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Examining the utility and use of long-term climate information for hydropower schemes in sub-Saharan Africa

MAR5322-RT001-R01-00

October 2014

Document information

Document permissions	Confidential - client
Project number	MAR5322
Project name	Future Climate for Africa - Scoping papers
Report title	Examining the utility and use of long-term climate information for hydropower schemes in sub-Saharan Africa
Report number	RT001
Release number	R01-00
Report date	October 2014
Client	Climate and Development Knowledge Network
Client representative	Lindsey Jones
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Document history

Date	Release	Prepared	Approved	Authorised	Notes
16 Oct 2014	01-00	DML	GW	NW	Updated between 1 and 3 October 2014 to take into account additional comments

Document authorisation

Prepared	Approved	Authorised
		N. Walmsley.

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1. Purpose of this paper

This paper has been prepared to support the scoping phase of the Future Climate for Africa (FCFA) programme. The focus of the FCFA is to advance scientific knowledge, understanding and prediction of African climate variability and change on 5 to 40 year timescales, together with support for better integration of climate science into longer-term decision making, leading to improved climate risk management and the protection of lives and livelihoods (NERC, 2014).

The paper investigates the current and potential use of long-term climate information for decision making for hydropower schemes in sub-Saharan Africa. Hydropower schemes are long-lived infrastructure. These are pieces of infrastructure that usually can be maintained for a significantly greater number of years than most other capital assets. The main objectives of this paper are to provide evidence on the following areas:

- The risks and opportunities which climate change presents to hydropower schemes; and
- The use of climate services in medium to long-term decision making related to hydropower infrastructure.

Climate change is a particular threat to long-lived infrastructure because many existing and planned hydropower schemes could still be in operation in 50 or even 100 years' time, when the effects of climate change could in some cases be substantial (Giordano, 2012). Long-lived infrastructure, such as hydropower schemes, is generally less adaptable to climate change because such infrastructure is challenging to alter retrospectively (Pittock, 2010). For example, to adapt a hydropower dam to climate change may require it to be raised in height or to increase the size of its spillway, which is often not technically or economically feasible; whereas assets with a short-lifespan (e.g. less than 20 years) can be replaced with better suited assets more easily as the climate changes.

Africa's water resources are abundant but, owing to an absence of water storage infrastructure, they are grossly underutilised (World Bank, 2014). The continent experiences a particularly high level of hydrological variability, with large regional, seasonal and decadal changes in precipitation (World Bank, 2014). This variability will only be exacerbated by climate change. In 2008, the World Bank estimated that the cost of investment to redress Africa's power infrastructure deficit was US$23.2 billion per year with a further US$19.4 billion per year required for operation and maintenance; an overall price tag of US$42.6 billion (World Bank, 2008). However, bridging Africa's infrastructure funding gap is as much about improving the performance of the relevant institutions as it is about raising additional finance (World Bank, 2008).

Owing to a lack of investment in water-related infrastructure that could help to alleviate future energy shortages and the lack of modern institutional frameworks, sub-Saharan Africa is among the regions in the world most seriously threatened by an absence of water security (World Bank, 2008; Vörösmarty et al. 2010). For long-lived infrastructure, to be resilient in the future it is important that the planning process for this infrastructure integrates climate variability and climate change uncertainties.

This paper has been structured as follows:

- Chapter 2 covers the importance of hydropower infrastructure in sub-Saharan Africa;
- Chapter 3 provides background to the importance of climate services in the planning, design and operation of long-lived infrastructure;
- Chapter 4 highlights the importance of climate services for hydropower schemes;
- Chapter 5 gives conclusions and policy recommendations;
- Chapter 6 gives the references that were used to compile this paper.

2. The importance of hydropower infrastructure in sub-Saharan Africa

2.1. Introduction

The international community's emerging Sustainable Development Goals (SDGs) point to the need for countries to develop climate resilient sources of energy and food production. Stimulating the development of hydropower would lower the generation costs of electricity, reduce carbon emissions and insulate countries in sub-Saharan Africa from increases in the price of fossil fuels (World Bank, 2009). The implementation of hydropower schemes in sub-Saharan Africa should help to meet the following SDGs:

- Ensure universal access to affordable, reliable, and modern energy services;
- Substantially increase the share of renewable energy in the global energy mix;
- Double the global rate of improvement in energy efficiency by 2030;
- Expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, particularly least developed countries (UN, 2014).

2.2. The scale of hydropower infrastructure in Africa

Hydropower is increasingly promoted as a source of energy with low emissions of greenhouse gases, with a production capacity at a scale necessary to meet pressing energy demands with current technology (Pittock 2010). In Africa, regional power generation and interconnection projects play a significant role in the strategies for increased access to electricity. The Regional Economic Communities (RECs) promote regional power projects and trade through their respective power pools. In sub-Saharan Africa, there are four power pools. Details of their installed capacities are given in Table 2.1.

Table 2.1: Installed generating capacity for the four sub-Saharan African power pools

Sub-Saharan Africa	Installed capacity (MW)
Central African Power Pool (CAPP)	6,073
East African Power Pool (EAPP)	28,374
Southern African Power Pool (SAPP)	49,877
West African Power Pool	14,091

Source: ICA, 2011

Figure 2.1 shows the percentage of installed capacity in terms of the four main types of power generation (i.e. hydropower, diesel, coal and gas). In sub-Saharan Africa, hydropower makes up just under 20% of the installed generating capacity. By 2025, the power generation mix within these power pools will be moving substantially toward an increasing share of hydropower (ICA, 2011). In 2009 it was estimated that in sub-Saharan Africa there were hydropower schemes with over 7,900 MW of capacity currently under construction and further hydropower schemes with an installed capacity of between approximately 25,000 to 98,000 MW being planned (Hydropower and dams, 2009).

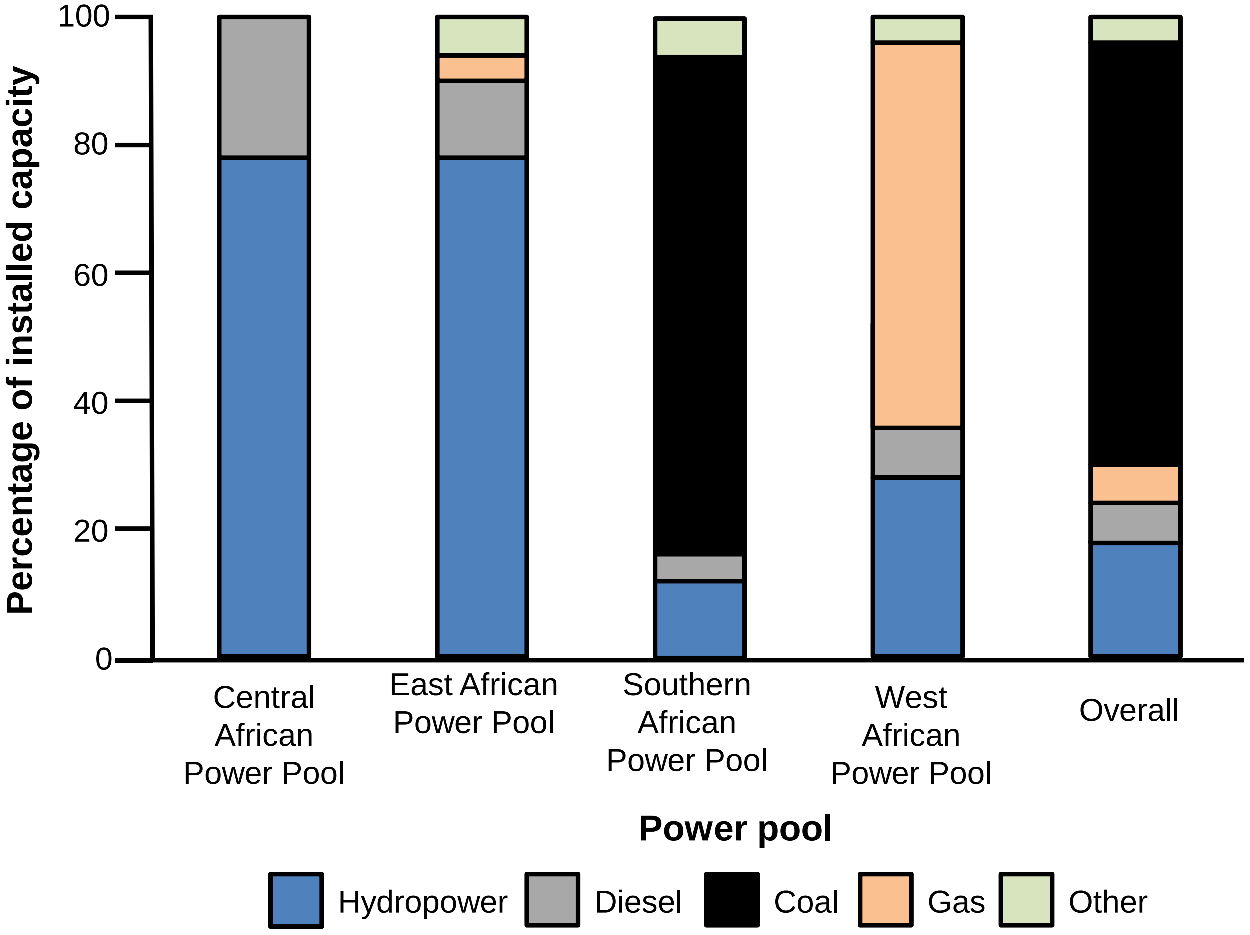


Figure 2.1: Generation technology as a percentage of the installed capacity in the four sub-Saharan African power pools

Note: *When South Africa is excluded, from the overall figures hydropower accounts for close to 70% of electricity production (or about 50% of installed generation capacity (Eberhard et al., 2008)*

Source: *ICA, 2011*

Figure 2.2 shows the percentage of electricity generated from hydropower for each country in Africa and the location of large dams used for both hydropower and irrigation. In the Upper Nile River Basin Ethiopia, Uganda and Kenya are highly reliant on hydropower; whilst in the Zambezi River Basin Zambia, Malawi, Mozambique and, to a lesser degree, Zimbabwe are the countries where hydropower dependency is high. Despite the considerable technically exploitable hydropower potential of about 1,750 TWh/year, and the opportunity to ensure energy security through hydropower generation, only 5% of the potential is currently tapped (Hamududu and Killingtveit, 2012). In the next 20 to 30 years, based on planned schemes, the hydropower generating capacity in Africa could almost quadruple (Hamududu and Killingtveit, 2012).

Modelling by the Norwegian University of Science and Technology examined climate impacts on river flows and hydropower generation to 2050. Systems at highest risk had both a high dependence on hydropower generation for electricity and a declining trend in runoff. South Africa is quoted as one example with a potential reduction of 70 GWh per year in generation by 2050, which is a 3% decrease compared to present day hydropower production in South Africa (Hamududu and Killingtveit, 2012; Energypedia, 2014). Table 2.2

provides a summary of potential changes in hydropower generation in Africa in the year 2050 as a result of climate change, relative to the year 2005.

