UNIVERSITY OF SUSSEX

CLIMATE CHANGE AND THE BUI DAM IN GHANA

JOSEPH NII ARMAH AYITIAH

Submitted in accordance with the requirements for the degree of MPhil in Development Studies

JULY, 2018

I hereby declare that this thesis has not been and will not be, submitted in whole or in part to another University for the award of any other degree.

Signature:………AJNA ………..

ABSTRACT

It is evident that the climate is changing and countries especially the developing ones are vulnerable. Various sectors such as water, agriculture and even land use are all being affected by climate change. Hydropower, a major source of electricity in Ghana is one key sector which has been hit by the changing climate thus contributing to the continuous power outages in the country. Government had to rush for emergency thermal plants at a cost whilst maintaining them with oil and gas has not been cheap.

It is important that economies are able to adapt to climate change and its uncertainties by being climate resilient as well as making sure long-lived infrastructure such as hydropower incorporate the problem of uncertainty. It would be also expedient for developing nations to be able to climate proof their entire energy sector and deal with climate change head on. In Africa, hydropower plants have been built without proper climate risk analysis. In Ghana, reports suggested that the Bui hydroelectric project did not consider climate change. Therefore this research was to understand how decision makers take decisions on hydropower investments in light of climate change and its associated risks and uncertainties. To be able to understand this process, the researcher used the Bui Dam as a case study, consulted various publications relating to the issue and conducted interviews with key informants. It was analysed using a framework adopted by Lemos et al. (2012) to understand the barriers to the use of climate information during the project. It was discovered that, the priority of the government was to attempt to solve the then power crisis and not necessarily consider climate change adaptation. A climate risk assessment has been scheduled to take place as part of the Environmental and Social Impact Assessment of The Pwalugu Dam. However, government must do more to support climate research as well as take advantage of various approaches that have been developed to aid decision makers when dealing with climate change uncertainty.

ACKNOWLEDGEMENTS

I would first like to thank my Father who art in heaven for His constant protection and love, in whom is the source of life and strength. I also thank my parents Mr & Mrs Ayitiah for their sacrifice and prayers. I am indeed grateful. To my siblings, Edwin, Kenneth and Shirley Ann as well as the entire ever growing family, may God Himself bless you for your support! I express my sincere gratitude to my supervisors Prof. Martin Todd and Prof. Dom Kniveton. It has been a long and difficult journey. You have been helpful and supportive than I could ever imagine. Thank you for your patience and guidance. I am extremely grateful. I thank Mr & Mrs Amarh, Mr. Solomon Tackie Oblie, Ms. Paulina Ayitiah, Dr. and Mrs Jonathan Nzak and Mr Kwame Darkwa for their support and hospitality during my stay. May God bless you!

This research would not have been successful without the input of officials from the Water Research Institute, Bui Power Authority, Energy Commission and Ghana Meteorological Agency. Your comments and directions as well as information provided made this work what it is. To the University library where I occasionally made by hiding place as well as the various journals, I am grateful. Finally, I hail my friends and my spiritual Father, George Edward Plange. Your prayers and encouragements got me to the finish line. I am grateful.

God bless you all

Joseph Nii Armah Ayitiah

ABBREVIATIONS

BPA- Bui Power Authority

CBA- Cost Benefit Analysis

CEA- Cost-effectiveness Analysis

CII- Country Implementing Institution

CMIP5-Coupled Model Intercomparison Project Phase 5

CSIR- Centre for Scientific and Industrial Research

DANIDA - Danish International Development Agency

DFID - United Kingdom Department for International Development

EIA - Environmental Impact Assessment

EPA – Environmental Protection Agency

ESIA - Environmental Social Impact Assessement

ESIA- Environmental and Social Impact Assessment

GAEC - Ghana Atomic Energy Commission

GDP - Gross Domestic Product

GHG - Green House Gas

GMet - Ghana Meteorological Services Agency

GSGDA - Ghana Shared Growth and Development Agenda

IEA - International Energy Association

IPCC - Intergovernmental Panel on Climate Change

LDC - Less Developed Countries

MCA - Multi Criteria Analysis

MDG - Millennium Development Goals

MOEP - Ministry of Energy and Petroleum

MW- Megawatts

NASA - National Aeronautics and Space Administration

NCCC - National Climate Change Committee

NCCP - National Climate Change Policy

NES- National Energy Strategy

NOAA- National Oceanic and Atmospheric Administration

OECD - Organisation for Economic Co-operation and Development

SCF- Seasonal Climate Forecasts

SNEP- Strategic National Energy Policy

SNEP - Strategic National Energy Plan

TCPD - Town and Country Planning Department

UKCIP- United Kingdom Climate Impacts Programme

UK- United Kingdom

UNDP - United Nations Development Programme

UNEP - United Nations Environment Programme

USD - United State Dollars

VRA -Volta River Authority

WMO - World Meteorological Organisation

WRC - Water Resources Commission

WRI - Water Resources Institute

Table of Contents

LIST OF TABLES

LIST OF FIGURES

CHAPTER ONE: INTRODUCTION

1.1 Background

Energy is essential as it drives economies and is essential in the fight against poverty according to the United Nations Millennium Development Goals (MDGs) (Flavin and Hull Aeck, 2005). Hydropower is the energy source which generates electricity from the natural water cycle (IRENA, 2012). It provides 16% of world electricity at competitive prices and has proven to be a vital source of electricity in both developed and developing countries (IEA, 2012). Although it is the dominant source of renewable electricity globally, it still has the potential to be developed further (IEA, 2012). Hydropower can expand electricity access to reach large populations, however in many less developed countries, especially in sub-Saharan Africa, not more than 10% of hydropower potential has been exploited (Balmer and Spreng, 2012).

Aside from its ability to offer cheap electricity, it also helps control water flows and availability (IEA, 2012). Also, many countries decide to invest in hydropower because of the stability it brings to electricity supply. It can, when there is a reservoir store electricity over short to long periods, (i.e., weeks to years) (IRENA, 2012). However, among its drawbacks is the colossal amount of capital required to kick-start its development, which can sometimes be up to tens of billions of United States Dollars (IEA, 2012). Another factor which might discourage nations from switching to hydropower in our current days is its effect on climate change. The construction of hydropower plants has been seen to have an adverse impact on the environment, affecting water quality and leading to the loss of biological diversity and the displacement of people (Kumar et al., 2011). For example, after the construction of the notorious Three Gorges Dam in China, a total of approximately 1.3 million people were displaced and 13 cities, 140 towns and 1,350 villages were submerged (International Rivers, 2011).

According to the Intergovernmental Panel on Climate Change (IPCC), climate change refers to a change in the state of the climate that can be identified (e.g., using statistical tests) by changes in the mean and the variability of its properties, and that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity (IPCC, 2007). Climate change is a threat to many economies and sectors, especially in agriculture and health. Its impacts are being experienced worldwide. Hydropower generation is the energy source that is most likely to be affected by climate change and climate variability because the amount of electricity generated is directly related to the hydrological regime (Lumbroso and Woolhouse, 2015). In other words, hydropower generation is sensitive to changes in precipitation and runoff (Alavian et al., 2009). These variables are likely to alter substantially with climate change. However, the magnitude and signs of these changes are largely unknown in many locations in the world. Many integrated assessment studies suggest that impacts from climate change, relative to population and GDP, will be most felt in Africa (African Development Bank, 2011). However, when it comes to hydropower projects, climate change is often not explicitly considered (Harrison, Whittington and Gundry, 1998) and (Jones et al., 2015). Currently, studies conducted to ascertain the magnitude of climate risks seem to dwell more on health, water resources and sea-level rise rather than energy, and transport (Hunt and Watkiss, 2011). It is therefore necessary to examine the potential impacts climate change can have over long-lived infrastructure projects such as hydropower (IFC, 2011).

