved in Uganda before this could be realised.

8.3. Recommendations

The Mpanga River faces a number of challenges, and it is clear that effective action will have to be taken at all levels – from local communities to the national government – to ensure that costs of inaction are minimised. It has been shown here that the adaptation costs for water and energy in Rushango are not that significant when compared to the potential benefits of action. The case for action will likely be enhanced with increased energy demand in the future. Further work is needed in terms of the water sector in particular to assess the effectiveness of interventions; but the costs seem likely to be less significant than the potential benefits.

It is also worth noting that national level policy on energy supply will either directly or indirectly impact on the case of the hydroelectric dam in the Mpanga River. Actions to reduce biomass demand, for instance, will improve the quality of water in the river and improve infiltration into soils, and measures to reduce (biomass) energy consumption would reduce the losses due to climate change in the energy sector in the Mpanga River Basin as trees help to prevent erosion and improve river water quality. Direct measures including actions to promote efficient management of resources – particularly by those sectors with significant consumption - will likely reduce the impact of the lost load.

Integrated River Basin management may offer Uganda a step change from current practice – and help reduce adaptation costs as a result. Further work is needed on the appropriate allocation of water resources, but this report provides a first estimate (albeit crude) of the costs and potential benefits of action. Uganda faces a number of specific challenges and that of meeting the needs of the urban and rural poor in terms of adaptation is likely particularly acute.

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APPENDIX 1: LIST OF PEOPLE INTERVIEWED

Family Name	First name	Organisation	Position (not necessarily official)
Sanjeewa	M	Mpanga Small Hydro Power	Electrical Engineer
Byabasaija	Rosemary	Kabarole district	Deputy Resident District Commissioner
Ruyonga	Godfrey	Kabarole District Local Government	Environment Officer
Bimbona	Simon	Kabarole District Local Government	Deputy Chief Administrative officer
Mugume	Sam	Kabarole District Local Government	District Planner
Monday	Christopher	Kabarole District Local Government	Labour officer
Balisanga	Tadeo	Kabarole District Local Government	Community Development officer
Omoko	Paul	Fort Portal Municipal council	Town Clerk-Fort Portal
Natugonza	Gladys	Fort Portal Municipal council	Environment Officer
Tibenda	John	National water and sewerage corporation	Area Manager
Muhumuza	Richard	Kampala Tea Estate(TAMTECO)	Team/Group Manager
Kikwaya		Buhing Hospital-Kabarole District	Hospital Administrator
Group members		Fort Portal	Near river mpanga
Numanya	Zanikire	Ibanda District Local Government	Deputy Chief Administrative officer
Kazwengye	Melchiad	Ibanda District Local Government	LV 5 Chairman
Ayebare	Jowani	Ibanda District Local Government	Senior Planner
Nuwagira	Tom	Ibanda District Local Government	Environment officer
Masabawekesa	Sam	Ibanda District Local Government	Community Development officer
Turyahura	Abel	Ibanda District Local Government	District water Engineer
Mugabi	Hassan	Ishongoro Town-Ibanda North	LC III chairman/Mayor
Ishongoro High School		Ibanda North	Deputy Headteacher
Nyamarebe group		Ibanda North	
Nasamba	Festo	Kiburara Prisons	In-charge
Karure	Bruno	Kamwenge District Local Government	District water Engineer
kamasaka	Robert	Kamwenge District Local Government	LC 5 Chairman
Assimwe	Balaam	Kamwenge District Local Government	District Planner
Kasanga	William	Kamwenge District Local Government	natural Resource officer
Tumusiime	Ferdenand	Kamwenge District Local Government	District procurement officer
		Kamwenge District Local Government	Chief Administrative officer
Local community		Kamwenge District	
Kansiime	Innocent	national water and sewerage corporation	Area Manager-Kamwenge