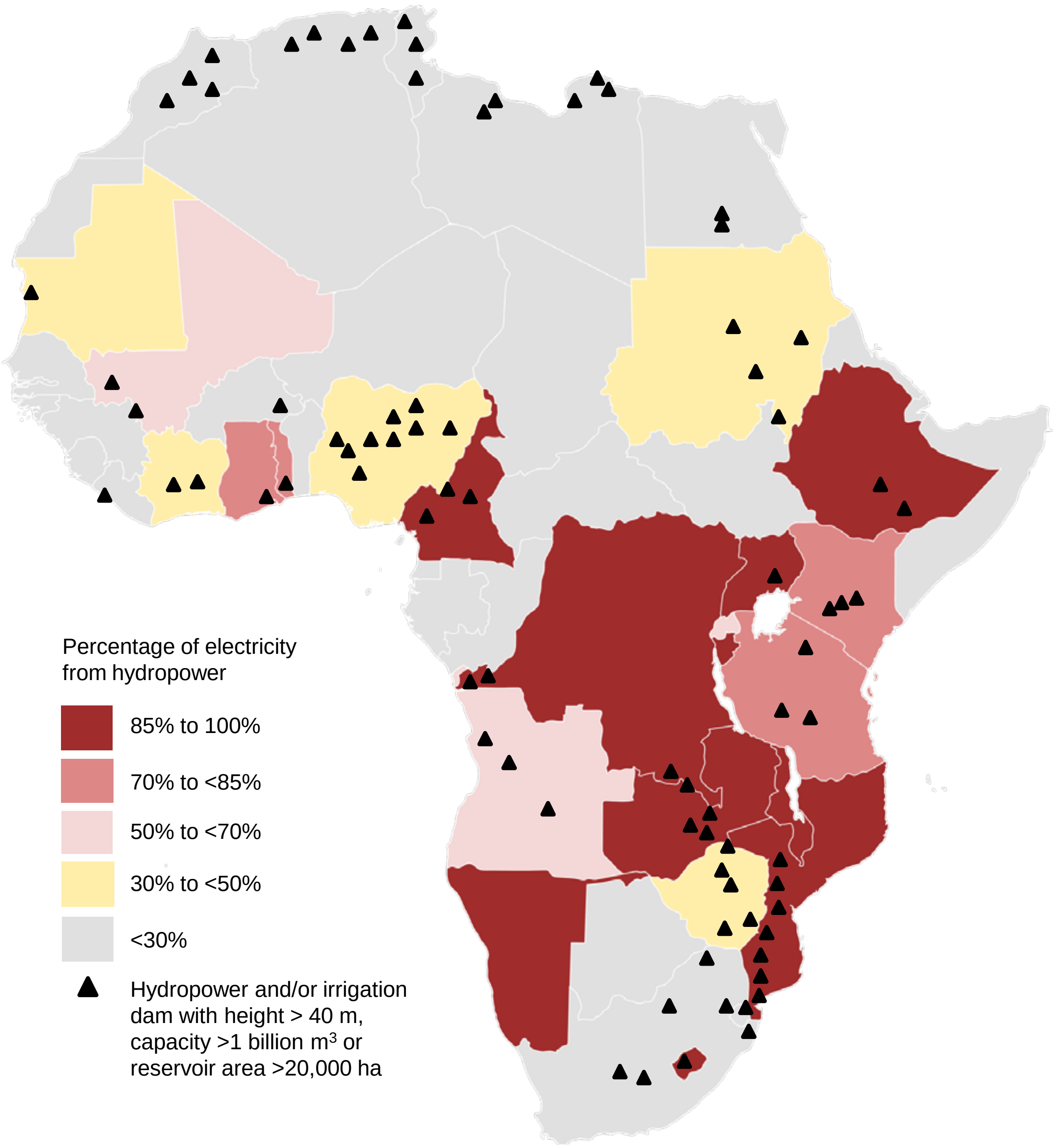


Figure 2.2: Percentage of electricity generated by hydropower dependency and large hydropower and irrigation dams in Africa

Source: Adapted from FAO, 2008, International Rivers, 2008

Table 2.2: Potential changes in hydropower generation in hydropower generation by the year 2050 relative to 2005

Region	Generation (TWh)	Change (TWh)	Percentage change of total (%)
Eastern	10.97	0.11	0.59
Central	12.45	0.04	0.22
Northern	15.84	-0.08	-0.48
Southern	34.32	-0.07	-0.83
Western	16.03	0.00	0.03
Total	89.6	0	-0.05

Source: Hamududu and Killingtveit, 2012

Hamududu and Killingtveit found that in Africa by the year 2050, there could be some countries with increasing hydropower generation and others with decreasing hydropower generation as a result of climate change (Hamududu and Killingtveit, 2012). The Eastern African region showed increases in almost all countries except Ethiopia where there were disagreements among the Global Climate Models (GCMs). The Southern and Northern regions showed decreases in hydropower generation (Hamududu and Killingtveit, 2012). The Western region remained nearly the same, but there were some countries with increases while others had decreases. In these countries there were disagreements among GCMs regarding future runoff. A detailed list of the African countries for which Hamududu and Killingtveit carried out modelling is provided in Appendix A.

It should be noted that the objective of Hamududu and Killingtveit's study was to present a global picture of impacts of climate change on hydropower generation and thus several simplifications and assumptions were made. These included:

- Ignoring impacts such as changes in timings of flow regimes and changes in sediment load both of which affect the operation of hydropower schemes;
- Not including adaption and/or mitigation on operations in the analysis;
- The changes were estimated at a country level. Climate change impacts vary significantly at a country scale; however, an average change was assumed because the objective was to provide a bigger global overview of the impacts of climate change.

3. The importance of climate services in the planning, design and operation of long-lived infrastructure

Climate information can generally be divided into three types:

- Short term weather forecasts (i.e. up to seven days);
- Medium term weather forecasts (i.e. seven to 30 days);
- Long term weather forecasts (i.e. three to nine months);
- Long term climate variability and climate change projections (i.e. greater than 10 years).

In terms of hydropower schemes each of these has a specific use as Table 3.1 shows.

Table 3.1: Types of climate information and the decision making options for hydropower schemes associated with them

Type of decision	**Climate**	**Weather**		
	Long term (10 to 50 years)	**Long term (3 to 9 months)**	**Medium term (7 to 30 days)**	**Short term (0 to 7 days)**
Type of information	**Decadal changes Climate change scenarios**	**Seasonal forecasts**	**Week to monthly weather forecasts**	**Daily forecasts observations**
Strategic	Sizing installed hydropower capacity Assessing future power generation under climate change Dam safety Reservoir sizing			
Tactical		Operating rules for scheme Downstream releases to meet downstream users and environmental requirements		
Operational			Estimation of short term power generation Downstream releases to meet downstream users and environmental requirements	Estimation of short term power generation Downstream releases to meet downstream users and environmental requirements

Source: Adapted from Ziervogel et al, 2009

Large hydropower schemes are generally designed for lifetimes between 50 and 100 years. Figure 3.1 presents global climate change projections for temperature for two emissions scenarios, showing the range of possible futures, with uncertainties increasing further into the future. Indicative infrastructure lifetimes (based on construction in the year 2000) are plotted on to the projections showing the range of climate futures which the infrastructure may be subjected to over its lifetime. It is important to note that the design life of infrastructure often exceeds the original plan. There are numerous examples of hydropower schemes in the USA that have exceeded their design life by more than 30 years (see US Department of Energy, 2010; US Army Corps of Engineers, 2013).

Long-lived infrastructure is generally designed to accommodate an estimated level of climate variability based on historical records. This may be highly uncertain in itself, depending on the length and quality of the available data. When future climate change is considered over the design life of the infrastructure, this uncertainty is substantially increased because the historical record become less valid for future planning, and a reliance is placed on the use of results from Global Climate Models (see Milly et al., 2008).

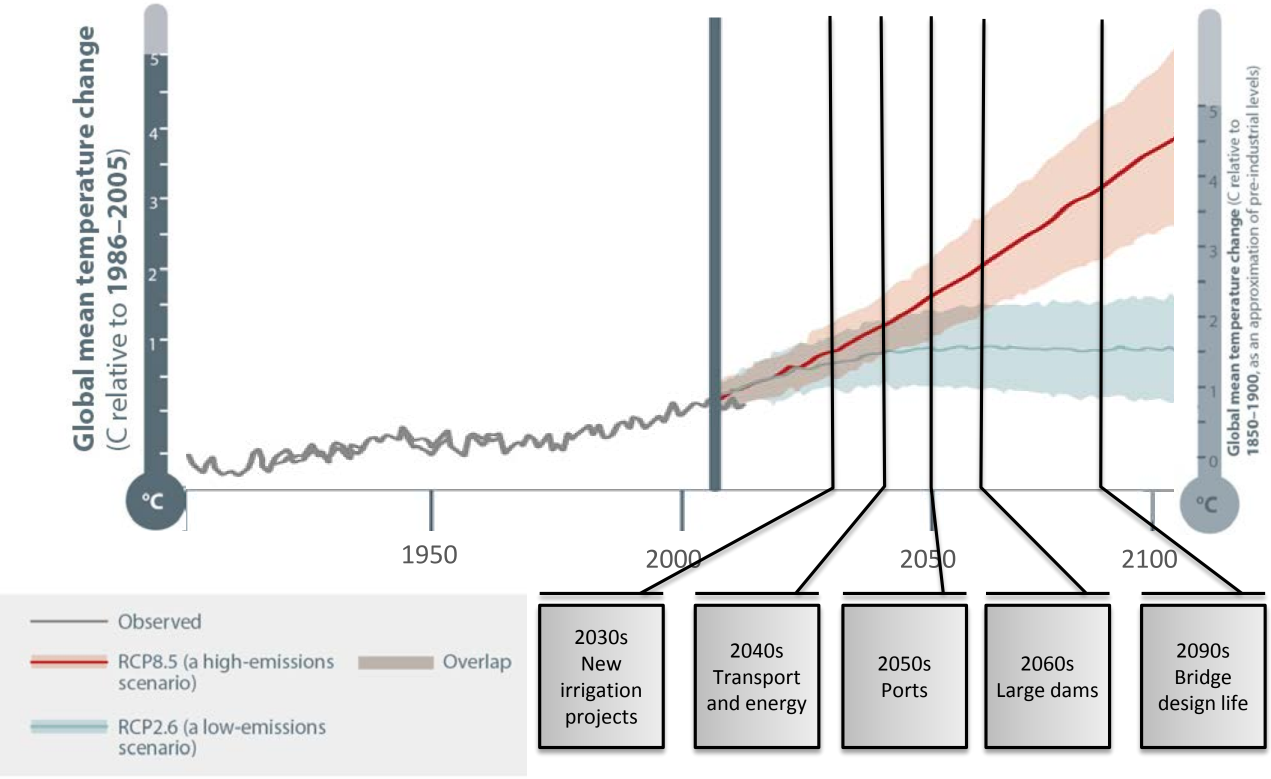


Figure 3.1: Indicative design lives of long-lived infrastructure compared with timescales for climate change

Source: *Adapted from IPCC (2014) with selected infrastructure lifetimes from Stafford Smith et al. (2011) and UNCTAD (1985)*

The potential for flexibility at the planning stage of hydropower schemes is relatively high, with many different potential solutions available to meet the desired objective, each of which can be evaluated against future climate change scenarios. Once a hydropower scheme is in place, flexibility is more limited and must rely on managing the residual risks which cannot be offset at the design phase. This can include management or operational practices such as forecasting and warning to manage climate hazards as they arise. These types of activities are inherently adaptable and can be improved and adjusted into the future, while the assets themselves remain fixed. The ability to influence adaptation strategies and measures for the various stages of a hydropower scheme is shown in Figure 3.2.