1.2 Research problem

As a result of climate change uncertainty, decisions need to be both climate-aware and responsive to risks (EU, 2009). Countries that experience droughts should not necessarily have power outages or power rationing exercises. Their energy sector should be resilient enough to withstand climate variability and change. Unfortunately, many national governments have yet to integrate climate change risks into current and long-term planning and policy-making primarily due to the inherent pressure on them to deal with pressing developmental issues (Lim et al., 2011). As stated above, the provision of electricity boosts and stimulates development. Industries cannot function without power. The power crisis that hit Ghana in the years 2008 and 2013 was attributed to the low levels of water in the country's dams (Chronicle, 2015). The crisis led to low productivity among businesses resulting in financial losses (Times, 2013). In 2013, Brazil which is the second largest producer of hydropower experienced a drought that led to a fall in output by 7%. The following year, the government had to resort to thermal plants due to the likelihood of blackouts (Mo et al., 2015). During the same period, Ghana also experienced droughts which caused low outputs in the various dams thus forcing the government through the Volta River Authority (VRA) to invest in emergency thermal plants costing over $100 million, excluding gas and oil costs to avert the issue (GhanaWeb, 2015). This shows how sensitive hydroelectric facilities are to climate risks. According to Laube et al. (2008), the ongoing hydropower problems are expected to worsen as rainfall is predicted to become even more scarce and variable.

In 2008, before the construction of the Bui dam, there were calls by international and local organizations to further investigate the possible impact of climate change on the project, but the government ignored such proposals (International Rivers, 2014). Considering the impact climate change is having on hydropower plants and the fact that most nations such as Ghana are highly dependent on it, there is the need to climate-proof the entire energy sector to minimize the shocks of droughts. This means that governments ought to thoroughly consider the issue of climate change during hydropower projects and ensure that their entire energy mix is resilient to the stress of climate variability and change.

1.3 Research aims and questions

In this era of climate change, it is clear that many parts of the world are likely to experience significant changes to both rainfall patterns and surface hydrological balances, affecting river flows(King *et al.*, 2015). The uncertainty in future projections represents a challenge to the use of climate projections in investment decision making (Oecd, 2009). As various studies suggest calls for hydropower projects to undergo climate change risk analysis have been to date ignored, it is important to find out the reasons for this. This research contributes to the literature on hydropower and climate change uncertainty in Africa and Ghana. Since there has not been any substantial research done to inquire about the events surrounding The Bui Dam, this study attempts to fill some gaps as well as provoke further research into how best to climate-proof the nation’s energy policy to make it resilient to climate change and its uncertainties.

The aim of this research is:

To understand to what extent climate information is used in hydropower planning in Africa, specifically in Ghana.

The research questions of this study are:

1. What is the planning process for dams in Ghana?
2. What are the barriers to the use of climate risk analysis in dam planning?
3. How can decision-makers climate-proof the hydropower sector?

Scoping through various literature, the researcher discovered some themes which would not be addressed in this particular research. Therefore, the delimitations of this study are:

- It does not consider the impact hydropower might have on the climate, in terms of GHG emissions as shown in (Tremblay et al., 2006) and (Arntzen, Miller and O'Toole, 2013). This would not be necessary as the research wants to focus on climate change uncertainty and how it affects hydropower planning.

- It does not examine mathematical models to explain how decisions can be taken under uncertainty (Green and Weatherhead, 2014). This would take quite some time to run and might be quite complicated.

- It also does not consider the environmental and social impacts hydropower plants might have on its surroundings, regarding displacements as explored by (Chowdhury and Kipgen, 2013).

- It does not run climate simulations, as done in by (The World Bank, 2014).

- It does not consider how uncertainties should be quantified as demonstrated by (Reilly et al., 2001).

- It does not consider the impact transboundary water issues can have on hydropower as described by (Moller, 2005).

Despite the many delimitations this study has, it is significant because it builds on research undertaken in Africa on why climate information is ignored as well especially when long-term investments are considered as well as. It offers practical solutions to dealing with the issue of climate change uncertainty in the hydropower sector, which can be adopted in the other crucial sectors of many economies.

As shown in **Figure 1.0**, this study is presented in six distinct chapters. Chapter One introduces the topic of discussion, the background of the study and defines the research aims and objectives. The second chapter is the literature review chapter where past studies and methods related to climate change and adaptation are discussed as well as a review of the issue of uncertainty is done. The theoretical framework is found in chapter three. The various concepts and theories which form the basis are explained. A previous study is used as the focal point with the attempt of answering the questions this project seeks to address. Chapter four is outlines the methodology of this study. It details how data would be collated and analysed in order to arrive at a credible conclusion. Chapter five presents the findings and results of the study and analyses them to bring clarity and understanding regarding how issues concerning climate change and its uncertainties were managed during the construction of the Bui hydroelectric project. The final chapter highlights the critical observations and offers a practical solution of ensuring the energy sector can be made more robust and resilient. This is shown in Figure 1 below.

1.4 Thesis outline

CHAPTER ONE (INTRODUCTION)

- Climate change is affecting hydropower plants.
- What are the generic barriers to the use of climate risk analysis?

CHAPTER TWO (LITERATURE REVIEW)

- The uncertainty posed by climate change deters the use of climate information in dam planning.
- In dealing with climate change uncertainty, decisions can be taken using various approaches.

CHAPTER THREE (THEORETICAL FRAMEWORK)

- It is based on findings from an earlier study

CHAPTER FOUR (RESEARCH METHODOLOGY)

- The Case study of the Bui Dam is used to answer the research questions

CHAPTER FIVE (RESULTS AND DISCUSSION)

- The immediate need for power surpasses the relevance of a climate risk analysis as seen with The Bui Dam.

CHAPTER SIX (RECOMMENDATION)

- The energy sector must be climate proofed.
- Hydropower is still relevant today

CHAPTER SEVEN

(SUMMARY AND CONCLUSION)

Figure 1 Research Outline

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

According to the IPCC countries across the globe are experiencing climate change (IPCC, 2013). Hydropower generation is dependent on rainfall and river flow (Alavian et al., 2009; Gjermundsen and Jenssen, 2001). These variables are likely to alter substantially with climate change. However, the magnitude and even sign of these changes are highly uncertain for many parts of the world especially the tropics (IPCC, 2013). As a result, planning and designing long-lived hydropower infrastructure so that it is climate risk-proof can be challenging. The purpose of climate proofing is to factor issues of climate change into planning (Hahn and Fröde, 2010). Within this context, there is a need to understand how policymakers treat the issue of climate change in planning for hydropower development.

This chapter is divided into two parts. The first describes the study area, and the second attempts to review the literature relating to current climate change projections, the problem that has arisen as a result of uncertainty, the benefits as well as the risks climate change is likely to have on hydropower and how climate change uncertainty and risk is being assimilated into the decision making process. The purpose of this chapter is to provide the geographical and academic context for the research aims identified in the previous chapter.