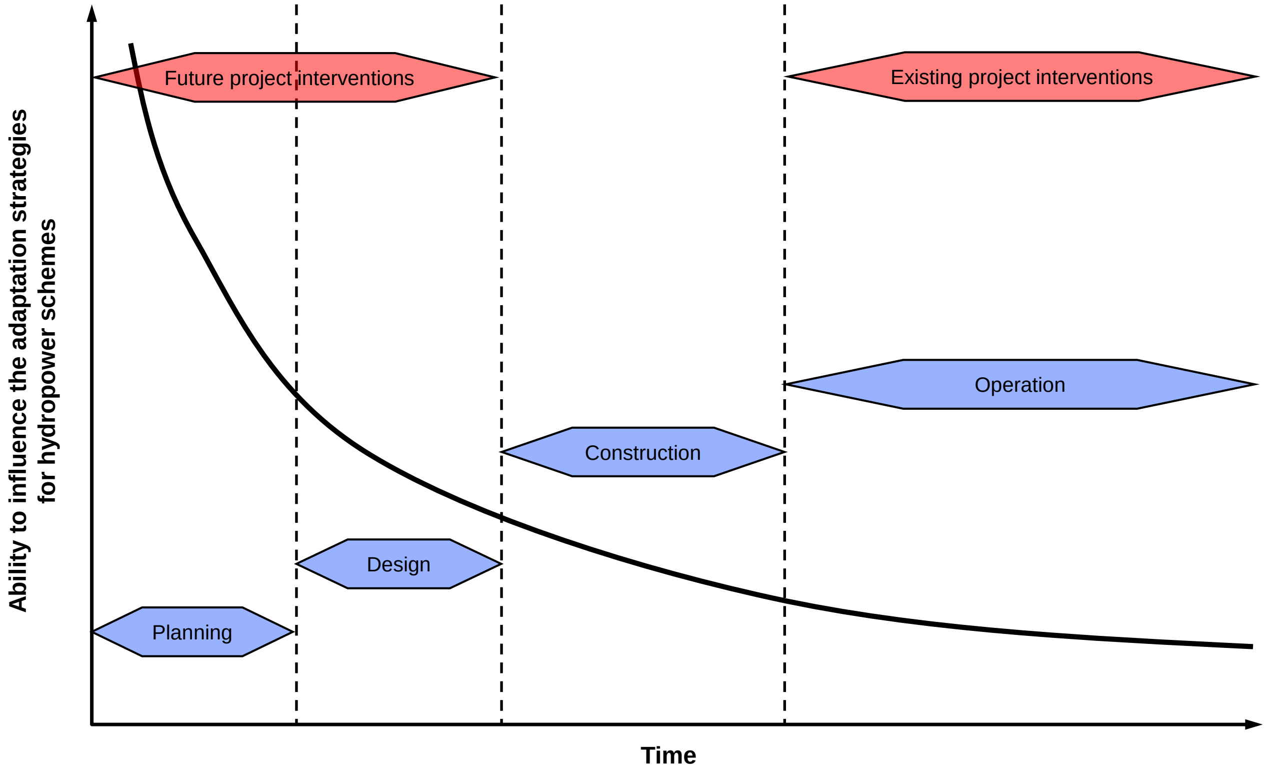


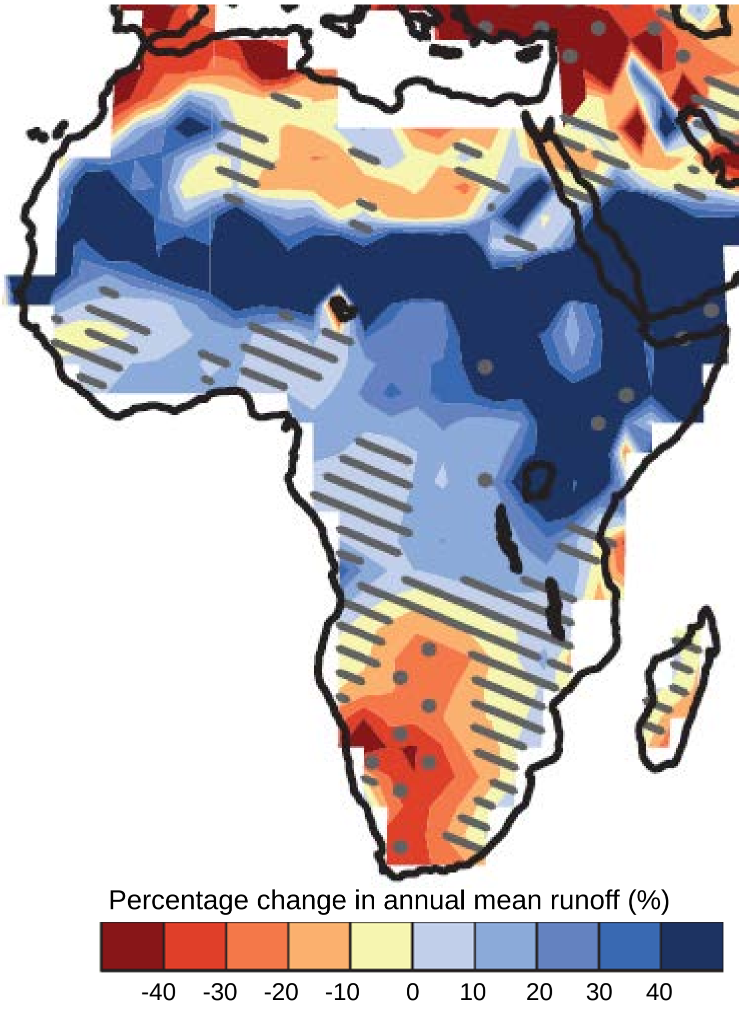
Figure 3.2: The ability to influence climate change adaptation measures for hydropower schemes

Source: MWH, 2009

Changes in the water cycle are forecast to occur in a warming climate. Global-scale precipitation is projected to gradually increase in the 21st century (IPCC, 2013). Changes in mean precipitation in a much warmer world will not be uniform, with some regions experiencing increases, and others with decreases or not much change at all (IPCC, 2013). Regional to global-scale projections of soil moisture and drought remain relatively uncertain compared to other aspects of the water cycle (IPCC, 2013). However, a drier climate in southern African is consistent with projected changes in the Hadley Cell Circulation. Expansion of the Hadley Cell as a result of climate change is likely to reduce rainfall in region around 30 degrees latitude.

Figure 3.3 shows changes in the annual mean changes runoff for Africa for the period 2081 to 2100 relative to the period 1986 to 2005 based on the result of 33 Global Climate Models. Figure 3.3 shows that runoff in East Africa is likely to increase, whilst runoff in Southern Africa is likely to decrease. It is important to note that Figure 3.3 only shows mean annual changes in runoff. For example, Figure 3.3 shows that runoff is likely to increase in Ethiopia. However, Ethiopia has highly variable rainfall. Increases in annual precipitation may increase hydropower generation if excess resources can be stored and used for power generation. However, the impacts will be catchment and site specific and depend on changes in seasonal precipitation, rainfall intensities and most importantly year to year variability that may result in years with more flooding and periods of drought. Box 3.1 provides an example of modelling of climate change scenarios and dam operations in the Upper Blue Nile catchment that indicate for this catchment climate change could have a potentially positive impact.

It is important that when assessing new hydropower schemes it is important that studies are carried out, with the commensurate level of detail, that allows the trade-offs between hydropower generation, food security, water supply and other users of water to be assessed under a range of climate change scenarios, ideally at a catchment scale. Figure 3.4 shows a diagrammatic representation of the process that could be used to assess these trade-offs under different future climate change scenarios. This integrated hydro-economic framework would account for not only the impacts of climate change, but also the interactions between agricultural productivity, non-agricultural water demands, and changes in resource availability in order to allow different future scenarios to be assessed. Figure 3.5 shows a hypothetical example of the outputs that could be derived from such a framework, in this case in terms of the amount of hydropower generated under 10 future climate change scenarios. Figure 3.5 compares the baseline[1] hydropower generation with 10 future climate change scenarios. In this example it can be seen that for eight out of the 10 future climate change scenarios the amount of power generated by the scheme will decrease. Such a framework could also be used to show how a number of other important parameters (e.g. crop yields and generated revenue) vary with climate change.



The map is based on the results of 33 Global Climate Models.
Areas of stippling indicate areas of significant change where 90% of the models agree.
Areas of hatching indicate where the changes are relatively small.

Figure 3.3: Mean annual percentage increase in runoff for Africa for the period 2081 to 2100

Source: IPCC, 2013

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[1] A baseline period serves as a reference period from which the modelled future change in climate is calculated. The choice of baseline period is often governed by the availability of climate data period . The period 1961 to 1990 is often used (see Kittel et al, 1995; Hulme et al., 1999).

Box 3.1: Modelling of climate change scenarios and dam operations in the Upper Blue Nile

Studies have been carried out in the Upper Blue Nile to understand how changes in the hydrological regime in the 2050s caused by climate change could affect the performance of hydropower dams in the basin. The results of these studies can help to inform decision-makers about possible ways of modifying dam operations in the future to optimise power generation and to ensure that the demands of other users are met. The results of modelling the Upper Blue Nile suggested that the water resources of the basin may not be adversely affected by climate change unlike many other regions in the world, and that increases in precipitation and associated water resources may help to meet future water needs in the region. This work addressed the hydrology and water resources of the Upper Blue Nile River Basin using limited data and simple, but "robust" hydrological model. The initial findings found that coordinated operations of hydropower dams under future climate scenarios could increase power generation, enhance the duration of flows, and impound more water without affecting water availability to downstream countries.

(Source: Kim et al., 2008)

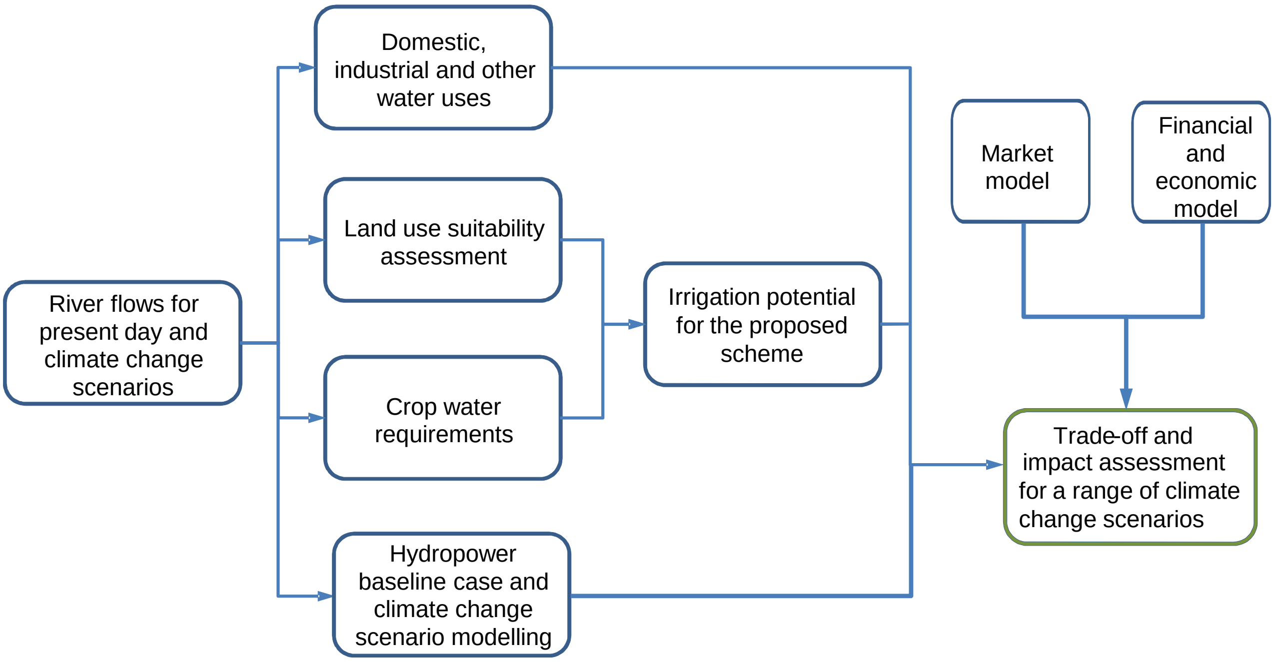


Figure 3.4: Integrated hydro-economic framework to assess the impacts of future climate change and trade-offs between hydropower, irrigated agriculture and water security for other users

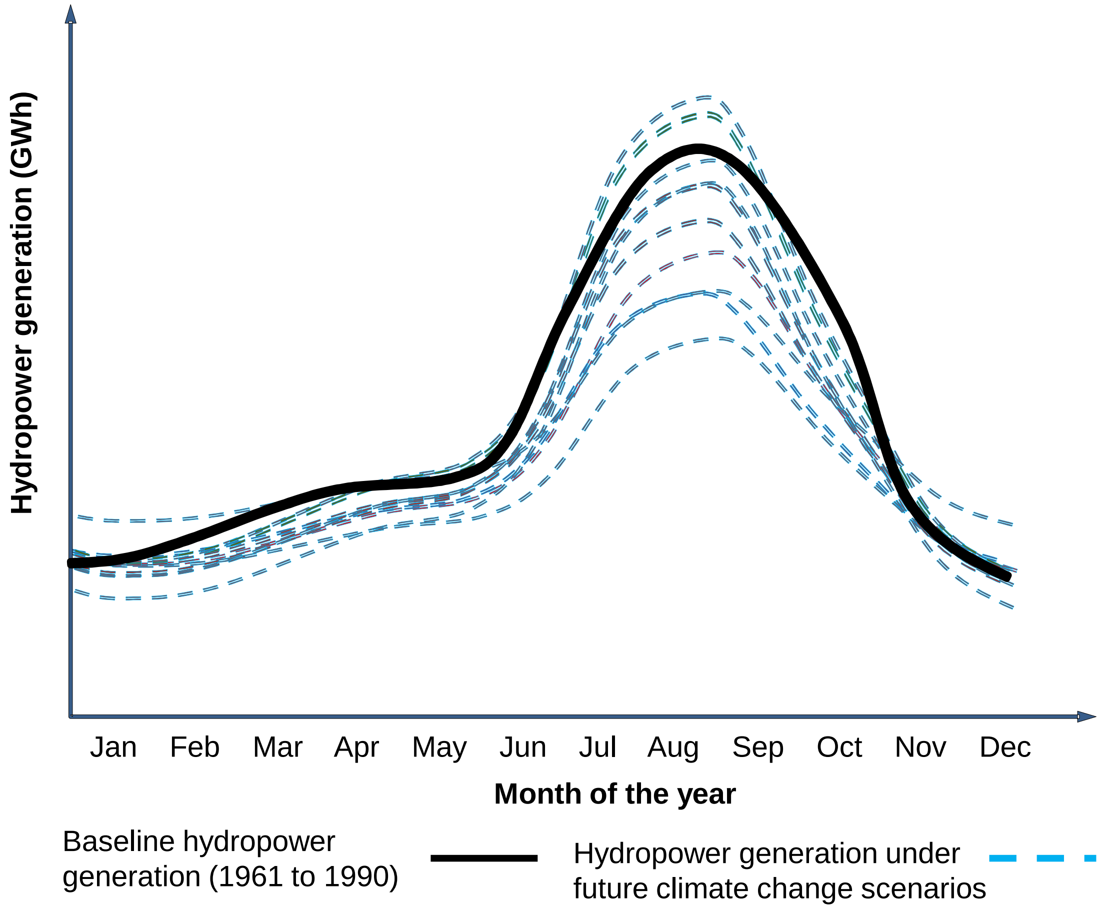


Figure 3.5: Hypothetical example from an integrated hydro-economic framework showing future hydropower generation under a range of climate change scenarios compared to the baseline

Box 3.2 provides a summary of a modelling study carried out by Grijsen (see Grijsen, 2014) to assess the effects of climate change on the generation of hydropower from five dams in Cameroun. Figure 3.3 shows that the mean annual runoff for Cameroun is likely to increase slightly for the period 2081 to 2100. Grijsen found that long-term hydropower generation relative to the period 1961 to 1990 could be between -15% and +5%. There is considerable uncertainty in these future hydropower generation projections and this is partly because the variability in the current hydrological regime was found to the same magnitude as the forecast flows under various future climate change scenarios.

Box 3.2: The impact of climate change on hydropower generation in Cameroon

Grijsen recently carried out a climate change risk assessment for the five major river catchments in Cameroon to assess the possible impact on hydropower generation. The Lom Pangar dam, which is currently under construction, was one of the hydropower schemes that was investigated. It will be the fourth dam built to help regulate the Sanaga River for the benefit of the country's two primary hydropower dams, Song Loulou (384 MW) and Edea (264 MW). These run of river hydropower dams have experienced significant reductions in power generation owing to dry seasons exacerbated by drought. The Government of Cameroon hopes the Lom Pangar Dam will increase the Song Loulou and Edea dams' ability to generate power during dry periods by an estimated 105 MW to 216 MW.

> Grijsen found that by 2050, the total long term average power generated by the Edea, Song Loulou, Lom Pangar and Nachtigal hydropower schemes could vary between -15% and +5% compared to the baseline hydrology for the period 1961 to 1990. Grijsen also found that the historical variability of precipitation and runoff was of the same magnitude as future flows projected under various climate change scenarios for the 21st century.
>
> The results of the available climate projections demonstrate the large uncertainty in individual climate projections and the importance of taking all Global Climate Model (GCM) projections into consideration, rather than carrying out a climate risk assessment for hydropower schemes based on the projections of only a few selected GCMs.
>
> Grijsen states that “anticipatory” adaptation measures are important for investments or decisions that are inflexible or irreversible and have long lifetimes or lead times such as hydropower schemes. The methodology and modelling tools developed as part of this study allow the sensitivities of the hydropower generated to future climate change scenarios to be assessed and to identify where proposed developments might fail to meet their goals. These scenarios can be used to identify potential actions to address vulnerabilities and evaluate trade-offs. However, various documents, including a World Bank technical appraisal in 2012, indicate climate change scenarios do not appear to have been taken account in the planning of the Lom Pangar Dam, a situation that would appear to be typical in sub-Saharan Africa (see International Rivers Network, 2006; World Bank, 2012b).
>
> (Grijsen, 2014)

4. Climate services and hydropower schemes

4.1. Background to the different types of hydropower schemes

Hydroelectricity is generated by water falling under the force of gravity that turns the blades of a turbine, which is connected to a generator. The amount of power that can be generated is dictated by the following:

- The vertical height of water above the turbines, often referred to as the hydraulic head;
- The rate of flow through the turbines.

Hydropower is an efficient form of energy generation, with a typical efficiency of converting potential energy to electrical energy of approximately 90% (USBR, 2005).

There are three main types of major hydropower schemes:

- **Storage schemes** – These have a dam that impounds water in a reservoir that feeds the power plant. Storage schemes generally have higher environmental and social costs than pumped storage or run of river schemes because more land is inundated and the natural flow regime is disrupted.
- **Run of river schemes** – These have either no storage at all, or a limited amount of storage, referred to as pondage. Run of river schemes are generally only appropriate for rivers with a sufficiently high minimum dry weather flow or those regulated by a much larger reservoir or lake upstream.
- **Pumped storage schemes** – These are designed solely to store energy to provide power during peak loads and they offer the flexibility to supplement other electricity supplies at very short notice. Owing to their configuration and the manner in which they are operated, they are not likely to be significantly affected by future climate change.

Figure 4.1 shows the three types of hydropower schemes.

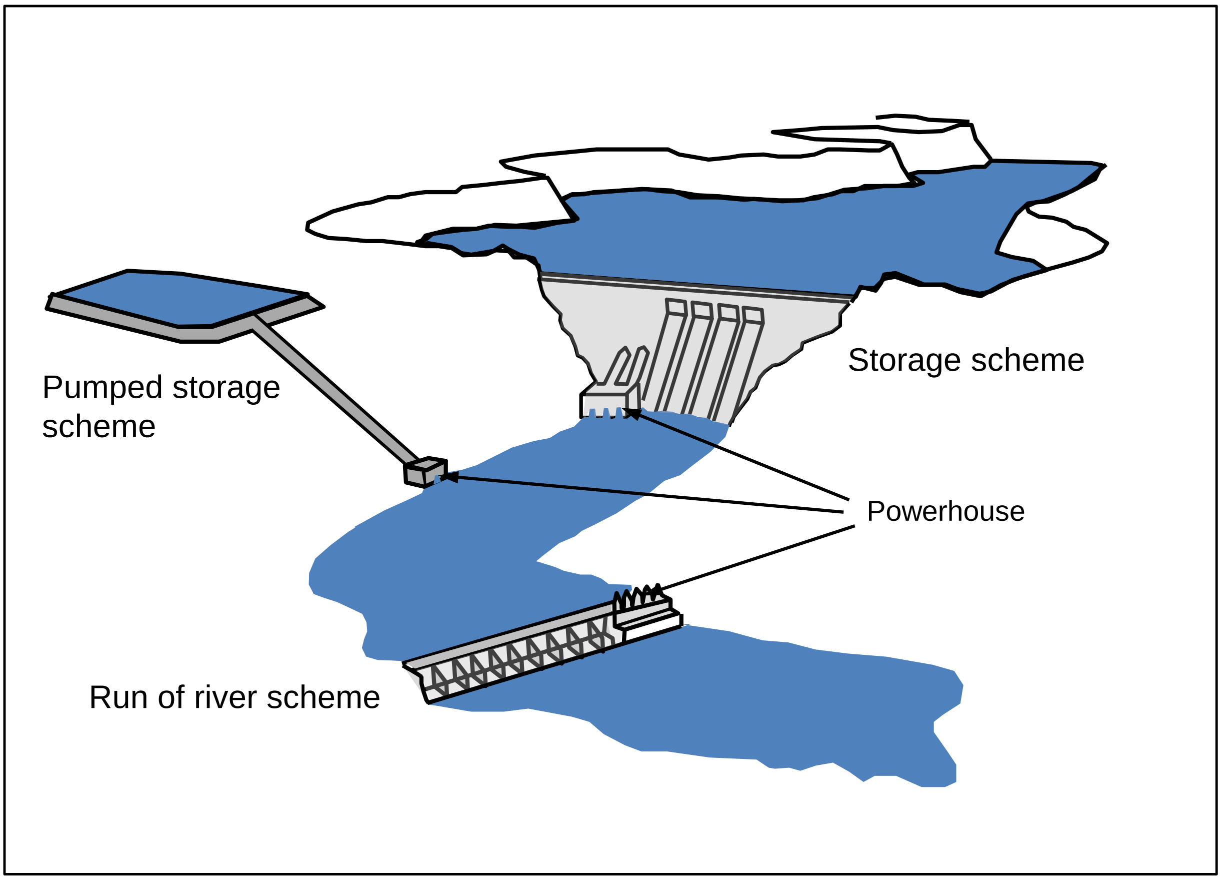


Figure 4.1: Diagram illustrating the main types of hydropower schemes

4.2. Synthesis of the climate related risks to hydropower schemes

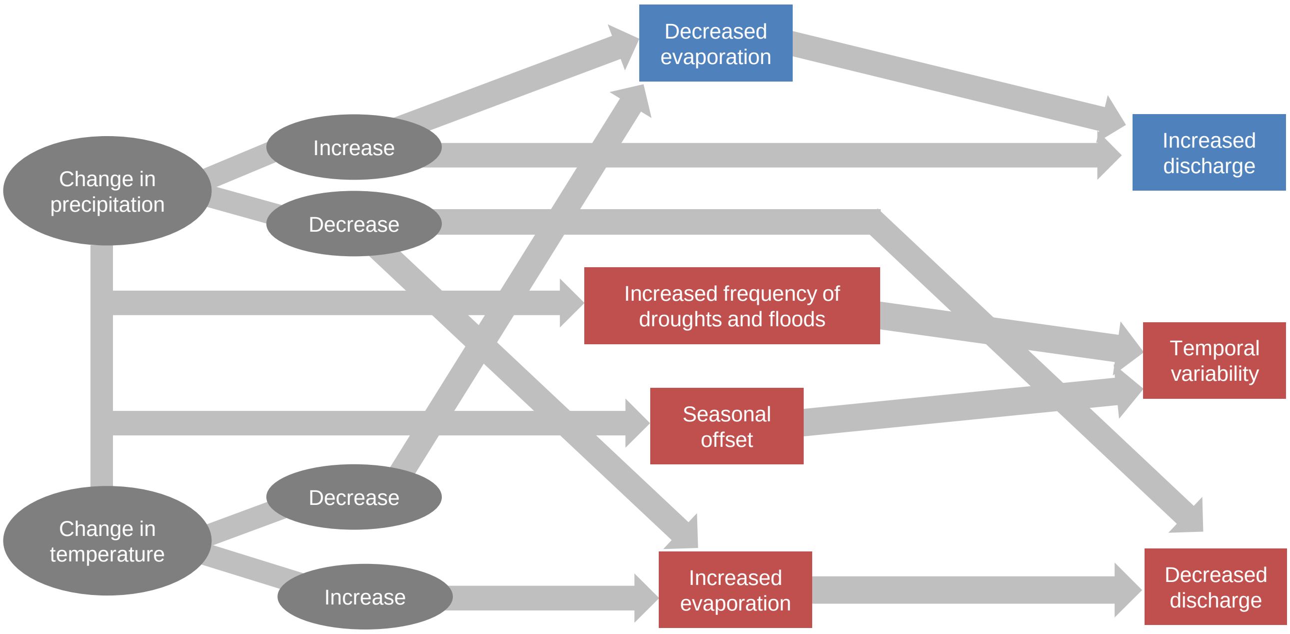
Hydropower generation is one of the energy sources most likely to be affected by climate change and climate variability because the amount of electricity generated is directly related to water quantity and its timing. However, the impacts of climate change through temperature and rainfall pattern changes upon hydrological cycles are complex and poorly understood in most low income countries (Harrison and Whittington, 2001). The potential impact of climate change on water resources has been postulated since the 1980s. Although Global Climate Models (GCMs) can be used to predict runoff directly, their coarse scale means that this information is only useful for the most general studies (Harrison et al., 2004; Kumar et al., 2011). As a result, many studies have been carried out on individual basins, showing that river basins display a range of sensitivities to climate change.