2.1.1 Project Location

The Bui Dam is located on the Black Volta River at the border of the Bole (Northern Region) and Wenchi (Brong-Ahafo Region) districts in the northwestern part of Ghana. This is situated about 150 kilometers (km) upstream of Lake Volta. Although a section of the project is within The Bui National Park, all components of the project are entirely within Ghana. The Black Volta River begins in Burkina Faso and flows approximately 1,350 kilometres south creating the western border of Ghana with both Burkina Faso and the Ivory Coast, then meeting the White Volta River and flowing into Lake Volta in southeastern Ghana (ERM, 2007). On the Downstream part of the Black Volta River is where the Akosombo and the Kpong Hydroelectric dams are located. The location of the

Bui Project at Bui Gorge is shown in Figure 2.1 This site is particularly suitable for a hydroelectric project because of the relatively deep gorge where the Black Volta River flows through the Banda Hills (ERM, 2007).

2.1.2 Project Components

The general layout of the Bui Project is illustrated in Figure 2.2. It is made up of a main dam and powerhouse in Bui Gorge and two smaller saddle dams in the neighbouring Banda Hills. The dams have a reservoir extending roughly 40 km upstream, within Ghanaian borders. Three new transmission lines deliver the power generated by the Bui Project to the national grid. They run east from the project site to the existing North-South transmission line corridor near Teselima and then south to substations at Techiman and Kumasi (ERM, 2007). The critical components of the Bui Project are as follows, and are described below:

- Main dam;
- Two saddle dams;
- Reservoir;
- Powerhouse and power intake;
- Three transmission lines;
- Switchyard; and
- Other facilities including site access roads and project control; and maintenance facilities;
- Temporary construction-related project components.

The general terrain is gently undulating with few deeply incised stream valleys. The primary relief and geomorphological features are the high elongated Banda Hills, deep and broad valleys of the Black Volta River, few inselbergs, and ridges and the gentle undulating topography of the interfluves and the piedmont drift slopes. The Banda Hills originate from near Banda Ahenkro and run in a north-east to the south-west direction to near Jama township in the Bole district. The hills have been deeply incised by the Black Volta, forming a deep gorge at the proposed dam site (Coyne and Bellier, 2006).

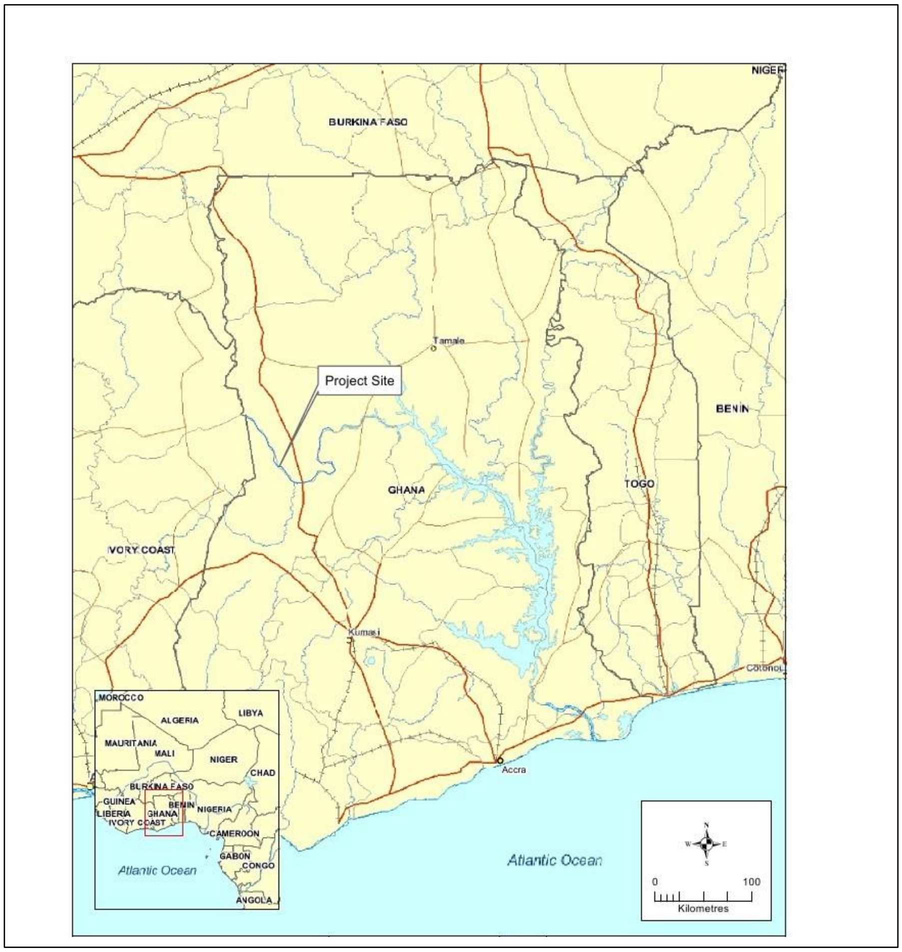


Figure 2. 1 Location of The Bui Project

Source: (ERM, 2007)

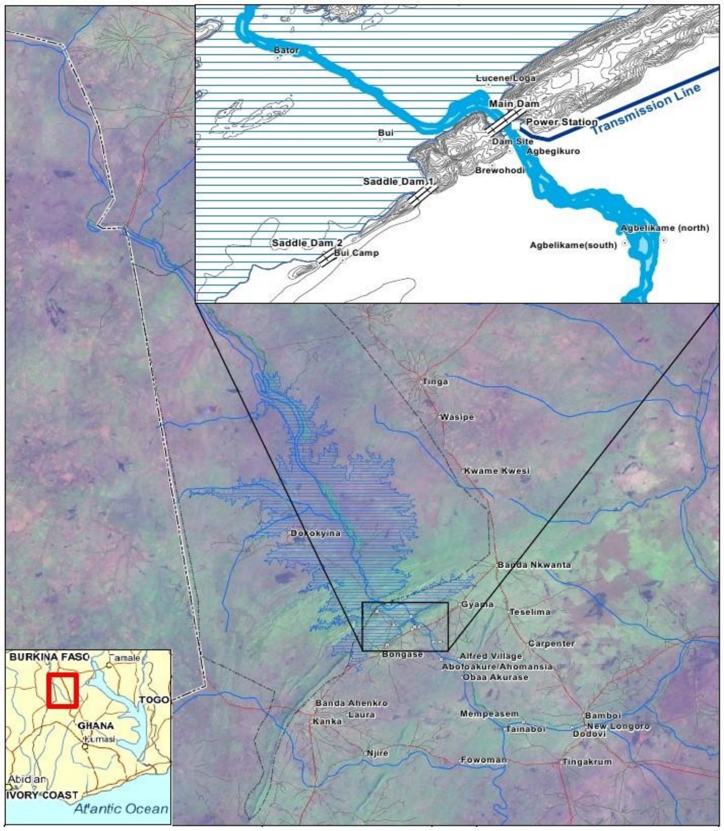


Figure 2. 2 Layout of the Bui Project

Source: (ERM, 2007)

2.1.3 Climate and rainfall

The climate of the project area has been classified as ‘Dry Equatorial,’ a sub-classification of the Hot Equatorial-Tropical climate of the majority of West Africa (ERM, 2007). The climate is characterised by a double-peak wet season (maxima in May-June and October) or a single rainy season (maxima in July-August) depending on the northernmost yearly limit of the Inter-Tropical Convergence Zone (ITCZ). The climate in the Bui area tends towards the latter (Coyne and Bellier, 2006).