Numerous studies have indicated that hydropower economics are sensitive to changes in precipitation and runoff (Alavian et al. 2009; Gjermundsen and Jenssen 2001; Mimikou and Baltas 1997; Harrison and Whitington, 2001, 2003). Uncertainty about future hydrology presents a great challenge for infrastructure planning and engineering. Most hydropower projects are designed on the basis of “recent” historical hydro-meteorological data (typically a 30 to 50 year historical time series of flow data) and the assumption that future hydrological patterns (average annual flows and their variability) will follow historical patterns (Milly et al. 2008). This notion that hydrological patterns will remain “stationary” (unchanged) in the future; however, is no longer valid (Milly et al. 2008; Jayawardena, 2014).

Future hydropower performance is likely to be affected by both climate change and socio-economic change. The future risks (and opportunities) that could be cause by climate change include:

- Changing quantities, as well as spatial and temporal patterns of rainfall and river flows could increase or decrease the period when turbines can operate at full capacity;
- Increased evaporation rates from reservoir surfaces could reduce the water available for power generation;
- Increases in sediment loads in rivers, as a result of more intense rainfall and land use change, could lead to greater silt loads and rates of sedimentation in reservoirs that can lead to loss of storage and damage to turbine blades;
- Increased flood magnitudes, as a result of climate change, could lead to an increased probability of dam failures, as a result of spillways not being able to pass the flood flow safely. This has the potential to increase the number of people at risk downstream.

Figure 4.2 summarises the effects of changes in temperature and precipitation on the performance of hydropower schemes. Increasing temperature coupled with population and economic growth will increase demands for water for domestic, industrial and agricultural purposes, meaning that greater competition for water reduces the water available for hydropower thus reducing power generation.



Red indicates effects that are typically detrimental to hydropower performance
Blue indicates effects that typically improve hydropower performance

Figure 4.2: Flow chart illustrating the possible impacts of climate change on hydropower performance in sub-Saharan Africa

In 2011 construction started on the Grand Ethiopian Renaissance Dam which is the largest hydropower project in Africa with ambitions to generate around 6,000 MW. Figure 4.3 shows a computer-generated image of the dam. The Ethiopian Government has argued that as well as supplying Ethiopians with electricity, the dam will generate surplus energy for export to neighbouring countries, benefitting the wider region. However, economic studies have shown that the expansion of hydropower capacity would be beneficial; there are numerous sources of uncertainty that could change these conclusions including the fact that (Hammond, 2013). Box 4.1 provide details the consideration of climate change in the planning of the Grand Ethiopian Renaissance Dam.

Box 4.1: Consideration of climate change in the planning of the Grand Ethiopian Renaissance Dam

In April 2011, the Ethiopian Government commenced construction of a hydropower dam on the Blue Nile, 45 km east of its border with Sudan, which has been named the Grand Ethiopian Renaissance Dam. Ethiopia made a unilateral decision to build and finance the project (Hammond, 2013). A computer-generated image of the dam is shown in Figure 4.3. The hydropower scheme will generate approximately 6,000 MW of electricity and will cost nearly US$5 billion (Hammond, 2013). To date, the World Bank and other international donors have refused to support the project, and the Ethiopian Government is attempting to finance the project through a national bond (Hammond, 2013; Whittington et al., 2013). The hydropower scheme is scheduled to open in July 2017 (International Rivers, 2014a).

It has been reported that the lack of transparency in regards to planning of the project is "*unnerving*" some Non-Governmental Organisations and neighbouring countries (Power-Technology.com, 2013). There are also concerns that Ethiopia will be over-dependent on hydropower. Ethiopian Electric Power Corporation's Mulugeta Asaye said recently that: "*The rainfall in Ethiopia varies considerably from year to year, therefore an overdependence on hydropower makes the energy supply very unstable*" (Power-Technology.com, 2013). There is currently no comprehensive integrated water resources management plan for the Blue Nile basin, nor adequate monitoring infrastructure (Veilleux, 2013).

In 2013 an international panel of experts was convened to assess various aspects of the project. The panel noted that the scheme's sensitivity to climate change and the potential impacts that could result from future climatic changes had not been taken into account in the planning and design of the dam. The expert panel stated that: "*A project of this scale and with such heavy reliance on rainfall patterns requires a better understanding of future hydrologic conditions to ensure the highest degree of flexibility and resiliency in its design and operation. The panel recommends a study that looks at the potential influence of climate change on the flow regime at the Grand Renaissance Dam and further downstream*" (International Panel of Experts Grand Renaissance Dam, 2013).

Unilateral responses by Nile Basin countries, such as the construction of the Grand Ethiopian Renaissance Dam, to the consequences of increasing temperatures, and changing hydrology, will almost certainly be both economically inefficient and politically risky (Whittington et al., 2014). Because adaptation to climate change is also likely to be expensive, the Nile Basin countries need the benefits of cooperative trade agreements and more integrated markets to finance effective adaptation measures. The prospect of climate change thus enhances the value to Nile Basin countries of finding a cooperative water development path, and increases the incentives for them to reach cooperative water management agreements. However, there are no guarantees that cooperation on climate change adaptation will in fact occur (Whittington et al., 2014).

Figure 4.3: Computer-generated image of the Grand Ethiopian Renaissance Dam

The Bui Dam in Ghana is a gravity roller-compacted concrete dam that will generate 400 MW of hydropower and facilitates the irrigation of about 30,000 ha of land (Water-Technology.net, 2014). In 2012 the total cost of the scheme's construction was estimated to be approximately US$800 million (Water-Technology.net, 2014). The dam will commence generating power in 2014; however, despite its cost climate change does not appear to have been taken into account in its planning and design as Box 4.2 details.

Box 4.2: Assessment of the impacts of climate change on the Bui Dam hydropower scheme, Ghana

Ghana has been experiencing a severe energy shortage as a result of the low water levels and capacity problems at the existing Akosombo Dam on the River Volta, which supplies around 60% of Ghana's electricity (Sackitey, 2012). To increase Ghana's generating capacity the construction of the Bui Dam hydropower scheme has recently commenced. In 2007, the Chinese government agreed to a loan of US$622 million to cover the dam and power station construction. In April 2007, the Ghanaian Government signed an agreement with Sino-Hydro, the Chinese Company that are constructing the 400 MW scheme. The completion of the scheme is expected in 2014. The project's environmental analysis ignored the potential for climate change to reduce the dam's power output. The International Water Management Institute, in conjunction with the Ghana Dams Dialogue, proposed the need for further assessments of the Bui project's impacts and the issue of climate change, but this did not slow construction.

Source: (Davies et al., 2008; International Rivers, 2014b)

4.3. Climate services to support climate change adaptation in the planning, design and operation of hydropower schemes

A hydrological study, which determines the fluctuations of river flows, is the basis for the planning and design of a new hydropower scheme. The results help to determine the following:

- The capacity of the turbines that can be installed. This influences the design of civil engineering structures (e.g. dam, offtakes, powerhouse), as well as, the design of the electro-mechanical equipment;
- The reliable and peak energy production throughout an "average" year and a drought year;
- The economic viability of the scheme;
- The impact of the scheme on the aquatic environment and other water users.

Ultimately, the economic and overall viability of a new hydropower scheme are dependent on the hydrological analysis. A "fit for purpose" hydrological study for a new hydropower scheme requires the following climate services:

- Flow data – A continuous record of river flows, ideally at the site where the hydropower scheme is to be constructed, is required. A flow series of at least 30 years is often quoted as being sufficient. However, longer flow series improve the estimates of the reliable power generation. In practice flow records in sub-Saharan Africa are often limited and sporadic. This means that rainfall – runoff models are often used to generate and/or extend flow series.
- Rainfall data – Rainfall records are generally longer than flow records. These are often used to generate flows at proposed hydropower schemes using a rainfall – runoff model.
- Other meteorological data (e.g. temperature, solar radiation) – These are required to estimate evaporation from the reservoir, which can be significant for large reservoirs in sub-Saharan Africa.
- Climate change scenarios – There is need to have relevant climate scenarios that can be incorporated into the planning of new hydropower schemes. Downscaled climate data are used for generating locally relevant data from Global Climate Models (GCMs). The objective is to connect global scale predictions and regional dynamics to generate regionally specific forecasts.

4.4. Review of industry practice for incorporating climate change into the planning and design of hydropower schemes

This section explores the extent to which future climate change is included in the planning and design of hydropower schemes. Both Pottinger (2009) and Iimi (2007) claim that climate change impacts are rarely explicitly considered when planning hydropower projects. Cole et al (2013) states that it "*would appear that the siting of hydropower dams is often a process dominated by political and fiscal considerations, lobbying, corruption and compromise*" (Cole et al., 2013). In 2010, the Economist said that when planning dams "*the standards set in 2000 by the World Commission on Dams…are often ignored in Africa. Projects are rushed. Huge contracts are open to corruption. Engineering can be shoddy…*" (Economist, 2010).

A recent scoping study conducted for the World Bank noted that: "*Most hydropower/reservoir operators do not see climate change as a particularly serious threat. The existing hydrological variability is more of a concern, and the financially relevant planning horizons are short enough that with variability being much larger than predicted changes, the latter do not seem decisive for planning*" (Rydgren et al. 2007).

Rainfall and river flows in Africa display high levels of variability across a range of spatial and temporal scales (Conway et al., 2008). Figure 4.4 illustrates the variability of 20 year moving average flows in the River Congo and Zambezi River over the last century. Figure 4.4 shows that future trends in river flows and rainfall related to climate change will need to be large and prolonged over time, in order to enable “formal attribution”, and to create conditions beyond those which have already been experienced during modern times (Conway et al., 2008).

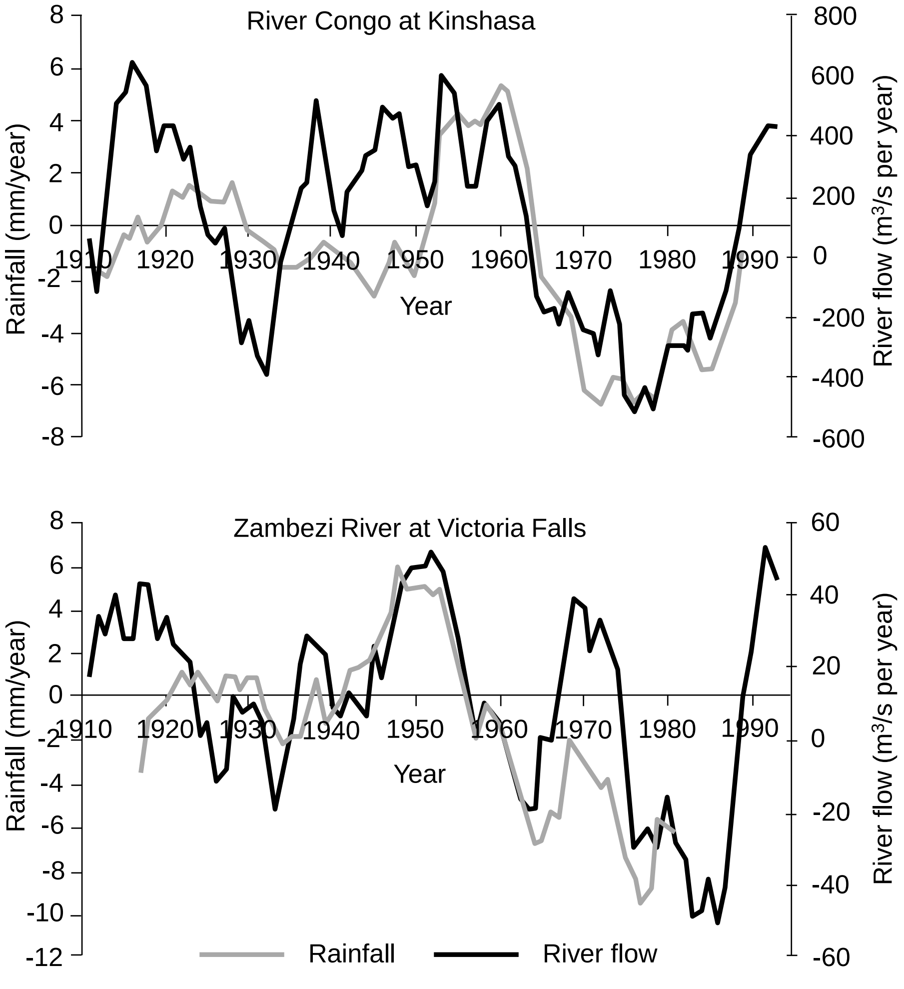


Figure 4.4: 20 year running trends in rainfall and flows for the Zambezi River and River Congo

Source: Adapted from Conway et al., 2008

This has important consequences for the management of hydropower schemes under future climate change scenarios. The planning horizon for hydropower schemes rarely stretch beyond 2050 (Holm et al., 2008; IRENA, 2013). As an example, in South Africa the planning horizon for Integrated Water Resources Management is 25 years (Department of Water Affairs, 2010)[2]. However, in most parts of the world, including sub-Saharan Africa, it is only after the 2050s at which climate-driven changes in rainfall and river flows are expected to emerge from natural variability (EEA, 2007). Hence if the planning horizon of water

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[2] The IWRM approach informs policies related to water allocation, conservation and management and monitoring in South Africa (Denison and Mazibuko, 2009).

resources projects is of the order of 25 years this means that that when planning a hydropower scheme the natural variability of the existing hydrological regime is often within the variability of the climate change projections.