The average yearly rainfall in the project area is given in 2005 as 1140 mm (Coyne and Bellier, 2006)based on a study by the Ghana Meteorological Agency (GMA) for The Volta River Authority (VRA) using interpolated data from the nearest weather stations for the period 1983-2000. The annual mean rainfall between 1917 and 1993 is 963 mm (Coyne and Bellier, 2006). Coyne and Bellier (2006) could not obtain any other meteorological data for their 2006 update of the feasibility study.

2.1.4 Temperature and Humidity

The equatorial air masses affecting the Bui area are warm and moist, and wind velocities are low. Monthly temperatures range from around 26ºC in August to around 30ºC in March (Coyne and Bellier, 2006). The hottest months are February to May and in November. The project area has a mean annual relative humidity of 75%, with a maximum mean monthly value of 87% in September and a minimum of 58% in January (ERM, 2007).

2.1.5 Catchment Characteristics

The Bui Project will require the damming of the Bui Gorge on the Black Volta River. The project area is drained into the Volta Lake by the Black Volta and numerous tributaries of different sizes and lengths. The Black Volta has its headwaters in Burkina Faso, where it is called the Mohoun River. From here, it flows some 400 km to the northeast before it is joined by the Sourou River, with a combined catchment area to this point of some 47,000 km2. Downstream of this confluence, the Mohoun flows southeast, then south for a further 510 km before reaching the Koulbi-Noumbiel dam site. The Black Volta then flows directly south until it reaches the Bui gorge (dam site) 200 km downstream of Noumbiel. It has a catchment area of 123,000 km2. It then forms a big loop northeastwards to enter the Volta Lake near Mpaha. The principal tributaries of the Black Volta are dendritic in pattern and feed the Black Volta from surrounding hills and ridges. These tributaries include the Tain, Chiridi, Jahol, Tombe Fanko Diapoli, Gbungbun, and Yoko. Apart from the Tain River, the tributaries dry out early in the dry season forming discontinuous pools along their course (ERM, 2007).

2.2 Climate in West Africa

This part of the study briefly looks at the past and future climate of West Africa, where The Bui Project is located. Lélé and Lamb (2010) describe "West Africa" as being bounded by the Atlantic Ocean to the west and south, by the north of the Sahel-zone at around 20° N latitude to the north, and by 10° E to the east. Fifteen countries exist within the West African region namely: Benin, Burkina Faso, Cape Verde, Gambia, Ghana, Guinea, Guinea-Bissau, Ivory Coast, Liberia, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo.

Global scale temperatures have been increasing since the 1950s, and global temperature will rise when the century ends according to IPCC AR5. Africa has experienced an increase in temperature of 0.5% during the last century (Niang *et al.*, 2014). Also, minimum temperature outstrips the maximum temperature and considering climate scenarios; it is entirely possible that land temperatures over Africa will rise faster than the global average, especially over the arid regions like the Sahel (Stocker et al., 2013). Datasets provided by the IPCC indicate that on the regional scale for West Africa and the Sahel, observations show an increase in annual mean temperature over the last 50 years. As mentioned by the AR5 of the IPCC, there was significant warming of between 0.5ºC and 0.8ºC between 1970 and 2010 over the region using remotely sensed data with a greater magnitude of change in the latter 20 years of the period compared to the former (Collins, 2011). Moreover, there was also substantial evidence of an anthropogenic signal in continent-wide temperature increases in the 20th century (Stott et al., 2010). Again, climate extremes increased, as there was a decrease in the number of cold days and nights and an increase in the number of warm days and warm nights between 1961 and 2000 (Niang et al., 2014).

2.2.1 Future climate of West Africa

It has been projected that in the 21st century the temperatures in Africa will increase more than global average figures with scientists associating this to the massive land mass on the continent (Christensen et al., 2007; Joshi et al., 2011; James and Washington, 2013). Again, the global mean temperature has been projected to exceed the 2ºC on average in the ensemble-mean of global projections above the late-20th-century baseline over most land areas of the continent in the mid-21st-century for RCP8.5, and could exceed 4º C over most land areas in the late-21st-century for RCP8.5 (Riede et al., 2016). The most recent publication by the IPCC reports that during the late 20th century the continent experienced a warming of between 3ºC and 6ºC (Meehl et al., 2007; Niang et al., 2014). According to

Diffenbaugh and Giorgi (2012), the impacts of climate change would be significantly felt in West Africa especially between the late 2030s and 2040s based on the RCP4.5 and RCP8.5 pathways. Observed and simulated variations in past and projected future annual average temperature over the Economic Community of West African States (ECOWAS) are shown in **Figure. 2.3** while the annual temperature and precipitation change are captured in Figure 2.4; the graphics indicate that the projected temperature rise is likely to exceed the 1986–2005 baseline by between 3ºC and 6ºC across the region by the end of the 21st century under RCP8.5.

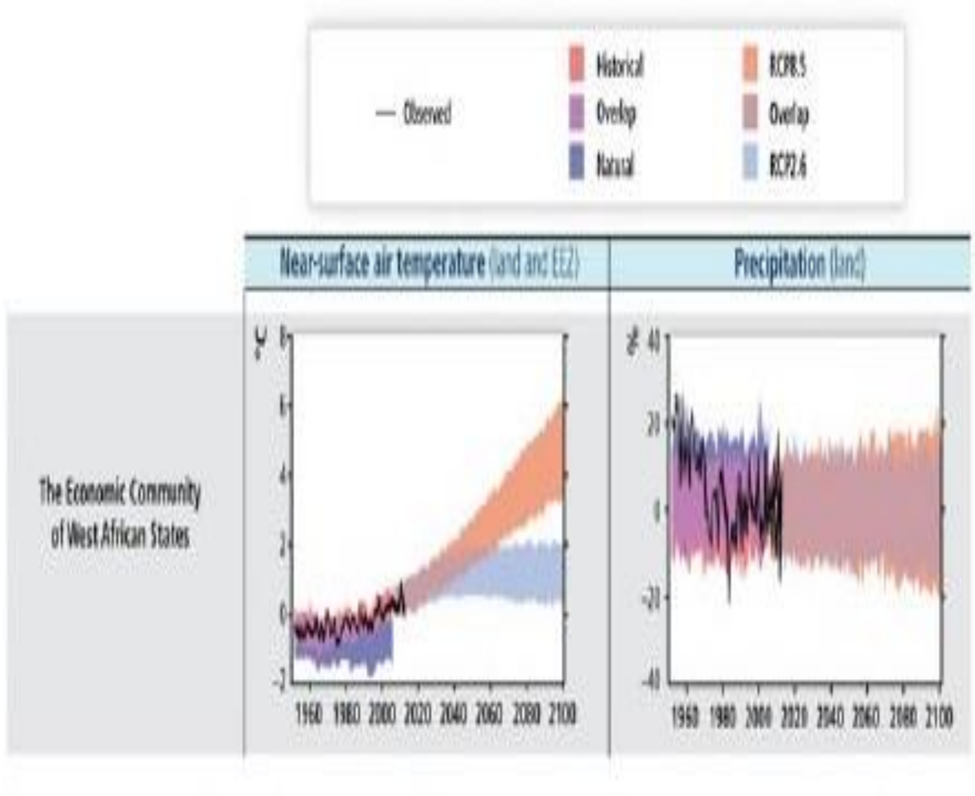


Figure 2. 3 Near- Surface air temperature and Precipitation of West Africa

Source: Niang et al., 2014

The above figure describes the observed and simulated variations in past and projected future annual average temperature over ECOWAS. It compares the expected responses of temperature and precipitation to both human-induced and natural forcing, it is evident that there is an increase in the observed and projected temperature which is linked to human-influenced forcing and is, therefore, a likely climatic response to future increases in greenhouse gas emissions under ‘business as usual’ activities. The black lines show various estimates from observational measurements. Shading denotes the 5th –95th percentile range of climate model simulations driven with “historical” changes in anthropogenic and natural drivers (63 simulations), historical changes in “natural” drivers only (34), the “RCP2.6” emissions scenario (63), and the “RCP8.5” (63). Data are anomalies from the 1986–2005 average of the individual observational data (for the observational time series) or the corresponding historical all-forcing simulations (Niang et al., 2014). Figure 2.3 (adapted from Figure 22-1 in Ch 22 of the WGII report in AR5: Niang et al., 2014) depicts an increase in mean annual temperature over the past century across much of the African continent.

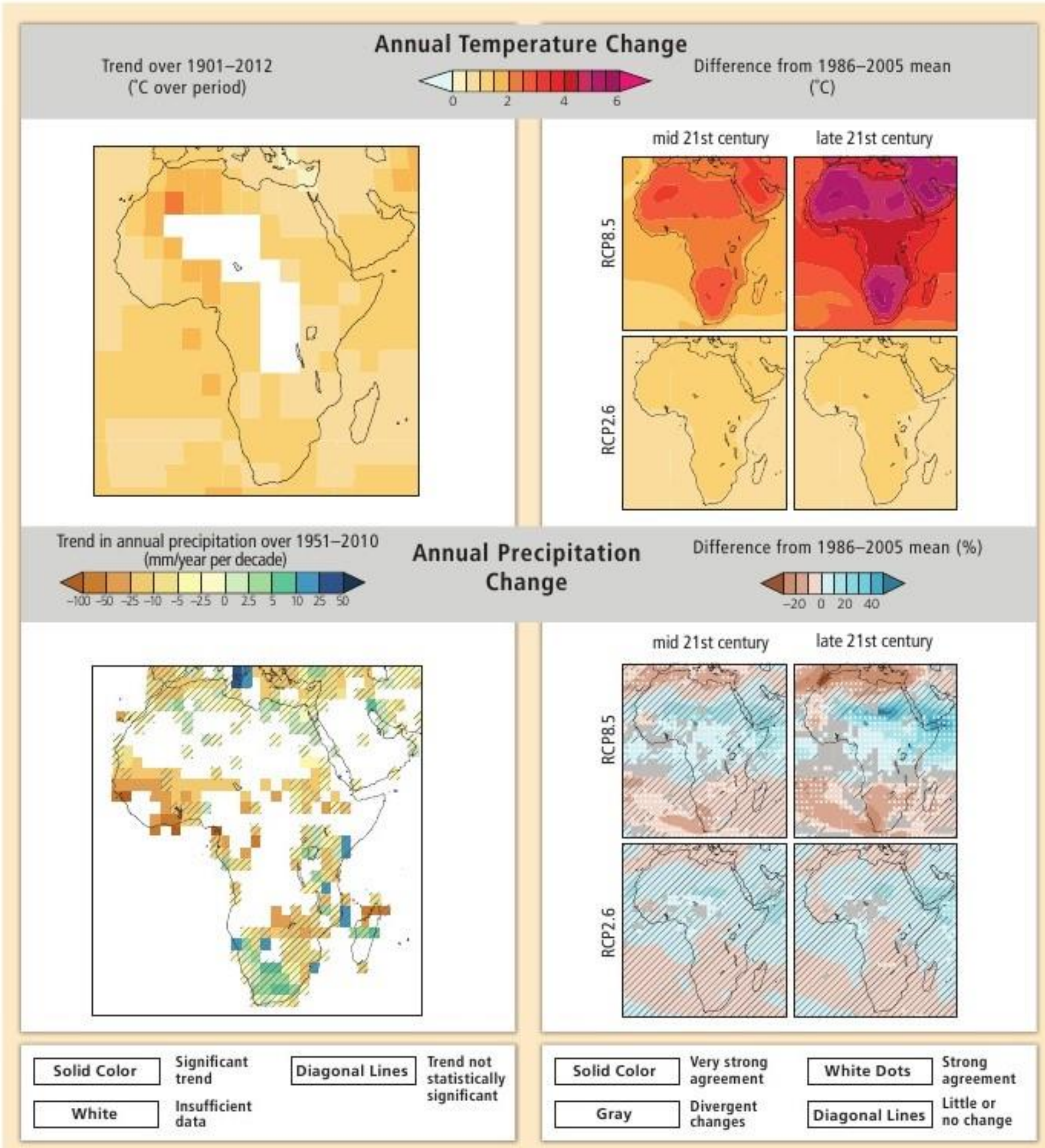


Figure 2. 4 Annual Temperature and Precipitation change of Africa

Source: Niang et al., 2014

This shows observed and projected changes in annual average temperature and precipitation. (Top panel, left) The observed annual average temperature change from 1901–2012, derived from a linear trend. (Bottom panel, left) Map of observed annual precipitation change from 1951–2010, derived from a linear trend. Solid colors indicate areas where trends are significant at the 10% level. Diagonal lines indicate areas where trends are not significant. (Top and bottom panel, right) CMIP5 multi-model mean projections of annual average temperature changes and average percent changes in annual mean precipitation for 2046–2065 and 2081– 2100 under RCP2.6 and 8.5, relative to 1986–2005. Solid colors indicate areas with a very strong agreement, where the multi-model mean change is greater than twice the baseline variability (natural internal variability in 20 year means) and ≥90% of models agree on the sign of change. Colors with white dots indicate areas with a strong agreement, where ≥66% of models show change greater than the baseline variability and ≥66% of models agree on the sign of change.

West African precipitation projections in the CMIP3 and CMIP5 archives show inter-model variation in both the amplitude and direction of change that is partially attributed to the inability of GCMs to resolve convective rainfall (Biasutti et al., 2008; Roehrig et al., 2013). Most CMIP5 models indicate a wetter core rainfall season with a small delay to the rainy season by the end of the 21st century (Biasutti, 2013). However, Regional Climate Models (RCMs) can alter the sign of rainfall change of the driving GCM, especially in regions of high or complex topography (Saeed et al., 2013). There is therefore low to medium confidence in the robustness of projected regional precipitation change until a larger body of regional results become available through, for example, the Coordinated Regional Downscaling Experiment (Jones et al., 2011).

The principal sources of uncertainty in climate projections as far as West Africa are concerned is as a result of three different factors. First of all, the climate system experiences much internal variability which is quite visible in the long-term movement of each projection (Deser *et al.*, 2012). The next source of uncertainty is known as model uncertainty(Hawkins and Sutton, 2011). This is merely various models that provide different changes in the climate in response to the same radiative forcing. Third, there is forcing scenario uncertainty, caused by the future emissions of greenhouse gases. Previous studies (Knutti, 2008; Hawkins and Sutton, 2011) have indicated that internal variability and model uncertainty are the dominant contributors to the total uncertainty in precipitation projections for a specified greenhouse gas emission scenario. Although the uncertainties sourced from emission scenarios play an essential role in the future projections of climatic extremes (Sillmann et al., 2013b), only internal and inter-model variability are considered as sources of uncertainty in the RCP4.5 scenario in this study.