Rydgren et al. also stated that the thinking that pervaded the stakeholders that they had contacted as part of their work was that when climate models were applied to sub-Saharan African rainfall, the predicted changes over the next 100 years were smaller than natural variability, making interpretation difficult (Rydgren et al., 2007).

It is also important to note that a calculation of the internal rate of return is often used by international funding agencies such as the World Bank to assess the viability of investments in long-lived infrastructure. When calculating the internal rate of return of a project, the mathematical function used is such that a small value is put on income and/or costs incurred beyond 25 to 30 years into the future. Rydgren et al. postulate that one of the reasons that climate change is not taken into account when planning hydropower is that within such a relatively short planning horizon, an increase in the variability of river flows as a result of climate change are often not expected to be noticeable on top of historical variability (Rydgren et al. 2007).

Box 4.3 details the complexity involved in developing climate scenarios for Tanzania. The Global Climate Models for this part of Africa suggest an increase in annual average precipitation by 2030. However, national power producers who rely on hydropower have plans to diversity their generation sources owing to anticipated increase in droughts in the central region of the country where their hydropower reservoirs are located (SCA, 2009). This apparent conflict is a question of understanding the temporal variability of the data. Regional climate models indicate that Tanzania will face more rain and storms on the coast, but greater drought in the central regions. Box 4.3 shows the potential impact of climate change on hydropower production in central Tanzania.

Box 4.3: Climate change and hydropower in central Tanzania

Central Tanzania is critical in terms of hydropower generation, contributing 50% of Tanzania’s hydropower production capacity. A recent study has shown that by the year 2030, the low availability of hydropower might lead to significant additional costs for the country if it chooses to use thermal technologies, which are more expensive than hydropower. In the high-climate scenario, the expected losses would lead to a 1.7% decrease in national Gross Domestic Product (GDP) in 2030. Even in the moderate-climate scenario, it would imply a 0.7% decrease in national GDP. However, efficiency provides a no-regrets option. The analysis showed that it is possible to compensate most of the expected shortfalls in power production by implementing energy efficiency measures such as demand reduction and/or reduction of spills at hydropower dams. To assess more accurately the impact of droughts on power generation, historical rainfall data were correlated with historical power production at Kidatu, the largest hydropower plant in the country. The analysis revealed that 1 GWh can be produced for every 2 mm of rain in the central region of Tanzania. This result was then extrapolated to all hydropower schemes in central Tanzania, which provided an understanding of the amount of hydropower available under the different climate change scenarios considered. It was estimated that although the energy reserve margin by 2030 could be as high as 26% with no climate change, it could fall to 12% under moderate climate change, or 0% in the high climate change scenario. Typically a reserve margin under 15% is considered to be a risk.

(Source: ECA, 2009)

Harrison et al. carried out research to investigate the effect of future climate change on the net present value (NPV) of the proposed Batoka Gorge hydropower project on the Zambezi river in southern Africa in context with other key project parameters (Harrison et al., 2003). The project will comprise a 181 m tall concrete, arch dam and two hydropower plants, each with an installed capacity of 800 MW; one on the Zambian side and another on the Zimbabwean side of the river.

The first stage of Harrison et al.'s research was to investigate how changes in future flow directly affect the potential amount of power that can be generated by the Batoka Gorge hydropower project. The study found that although volumetrically greater changes in output occurred during the high flow period, changing climate has a proportionately greater impact on low flows (Harrison et al., 2003). Under the wet climate change scenario (an increase in precipitation of 20%), power production was found to be raised by 7% and 18% for high and low flow periods, respectively, while under the dry scenario (a decrease in rainfall of 20%), monthly power output decreased by 23% and 30% on the same basis (Harrison et al., 2003). These changes are shown in Figure 4.5.

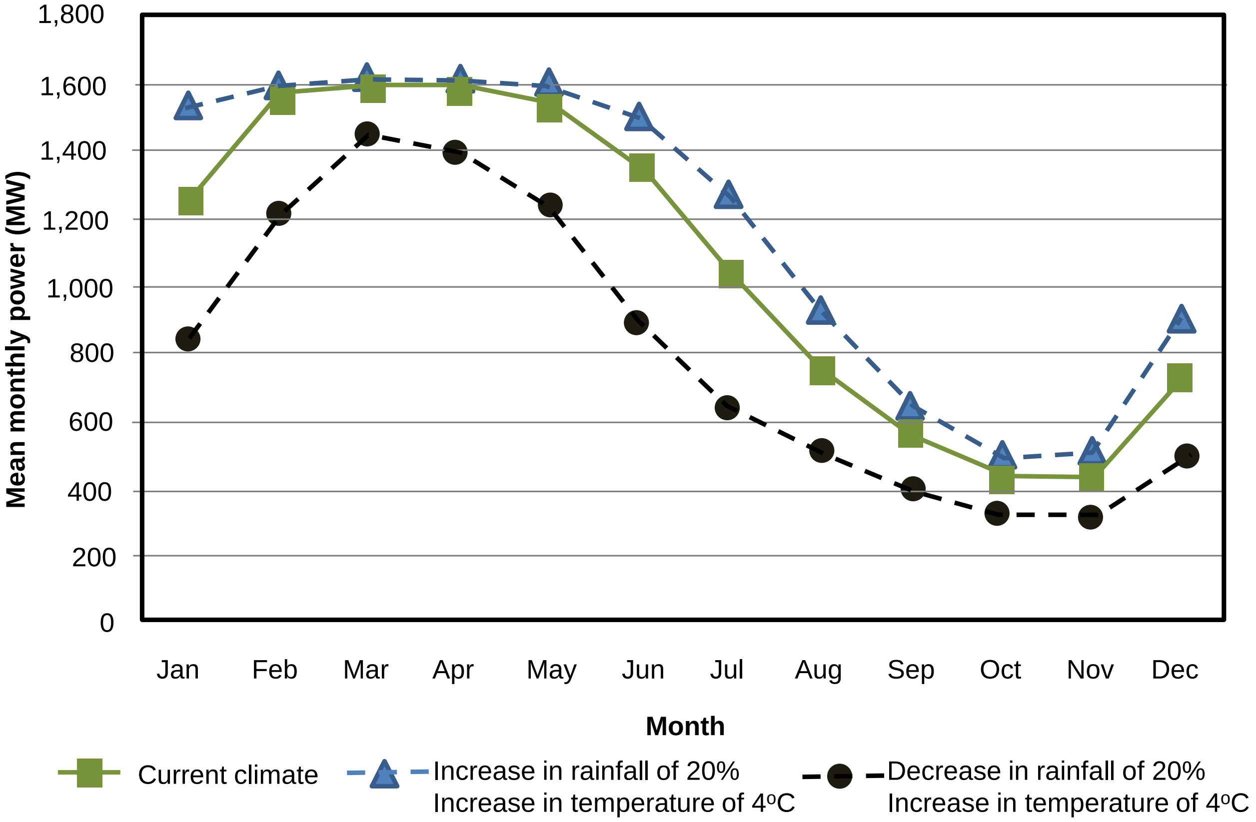

Figure 4.5: Impacts of two future change scenario on predicted mean monthly power generation at the proposed Batoka Gorge hydropower site on the Zambezi

Source: Adapted from Harrison et al., 2003

Hydropower projects, involving large dams, are often prone to cost and programme overruns (WCD, 2000). In addition to extending the period where there is no revenue associated with scheme, in the intervening period the price of electricity may change or the generating station may default on an electricity supply contract (Harrison et al., 2003). Harrison et al. selected key project parameters including changes in rainfall to test the sensitivity of the NPV of the Batoka Gorge hydropower project to these. These parameters included:

- Civil engineering costs because they represent the main capital cost and inaccurate estimates of these having a significant impact on project returns;
- Construction period, which affects the amount of loan interest capitalised;
- Electricity tariffs;
- Discount rates;
- Changes in rainfall under climate change.

(Harrison et al., 2003)

Each parameter was changed, in turn, by ±20% from its original value and the change in net present value (NPV) calculated (Harrison et al., 2003). Harrison et al. found that the NPV of the proposed Batoka Gorge hydropower scheme is most sensitive to changes in discount rate, with increases in this parameter reducing the present worth of future sales income. The next most sensitive variable was found to be the electricity tariff, followed by the civil engineering costs and length of the construction period (Harrison et al., 2003). This is shown in Figure 4.6. Decreases in the tariff price or increased construction cost and construction programme reduced the financial performance. However, the sensitivity to changes in precipitation as the result of climate change was found to be of a similar magnitude to both the discount rate and electricity tariff (Harrison et al., 2003) as shown in Figure 4.6. Harrison et al. conclude that this adds credibility to the view that funding agencies should take into account the effects of "*this uncontrollable risk factor*" i.e. climate change (Harrison et al., 2003). It is interesting to note that there is no evidence to suggest that the work of Harrison et al. has been taken into account in the planning of the Batoka Gorge hydropower scheme.

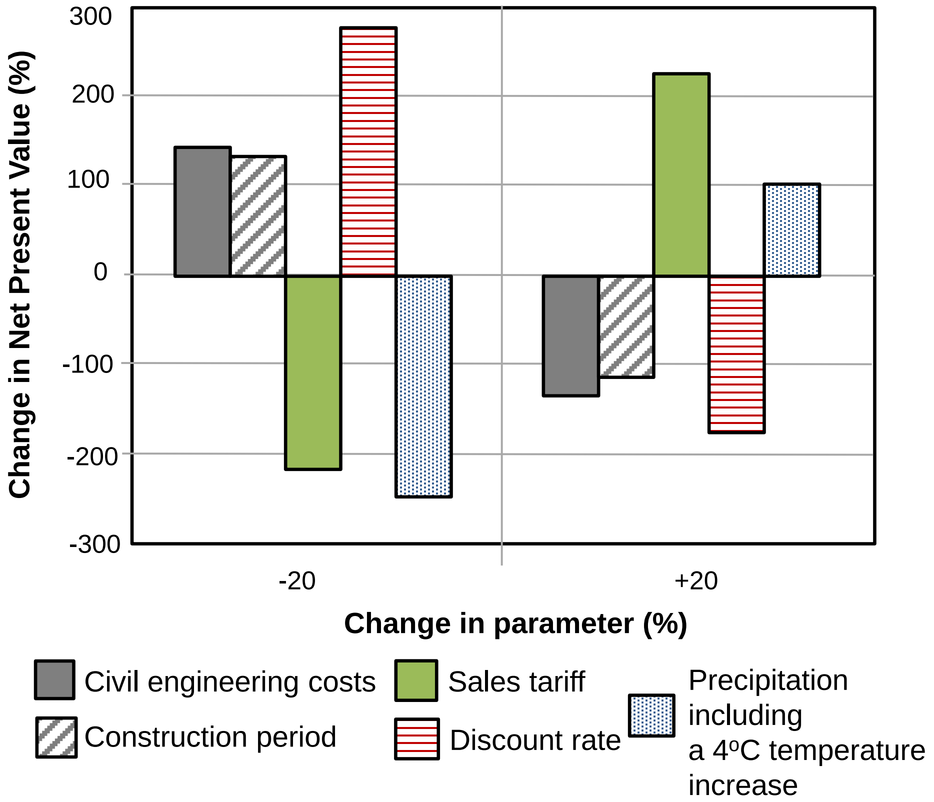

Figure 4.6: Variation of the net present value of proposed Batoka Gorge hydropower project on the Zambezi with changes to key project parameter and climate change

Source: Adapted from Harrison et al., 2003

4.5. Policy, institutional, cultural and technical capacity barriers to the uptake of long-term climate services in the planning and design of hydropower schemes

Policy, institutional and cultural issues can impede or advance the integration of climate change adaptation in the planning and design of hydropower schemes. Technical solutions by themselves are of no practical value unless they are supported by people with the power to make policies and to ensure that the policies are implemented through appropriate governance and institutional processes (McCornick et al., 2013).