2.2.2 Climate Change in the Volta Basin

The Volta River basin encompasses 403,000 km2, covering six West African countries. They are Ghana (42%), Burkina Faso (43%), Benin, Cote d'Ivoire, Mali, and Togo. Four major rivers drain the basin, the Black Volta (147,000 km2), the White Volta (106,000 km2), the Oti (72,000 km2) and the Lower Volta (73,000 km2)(Sood, Muthuwatta, and McCartney, 2013). The Volta River is crucial for agriculture (Biney, 2010) and a resource in producing electricity for domestic use and export to neighbouring countries (Owusu, Waylen and Qiu, 2008). Climate change and its uncertainties are expected to severely affect the basin through shorter rainy seasons and increased temperatures (Sood, Muthuwatta and McCartney, 2013).

In the 1960s rainfall was high but began to decrease during the late 1970s and early1980s. Studies show that temperature in Ghana is rising while rainfall continues to reduce (Cameron, 2011). According to Oguntunde et al. (2006), the Volta basin has been drying only since the last three decades (i.e., since 1970) of the 20th century. Obuobie (2008) used climate series (1991–2000 and 2030–2039) simulated with the Long Ashton Research Station Weather Generator and reflecting the MM5-simulated monthly changes to evaluate the impacts of climate change on groundwater recharge in the White Volta River basin. The analysis showed an increase in mean annual rainfall (about 6% in 40 years), resulting in an increase of about 29% in the groundwater recharge (indicating a non-linear response) in the same period. Kirby et al. (2006) simulated the rainfall changes that occurred in the basin in the 1970s by using a drier or wetter scenario. The scenarios were developed for 20 years, with the year 2000 as the initial condition. It was observed that for all scenarios, the water levels in Lake Volta were susceptible to inter-annual variability in rainfall and that climate change similar to that observed in the recent past (i.e., the 1970s) will have a critical impact on Lake Volta water levels. Unfortunately, only a few studies use observations and simulations to investigate the case of droughts in the Volta Basin (Oguntunde, Abiodun, and Lischeid, 2017).

Past studies employed the use of the Water Evaluation and Planning (WEAP) model to access the impact of climate change and future development scenarios in the Volta River Basin (Andah et al., 2004; Leemhuis, Jung, Kasei, and Liebe, 2009). Andah et al. (2004) utilized the WEAP model to determine the effect of climate change on the environment, hydrology and energy generation in the basin. The Climate Research Unit data served as input for the historical baseline of 1961–1990, while the Hadley GCM A2 and B2 scenarios were used for the future time slices 2010–2039 and 2070–2099. The outcome revealed that climate change would cause a rise in rainfall (i.e., wetter conditions), variability will rise; mean annual runoff in the basin will generally rise as compared to that of the baseline. Condappa, Chaponnière, and Lemoalle (2009) also investigated the impact of future climate change and upstream development of small reservoirs on the basin’s water resources using a hydrological spreadsheet and the WEAP model. It was discovered that climate changes similar to what has been observed in the recent past would have a critical impact on Lake Volta (Condappa, Chaponnière, and Lemoalle, 2009). Kabo-Bah et al. (2016) showed that the trends and the slope estimations of the rainfall data indicate that most of the synoptic stations experienced decreasing annual rainfall. High temperature and low rainfall will affect water flow and likely worsen the intensity of the dry season, thus, leading to drought. In summary Kabo-Bah et al. (2016) suggest that hydropower is an essential asset in providing electricity in Ghana but climate change and its uncertainties could significantly hinder reliable hydropower generation.

2.3 Statistics and advantages of Hydropower

Statistics from the IEA indicate that hydropower is the most utilized form of renewable energy that produced more than 16% of global electricity production in the year 2011 (IEA, 2013). Global hydropower generation increased by 175% during 1973-2011 (IEA, 2013) and the IEA's 2012 Hydropower Technology Roadmap predicts this hydropower capacity to further rise by 2050 (IEA, 2012a) especially in Africa, Latin America, and Asia (IEA, 2012a, b). Countries such as Angola, Cameroon, and Sudan generate over 70% of their electricity through hydropower while others which include Mozambique, the Democratic Republic of Congo, and Zambia produce more than 99% of their electricity through hydropower (World Bank, 2013). Hydropower is receiving much attention and investment mainly because it is seen as a possible solution to the energy problem in Africa (IEA, 2012a).

Most countries use hydropower because it is relatively reliable and not prone to global price fluctuations that commonly affect oil and gas markets. It can also deliver baseload power to meet peak demand or be used as a storage system that is quick-start, meaning that it can help with fluctuations in supply or demand (Cole et al., 2013). As a result of these reasons, the hydropower sector is expected to "play a strong, multidimensional role in sustainable development and poverty alleviation" (World Bank, 2009).

2.3.1 Climate Change and Hydropower

Hydropower is one of the most vulnerable sectors to changing the global and regional climate (Iimi, 2007). The IEA (2012) have confirmed that climate change and its impacts on hydropower are uncertain while the impact on a river basin or a region could be severe (IEA, 2012). Evidence from the World Bank shows Africa to have a rather high level of hydrological variability, with significant seasonal and decadal changes in precipitation and there is no doubt that climate change is going to intensify significantly these already existing variabilities (World Bank, 2014). Despite all this, the Worldwatch Institute (2010) iterates that although currently many dams are already being affected by drought-caused power shortages, new dams are still being built without the concern of climate change. Considering the likelihood of poor hydropower production due to climate change, some have argued that the building of dams on the continent should be curtailed (Beilfus, 2012).

The future performance of hydropower schemes is likely to be affected by climate change resulting in:

- Underperforming of turbines due to low rainfall and river flows
- Low power generation due to higher evaporation rates
- Destruction of turbines blades as a result of increased sedimentation
- High flood risk as a result of increased rainfall intensity (WRR, 2011).

2.3.2 Impact of Climate Change on Hydropower in Ghana

Ghana is well endowed with water resources, but its availability season to season is not always guaranteed (WRI, 2000). Literature from WRI (2000), Andah et al. (2004), Kuntsmann and Jung (2005) show there is significant evidence of the impact of climate change on the water resources of Ghana. The EPA of Ghana conducted another study analysing data from 1960 – 2000 and concluded that temperatures are rising and are leading to the drying of rivers during the Harmattan and are also impacting the intensity of rainfall, thus, causing floods (Kankam-Yeboah, K. Amisigio, and Obuobi, 2010).