Given the pressing problems confronting African countries, there is a tendency for governments and policy makers to focus on relatively short term policy interventions. IRI found that probably nowhere on the African continent outside South Africa and northern Africa is climate change systematically integrated into longer-term planning and investment decision-making (IRI, 2006). In much of sub-Saharan Africa there would also appear to be a lack of effective institutional arrangements to facilitate the generation, analysis and systematic integration of relevant climate information with other pertinent information in a form that planning and operational agencies can use (IRI, 2006).

There are also governance issues in trans-boundary river basins in sub-Saharan Africa. McCornick et al. state that tensions between managing water within natural boundaries and managing water within national borders proliferate (McCornick et al., 2013). Competing political and economic interests between countries in trans-boundary river basins, while widely deliberated, are challenging to resolve (McCornick et al., 2013). For example, the Blue Nile river basin is an important resource shared by Ethiopia, Sudan, and, because it is the main tributary of the Nile, Egypt. There is significant uncertainty about the likely impacts of climate change in the basin. Some models indicate that there will be more rainfall (see Box 3.1) and some less. Future climate change will affect river flows and, thus, how much water is available for hydropower is even less certain.

Under the auspices of the Nile Basin Initiative countries in the basin have agreed to collaborate. However, there are still tensions. Formal mechanisms to develop the basin's water resources cooperatively are limited and these do not appear to incorporate the impacts of future climate change. Despite the potential benefits of cooperation countries continue with unilateral plans for development of hydropower schemes (see Box 4.1). In the absence of integrated planning, much of the currently planned investment in water storage is likely to underperform and intended benefits may not be fully realised (McCartney et al. 2013). A key aspect of adapting to climate change is that countries in transnational basins plan and work together much more than they have done in the past (McCartney et al. 2013).

Box 4.4 details some of the cultural reasons found by Dinku et al. as to why climate change scenarios are not taken into account in the planning of hydropower schemes in Ethiopia. This includes the finding that many water managers did not want to use probabilistic forecasts because they have the potential to be seen to be “wrong”. It is important to note that this issue is not one confined purely to sub-Saharan Africa. Research in to the dissemination of probabilistic forecast of floods in England found that broad societal debates about public understanding of probability and uncertainty have moved in the direction of arguing that it is a good thing that government institutions are more explicit and open about probability and uncertainty, promoting greater social trust and understanding. However, counterarguments point to the misunderstandings and undermining of expertise which might arise from using uncertain information in decision making (see Lumbroso et al, 2009).

Technical capacity is also an issue in sub-Saharan Africa. Washington et al (2006) reported that a significant constraint on climate science in Africa is the relative scarcity of African climate scientists

(Washington et al., 2006). Washington et al. state that "*journal publications in Africa is among the lowest anywhere in the world*" and that this limited international engagement isolates African climate science (Washington et al., 2006). Washington also states that the capacity of African climate science that does exist is "*fragile in terms of numbers*" (Washington et al., 2006).

FitzGibbon and Mensah, who looked climate change as a wicked[3] problem in the institutional context for Ghana concluded that: "*In the case of Ghana, climate change involves a level of complexity that goes beyond the capacity of national and local water institutions to meaningfully manage. The enormity has arisen from, among other things, the scalar dimensions of climate, diversity of climate, and water-related functions, and the multitude of linkages that these functions have with peoples' livelihoods*" (FitzGibbon and Mensah, 2012).

Box 4.4: Cultural reasons why climate change scenarios are not taken into account in the planning of hydropower in Ethiopia

In Ethiopia many Western donors have moved away from funding large infrastructure projects, with Chinese investment frequently being used to build new roads and hydropower projects. Ethiopia recently signed a US$1.9 billion deal with China's Sinohydro Corporation to construct several hydropower schemes (Paul et al., 2012). Chinese investments often do not require the same environmental and social standards that are applied by many international funding agencies (Paul et al., 2012).

In China water projects do not fully consider the potential impacts of climate change (Xia, 2012). This may be another reason why it would appear that climate change scenarios do not appear to be considered in the planning and design of hydropower schemes in many sub-Saharan African countries.

There are also cultural issues that may contribute for climate change and climate forecast not being used. The International Research Institute for Climate and Society (IRI) at Columbia State University recently delivered training in Ethiopia that targeted water resource professionals in the Ministry of Water and Energy. This focused on managing hydro-climatic risks in the water sector to assist in facilitating the use of climate information in decision models. Dinku et al state that two important non-technical outcomes surfaced from the training. The first was that some components of management decision making in East Africa are "*intrinsically tied to religious and/or cultural beliefs*" (Dinku, 2012). A second reason for not using forecasts given by Dinku is that the participants at the training, although acknowledging the benefits of the application of using the forecasts in the decision making process, said that they did not want to use probabilistic climate forecasts. Dinku states that "*it became clear that water managers considered the use of a probabilistic forecast, with the potential to be "wrong", as a personal liability. Presently, this is a critical institutional barrier, not unique to East Africa, deserving of attention from policy makers and high-level decision makers, to design measures for transferring this risk away from the manager*"

(Dinku et al., 2012).

Although public agencies around the world have put in place broad requirements that water resource infrastructures should incorporate climate change, no guidelines specify how this should be done (Vescovi, Baril and others 2009; Stutley 2010; Brekke 2011; USAID, 2012). Designers and managers of hydropower schemes are thus left with the challenge of being asked by funding agencies to incorporate climate change scenarios into their plans and operations of these schemes, but without any operational guidance on how this should be done or the necessary skills.

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[3] The term wicked problem is used to refer to adverse social and environmental situations that overwhelm existing practices and persist even after the application of best-known practices.

Another factor is that in recent years, the China Ex-Im Bank has become a significant new financier of power infrastructure in sub-Saharan Africa (Eberhard et al., 2008). Over the period 2001 to 2006, Chinese financing commitments to the sub-Saharan African power sector averaged US$1.7 billion per year, which is equivalent to around 0.2% of the region's GDP and more than official aid and other private investment combined (Eberhard et al., 2008). The major focus of Chinese support has been the development of six large hydropower projects with a combined generating capacity of over 7,000 MW (Eberhard et al., 2008). Once completed, these projects should increase the region's installed hydropower capacity by 40% (Eberhard, 2008). As stated in Box 4.4 it would appear that Chinese water projects do not fully consider the possible effects of climate change. This may be why Chinese financed hydropower schemes in sub-Saharan Africa do not appear to take account of climate change in their planning and design.

5. Conclusions and policy recommendations

5.1. Conclusions

The evidence available suggests that although historical hydro-meteorological data are used in the planning and design of hydropower schemes the impact of climate change is rarely taken into account. Several studies to assess the effects of climate change on hydropower performance in sub-Saharan Africa have been carried out (see Grijsen, 2014; Harrison and Whittington, 2001; Harrison et al., 2003). They have either been carried out after the hydropower scheme has been constructed or as academic exercises. The evidence available suggests that as a matter of course climate change is not taken into account in the planning of hydropower schemes. This was a view also reached by Rydgren et al. who carried out a study for the World Bank in 2007 addressing increases in climate-driven variability in the assessments of hydropower projects (see Rydgren et al., 2007). There appear to be numerous reason why climate change scenarios are not used in the planning and design of hydropower schemes in sub-Saharan Africa. These are summarised below:

- The majority of new hydropower developments in sub-Saharan Africa are being financed by Chinese investments. There is some evidence to suggest that these projects do not require the impacts of climate change to be taken into account in the planning and design of new schemes.
- Planning horizons for new hydropower schemes generally do not extend beyond the year 2050. The natural variability of rainfall and river flows is such that it is only after 2050 that climate change driven changes begin to emerge. There is pressure on many sub-Saharan African countries to develop new sources of renewable energy and there is a tendency for governments and policy makers to concentrate on the short-term and not to integrate climate change scenarios into the planning of long-lived infrastructure such as hydropower schemes.
- Taking into account climate change scenarios in the planning of long-lived infrastructure is a relatively new phenomenon. For example, it is only since 2011 that impacts of climate change have been taken into account in the planning for coastal flood defences in France (see Lumbroso and Vinet, 2011).
- It would appear that some stakeholders find existing climate services and downscaled climate change scenarios for sub-Saharan Africa difficult to access or understand, and therefore they tend to be underutilised. Dinku et al. also found that in Ethiopia water resources management decisions are often linked to religious and cultural beliefs (Dinku et al., 2012). Many water managers were reluctant to use probabilistic climate forecasts because they did not want to be seen to be "wrong" (Dinku et al., 2014).
- Often it is difficult for water managers and hydrologists to use climate change projects in the planning and design of hydropower schemes. An expert meeting on water manager needs for climate information

in water resources planning convened by the World Meteorological Organization in December 2006 reported that "*information on future climate variability and climate change is only rarely used by water managers in decision-making processes. There was a general observation that the state of the art of climate prediction is not yet at a level where it can be used directly*" (WMO, 2006). This meeting also concluded that "*most plans for Integrated Water Resources Management do not consider climate change*" (WMO, 2006).

Water managers typically deal with uncertainties in climate data; however, they usually deal with this information in a deterministic manner by converting probability distributions into discrete design criteria, for example, the "probable maximum flood" (WMO, 2006). In this context, much of the available climate change information, such as the long term scenarios presented by the IPCC, is "*relatively uninformative*" (WMO, 2006). To be of direct use, scenarios of long term change in climatic conditions need to be converted to reasonably reliable predictions of changes in flood and drought frequencies, as well as more general alterations to hydrological regimes. On a strategic horizon of years and decades the World Meteorological Organization meeting concluded that climate information is hardly used for planning and management purposes at of water resources related projects present (WMO, 2006).

There would appear to be a need for an improvement in the communication between meteorologists, climate change scientists, hydrologists, water managers and civil engineers responsible for planning hydropower schemes, in order to help ensure that future climate change is taken into account in the planning and design of these form of long-lived infrastructure. One of the issues is that there is a mismatch in scale between Global Climate Models and the catchment scale that needs further resolution. Water is managed at the catchment scale and the planning and design of a hydropower scheme is site-specific, whilst Global Climate Models work on large spatial grids (e.g. typically 100 x 100 km).

5.2. Policy recommendations

The following provide policy recommendations related to climate change services for the planning and design of hydropower schemes in sub-Saharan Africa.

Integrating climate services into policy

In 2006 the International Research Institute (IRI) completed a gap analysis for the implementation of the global climate observing system programme in Africa. In terms of integrating climate services into policy in Africa. This report identified that there is "*a significant gap in perspective exists between policy makers focused directly on growth and development in Africa and those focused on climate change issues*" (IRI, 2006). The IRI report also states that "*given the pressing problems confronting African countries, the tendency is for governments and policy makers to focus on shorter term policy interventions and problem solutions. It can probably be said that nowhere on the continent outside South Africa and northern Africa is climate systematically integrated into longer-term planning and investment decision-making*" (IRI, 2006). This certainly appears to be the case with respect to the planning for new hydropower schemes on the continent, the majority of which do not which appear to have integrated climate change scenarios into their planning and design. The issue may be that many policies in African countries do not allow the connection to be made with the fact that managing climate variability for hydropower schemes can improve the return on investments in this form of infrastructure. There is a need to integrate climate services into national and regional policies in sub-Saharan Africa that influence the development of hydropower schemes.

Improving institutional coordination

There is a gap in the understanding of institutional, policy and technical constraints to the effective use of climate information (IRI, 2006). IRI states that "*there is the lack of effective institutional arrangements to facilitate the generation, analysis and systematic integration of relevant climate information with other pertinent information in a form that planning and operational agencies can use*" (IRI, 2006). This may explain why climate information (other than historical climate data) are not used to improve the seasonal operation and to assess the performance of hydropower scheme under future climate change.

Of the sectors that IRI investigated, it was found that the water sector was probably the most advanced in terms of incorporating climate services into strategic planning, at least in the more water-scarce countries (IRI, 2006). This is because of the dependence of the performance of water resources projects, such as hydropower schemes, on climatic variability. However, it would still appear that both seasonal climate and climate change scenarios are not widely used by hydropower planners, designers and operators.

It is also important to note that water resources planning in Africa can be complicated because of the requirement to take into account trans-boundary issues and the associated weaknesses of information services and decision-making at the regional scale in Africa (IRI, 2006).

Improvements to hydro-meteorological networks

There are often limited hydro-meteorological data available in sub-Saharan African countries. Where data have been collected in the past, they are often only available in paper format. In many sub-Saharan African countries hydro-meteorological data are often underprovided and underused (World Bank, 2012a). To collect and store large volumes of hydro-meteorological data is still relatively expensive. However, low-income countries often allocate insufficient budget to hydro-meteorological agencies, meaning that they are often forced to sell data. As a consequence hydro-meteorological data in Africa are often not freely shared, despite World Meteorological Organization mandates (Peterson and Manton 2008; Viglione, Borga and others 2010). This means that many stakeholders are often unable to benefit from these data.

Under-investment in hydro-meteorological networks and climate change is especially evident in Africa (World Bank, 2012a). The network of hydro-meteorological stations is sparse and deteriorating. Hydro-meteorological data are often sporadic and inaccurate (World Bank, 2012a). Existing meteorological stations are often not functioning or fail to communicate with the global meteorological network (World Bank, 2012a). These inadequacies are especially serious given the large proportion of Africans engaged in agriculture and the reliance of many countries on hydropower. The African Climate Report (Washington et al., 2004) found that the climate-observing system in Africa is in a worse state than that of any other continent, and that it is deteriorating. The network of 1,152 World Meteorological Organization World Weather Watch stations in Africa, which provides real-time weather data as well as forming the basis of international climate archives, has an average station density of just one per 26,000 km^2, which is eight times lower than the World Meteorological Organization minimum recommended level (Washington et al., 2006).

More comprehensive and accurate hydro-meteorological data means stakeholders responsible for the planning, design and operation of hydropower schemes can better understand current and potential future climate so that adaptation responses can be tailored to meet end user needs. This will assist in strengthening food production and agricultural development to meet the food security and improve the performance of hydropower schemes. Even in South Africa, which is a relatively wealthy country in the context of sub-Saharan Africa, there is growing concern that reductions in the rainfall and river flow gauging networks are no longer sufficient to accurately detect trends in these variables (Department of Water Affairs, 2010).

Hydropower schemes based on limited and unreliable hydrological data have the potential to underperform and not to attain the benefits the infrastructure is designed to generate. Generally, in the past two decades hydro-meteorological networks in low income countries have deteriorated, hence this is an area that needs to be urgently addressed.

There is also a need to encourage the use and sharing of hydro-meteorological information within and *between* countries in sub-Saharan Africa. There is a need to provided support to developing sustainable hydro-meteorological products that are accessible and useful to a wide range of stakeholders.

Climate change scenarios should be incorporated into the planning and design of new hydropower schemes

Iimi (2007), Rydgren (2007) and Pottinger (2009) all claim that climate change impacts are rarely explicitly considered when planning hydropower projects. There is strong evidence to suggest that the possible effects of climate change are not being taken into account when new hydropower schemes are being planned (see Iimi, 2007; Pottinger, 2009; and Beilfuss, 2012). Climatic uncertainty as the result of climate change should be incorporated into hydropower design, as a matter of course to help to avoid over- or under-designed infrastructure and financial risk, and to improve the resilience of this long-lived infrastructure. There is some limited work that suggests that planned investment for hydropower in Africa is in regions that are unlikely to experience the worst effects of climate change and hence are fairly low risk in terms of being non-performing or not meeting internal returns targets, but there are also other studies that contradict these findings. More work is required to assess the impacts of climate change uncertainty on proposed hydropower schemes in low income countries relative to other variables (e.g. capital costs, operation and maintenance costs, internal rates of return).

New hydropower schemes need to be assessed within the context of comprehensive catchment-wide planning using a range of climate change scenarios

New hydropower schemes should be considered in the context of the whole catchment taking into account how climate change will influence flows, and how future river flows must meet competing demands made for energy, the environment, and water supply for domestic, agriculture and industrial uses.

Emphasis should be placed on investing in hydropower schemes that maximise flexibility and adaptive management

Climate change accentuates the risks related to the development of new hydropower schemes because stationarity in future river flow series can no longer be assumed. This means that a premium should be placed on hydropower schemes that maximise flexibility and operations that embrace adaptive management.

Development of guidelines to assist policy makers, planners and designers incorporate climate change into the planning, design and operation of hydropower schemes

There is a need to develop guidelines for incorporating the risks posed by climate change into the planning, design, appraisal, and implementation of projects. The African Development Bank is currently developing guidelines succinct climate change guidelines, which will enable water sector task managers to integrate climate change considerations into project cycle, seek access to additional funding, and incorporate adaptation and mitigation component in projects/programs; and to build the capacity of the staff on the implications of climate change and practical mitigation and adaptation measures, with specific details on the planning, social, environmental, financial, and technological aspects (Shoji, 2014).

The Word Bank is also considering producing guidelines, tailored to specific types of projects. These would include "*relevant risks to be assessed; guidance on available risk assessment tools including their strengths, limitations, and applicability; and options for integrating climate risk considerations into design and* *implementation*" (World Bank, 2012a). It is not clear when these guidelines will be available and if they will be applicable to large hydropower schemes.

Improvements in monitoring and evaluation of hydropower schemes

It is important to ensure that Monitoring and Evaluation (M&E) systems support adaptive management: These systems are essential to any strategy to adapt hydropower schemes to climate change. They should help society understand clearly whether current water management practices are delivering on their promised outcomes, and enable decision-makers to apply any lessons learned to improve present and future management of these schemes, as well as providing valuable lessons of how climate change can be incorporated into the planning and design of hydropower schemes.

Development of methods to rapidly assess data required from climate services for large hydropower schemes and how any gaps in information can be filled

For long-lived water resource infrastructure projects such as hydropower schemes it is necessary to assess the availability of relevant data and information and identify gaps in order to propose complementary studies that can enable a robust quantitative analysis of the effects of climate change on the future performance .

Capacity building in the use of climate services and climate change projections

It would appear that many stakeholders find existing climate services and downscaled climate change scenarios for sub-Saharan Africa difficult to access or understand. This could be one reason why they are not widely used. Work carried out recently in Ethiopia by the International Research Institute for Climate & Society on delivering capacity building focused on managing hydro-meteorological risks in the water sector and the use of climate information in decision models focus on Ethiopian water resource professionals reached the following conclusions:

"*Two important non-technical outcomes surfaced from the training. Firstly, some component of management decision making in East Africa is intrinsically tied to religious and/or cultural beliefs. While the science may be well understood and accepted, the social influences cannot be ignored. Working within the cultural context is crucial. Secondly, perverse incentives to not use forecasts exist. Upon completion of one training, the presenter asked the participants if they grasped the importance of climate risk management, particularly forecasts, if they realized benefits in its application, and if they understood how it could be integrated into a system of models to inform management decisions. All participants nodded affirmatively. The follow-up question of whether they would immediately and explicitly include climate forecasts and projections into their own operations was met with an unambiguous "no." After some prodding, it became clear that water managers considered the use of a probabilistic forecast, with the potential to be "wrong", as a personal liability. Presently, this is a critical institutional barrier, not unique to East Africa, deserving of attention from policy makers and high-level decision makers, to design measures for transferring this risk away from the manager."* (Dinku et al., 2014)

Downscaling of Global Climate Models and the use of these outputs in the planning of hydropower schemes

The effects of climate change on hydropower schemes rely on climate variables projected from downscaled results of Global Climate Models. For hydropower schemes rainfall and temperature must be converted into river flows at specific points to be able to assess climate impacts on the schemes. There is a need for relatively simple, easily accessible and widely agreed downscaled rainfall and temperature data series for future climate change scenarios for sub-Saharan Africa. These data could then be used by hydrologists in the planning of new schemes. This could also assist in providing a consistent approach to how climate change is taken into account in the planning of new schemes across the continent.

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Appendix

A. Changes in hydropower generation in the year 2050 relative to 2005 from Hamududu and Killingtveit, 2012

Table A.1: East Africa: Runoff, installed capacity, hydropower generation in 2005 and estimated changes in hydropower in 2050

Country	Runoff (mm/year)	Installed capacity (MW)	Hydropower generation 2005 (GWh)	Estimated changes in hydropower by 2050 (%)
Burundi	132	32	98	13.1
Comoros	723	1	2	
Djibouti	14	0		
Ethiopia	97	669	2,805	1.6
Kenya	52	677	2,996	
Madagascar	567	105	653	-4.5
Mauritius	1,081	59	113	
Reunion	1,941	125	575	
Rwanda	206	35	129	15.1
Somalia	21			
Tanzania	96	557	1,760	12.9
Uganda	272	306	1,839	14.9

Source: Hamududu and Killingtveit, 2012

Table A.2: Central Africa: Runoff, installed capacity, hydropower generation in 2005 and estimated changes in hydropower in 2050

Country	Runoff (mm/year)	Installed capacity (MW)	Hydropower generation 2005 (GWh)	Estimated changes in hydropower by 2050 (%)
Central African Republic	232	19	83	
Cameroon	612	805	3,874	0.0
Chad	37			
Democratic Republic of the Congo	549	2,410	7,322	-0.1
Gabon	627	170	806	-6.6
Sao Tome	2,100	6	11	
Republic of the Congo	2,409	92	351	-4.2

Source: Hamududu and Killingtveit, 2012

Table A.3: North Africa: Runoff, installed capacity, hydropower generation in 2005 and estimated changes in hydropower in 2050

Country	Runoff (mm/year)	Installed capacity (MW)	Hydropower generation 2005 (GWh)	Estimated changes in hydropower by 2050 (%)
Algeria	6	280	549	
Egypt	59	2,745	12,518	
Libya	0			
Morocco	72	1,498	1,398	
Sudan	26	308	1,227	7.1
Tunisia	30	66	144	-30.8
Western Sahara	3			

Source: Hamududu and Killingtveit, 2012

Table A.4: Southern Africa: Runoff, installed capacity, hydropower generation in 2005 and estimated changes in hydropower in 2050

Country	Runoff (mm/year)	Installed capacity (MW)	Hydropower generation 2005 (GWh)	Estimated changes in hydropower by 2050 (%)
Angola	147	497.5	2,197	-7.4
Botswana	25			
Lesotho	99	76	350	-8.8
Malawi	145	283	1,369	-0.4
Mozambique	274	2,136	13,131	-9.5
Namibia	22	249	1,641	-21.2
South Africa	41	661	903	-11.6
Swaziland	262	41	158	-12.7
Zambia	139	1,698	8,794	-4.5
Zimbabwe	51	850	5,776	-10.4

Source: Hamududu and Killingtveit, 2012

Table A.5: West Africa: Runoff, installed capacity, hydropower generation in 2005 and estimated changes in hydropower in 2050

Country	Runoff (mm/year)	Installed capacity (MW)	Hydropower generation 2005 (GWh)	Estimated changes in hydropower by 2050 (%)
Benin	213	1	1	
Burkina Faso	46	32	99	
Ghana	222	1,198	5,573	-1.6
Guinea	918	129	436	-2.9
Guinea-Bissau	922			
Ivory Coast	251	604	1,423	-6.2
Liberia	2,409			
Mali	80	155	240	
Mauritania	11	97	49	
Nigeria	314	1,938	7,871	0.4
Senegal	200	0	264	
Sierra Leone	2,206	4	0	6.1
Togo	257	67	73	

Source: Hamududu and Killingtveit, 2012

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