A report by the CSIR and WRI (2000) estimated that by 2020 and 2050, the annual river flows in the country would reduce by 20% and 40% respectively. Finally, by 2020, river basins could be at risk, thus, increasing the likelihood of water scarcity in the country which would have many adverse effects on the sustenance of people. Kunstmann and Jung (2005) compared historical streamflow and rainfall patterns from 1991-2000 with a global climate change scenario (2030-2039) and mainly suggested, river flows might experience slight reductions and an increase in droughts and floods. The difference in conclusions can be attributed to uncertainty in the climate models used. As a result of this, electricity generation in the Bui Dam will be negatively affected. Studies show water resources in the Black Volta Basin would be negatively affected as a result of increased evapotranspiration and increased temperatures (Kunstmann and Jung 2005). Studies also predict the occurrence of more floods which would increase the rate of erosion and lead to sedimentation which may affect the longevity of these infrastructures. Bekoe and Logah in their study on the Volta Basin which analysed 37 years of rainfall and intake water levels at the Akosombo and Kpong Dams revealed that the 1983, 1997 and 2006/7 power rationing was indeed as a result of hydrologic drought (Bekoe and Logah, 2013). Rainfall was not evenly distributed across 22 synoptic stations in the country (Kabo-Bah et al., 2016). This can pose an adverse effect on hydropower generation because water is the primary source of power. Temperatures during 1960-2011 were quite high posing a threat to the hydrological cycle and hydropower generation in particular (Kabo-Bah et al., 2016). As a result of this Figure 2.5 shows the relationship among these variables, rainfall, energy production (Akosombo) and evapotranspiration.

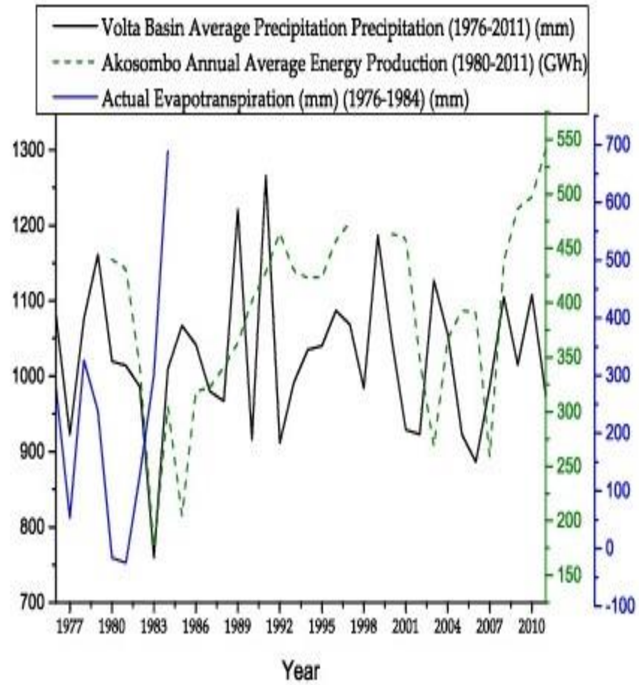


Figure 2. 5 Plot of average precipitation, plant discharge, water level, and energy production at Akosombo dam

Source: (Kabo-Bah et al., 2016)

Figure 2.5 was estimated using the Thiessen Method. There is an indication of likely high evapotranspiration around the Volta Lake, thus, affecting water availability for hydropower generation for the Akosombo Dam. As precipitation and energy production declines, there is an increment in evapotranspiration which shows that the Volta Basin has become arider which might affect hydropower generation (Kabo-Bah et al., 2016).

2.4 The Problem of Uncertainty

Considering the various impacts climate change might have on water resources and hydropower development in Africa and specifically Ghana, it is not easy for scientists to precisely tell us what would happen. A huge challenge of climate change is the issue of uncertainty. This section analyses the issue of uncertainty. There are uncertainties in climate science, and this is problematic for both the physical and social scientists in understanding and planning for climate change impacts. Changes in climate over regions and trends in precipitation are difficult to predict. There is a chance that climate change will be less severe than the current projections of climate science, but there is also a chance that it will be more severe. The IPCC defines uncertainty as a cognitive state of incomplete knowledge that results from a lack of information and from disagreement about what is known or even knowable (IPCC, 2007). There is the need to understand how to manage these uncertainties as the failure to do so could have a significant impact on investments and communities in the future.

Uncertainties in projecting climate changes into the future arise from difficulties in quantifying future concentrations of GHG in the atmosphere; unknowns in climate science including details of biochemical cycles; surface-atmosphere interactions; and cloud and aerosol processes; and downscaling issues (Hawkins and Sutton, 2011). Decision makers are increasingly demanding climate information at the national to local scale to address the risk posed by projected climate changes and their anticipated impacts. To derive climate projections at scales that decision makers desire, a process termed downscaling is used. Downscaling is the process whereby various tools are used to convert information from complicated and broad resolution Atmosphere-Ocean Global Circulation Models (AOGCM) for regional and local use (Schoof, 2013b). Downscaling is seen as a significant problem that has been identified in the modelling community (IPCC, 2007b). It adds another facet of uncertainty which has not yet been explicitly considered in most downscaling studies (Prudhomme et al., 2010). Regional Climate Models (RCM) are expensive to run and complex to implement (Rummukainen, 2010). Since simulations are based on just one or two GCMs, it complicates uncertainty assessments (Andreas and Køltzow, 2012). Model structural deficiencies and errors in the forcing data and parameters can also propagate from the driving GCMs to the RCMs and increase uncertainties (Buytaert et al., 2010).

2.4.1 The definition of risk and uncertainty

According to the UKCIP (UK Climate Impacts Programme), a risk is the likelihood of occurrence of a consequence. This implies the things that might happen and our knowledge about their likelihood. Uncertainty, however, deals with imprecise knowledge of what might happen and not being confident in determining their likelihood (Willows and Connell, 2003). Decision makers have been dealing with risk and uncertainty in areas of economic growth, population levels, migration patterns (OECD, 2009). In taking decisions from uncertain data, policymakers are mindful of the outcome each option can have on the development agenda of the nation. It is essential to examine how various studies suggest handling decision-making issues in an uncertain environment.

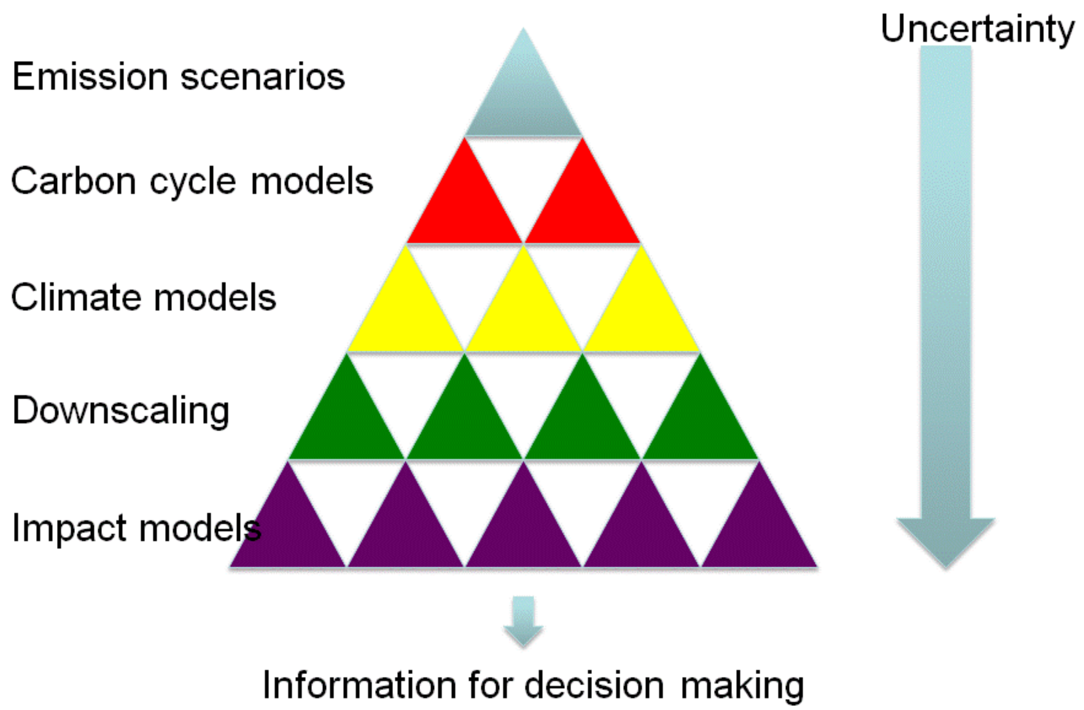


Figure 2. 6 Cascade of uncertainty

Source: (Wilby and Dessai, 2010)

Figure 2.6 describes the various sources of climate change uncertainty. It illustrates the fact that uncertainty emanates from various socio-economic pathways, which then translates into concentrations of atmospheric greenhouse gas (GHG) concentrations, expressed climate outcomes in global and regional models, then translated into local impacts on human and natural systems, and implied adaptation responses. For example, changes in the regional climate are used to inform impact models which seek to assess how these changes would affect the life of the people (Barker, 2008). The increment of triangles from top to bottom indicates that at each level uncertainty widens (Wilby and Dessai, 2010). It is at this point the information is disseminated to decision makers for them to take action but with the uncertainties increasing what are they to do?

2.4.2 Why should climate change uncertainty be a factor in taking decisions relating to Hydropower

Science identified climate change as a problem before it became an issue in public policy. According to Hartman (2008), policymakers have ignored this issue because of uncertainty. Pottinger (2009) believes that the impacts of climate change are often ignored during the planning of hydropower projects. Hydropower projects/ interventions are dependent on the state of the climate (Ranger, 2013) as dams need water to be able to produce electricity. In deciding to build such infrastructure, it is necessary to consider climate risks as they may impact future electricity generation potential, although projections are uncertain.

Climate change uncertainty should be considered for such a project because it is long-lived and a decision to modify it later would require a considerable capital investment. Building a dam and not considering climate change uncertainty could be catastrophic. Millions of dollars would be lost because excessive rainfall would lead to the collapse of the infrastructure when proper safety measures are not put in place as was in the case of The Lake Delhi Dam in 2010 (Koehn, 2010). Such decisions are critical and must be taken with great caution especially in countries that depend highly/ mainly on hydropower for its electricity needs. An important issue which decision makers or political leaders might have to answer is if hydropower is seen as a means of solving immediate electricity deficits, thus making it a short-term solution since planners have admitted that the planning horizon used in these projects do not exceed the year 2050 (Holm et al., 2008). The question is what happens after this period when the climate might have changed significantly. Further research should be conducted in developing nations because they are more vulnerable to the severe impacts of climate change (Jones et al., 2014). If countries are to be successful in dealing with climate change, it would depend on the decisions and policy choices made by their respective governments (OECD, 2009).

There is also a significant risk which might be overlooked when hydropower investments are being planned, and that is in the event where the project does not meet its intended benefit of producing enough electricity. What do decision makers do? The only thing available most often is to settle for expensive alternatives on a temporary basis which could have been avoided if a proper risk analysis was conducted. The 2009 drought in Kenya forced the government to buy a $30 million 140 MW temporary diesel generator excluding fuel costs for one year. (New York Times, 2007). Ghana is more or less heading for the same destination as recent construction of the 400MW Bui Dam in 2013 costing $622 million did not solve the power rationing issue. As a result of this, the government had to request for emergency power barges from Turkey to ease the crisis (Allotey, 2015). Before the construction of the Bui Dam, an environmental and social assessment was conducted but did not include scientific information to give an overview on the potential impacts of climate change on discharge scenarios (International Rivers, 2007).

When there are shortfalls in hydro production, the government has to import electricity from neighbours, Ivory Coast at an economical cost. It is therefore imperative for such nations to include extensive work on climate change when taking decisions which specifically deal with which form of energy to plan for. Decisions to build based on historical data might not be appropriate for such projects (Milly et al., 2008). Many climate models project a wetter climate for Africa while others believe the continent might experience its worst ever dry periods (Niang et al., 2014). In the light of this, choosing to refer to past climatic events in building long-lived infrastructure in this changing and unpredictable climate might not be the best decision to take.

2.4.3 Barriers to using long-term climate services in Hydropower Planning

The impacts of climate change, the issue of uncertainty in climate change and why it is vital to incorporate climate change in hydropower planning have been outlined above. Despite the amount of money that can be saved when climate change is considered in hydropower planning, it is surprising to note that climate service/ climate information is not a huge factor in the planning process. A study by Lemos, Kirchhoff, and Ramprasad (2012) compiled a list of studies which sought to outline the barriers to the use of climate information/services. Other studies by (Lumbroso, Woolhouse and Jones, 2015) also revealed that in hydropower planning, the use of climate information is generally limited.

According to Huang et al. (2011), a barrier is a situation or an impediment that makes it arduous to adapt. Considering the issue of uncertainty and the potential impacts and risks associated with hydropower investments, scientists believe that such information would readily be accepted in the planning and decision making divisions of various governments especially those in Africa. However, some obstacles prevent such information from being utilized in hydropower planning. Surmounting some of these might assist nations to reap the benefits of adaptation and dynamic planning in the hydropower sector and other sensitive fields as well. This section analyses the various factors that bar the use of climate information in long-term planning.

First of all, there is a gap between scientists and policymakers (Hoppe, 2005). This is due to failing to articulate the information needs both parties have clearly. The information provided is unable to match the needs of decision makers(von Winterfeldt, 2013) According to Bryson et al. (2010) government officials do not consider applying climate information because it is incomprehensible and unattainable. As a result of this, when drawing plans and taking critical decisions, they tend to rely on their feelings as well as intellect (Rosentrater, 2010). Bremond, Preston, and Rice (2014) reiterate an essential point which proves that countries which are expected to be most affected by climate change are seldom privy to the processing of climate information. This adds more credence to the notion that developing countries are not interested in the uptake of such information. For example, a simulation exercise carried out in Ghana which sought to find out the decision policymakers would take with regards to the construction of a 423MW dam, at the cost of $350 million, payable in 30 years, with a lifespan of 70 years. Despite predictions that rainfall and temperature changes could affect the dam's future capacity to generate electricity, the participants of the exercise agreed to build the dam on the basis that the need to solve short-term energy deficits was more critical. This exercise revealed developing countries would need some convincing if they are to consider integrating climate information into long-term planning (WRC, 2010). The transmission of information between these two parties is unproductive because they do not collaborate (Dilling and Lemos, 2011). This means that if decision makers are to apply climate information in their investment decisions, there should be constant communication and participation with scientists.

The complexity of medium- to long-term climate information requires high levels of scientific capacity to interpret and analyse the data generated. It also requires the technical capacity to communicate relevant information to decision makers in a manner that is both easily interpretable to decision makers and does not sacrifice the integrity of the underlying science (Ziervogel and Zermoglio, 2009). Failure to acknowledge and address these challenges may lead to the misinterpretation of climate information or under/overestimation of uncertainty and future risks (Srinivasan et al., 2011).

According to Bryson et al. (2010) decision makers do not use the long-term climate information simply because planning for the next decade should be the focus and not the next century. In Africa however, only South Africa and some countries in Northern Africa have incorporated climate change into their national long-term plans (IRI, 2006). The reason might be attributed to the fact that decision-makers in other locations are not convinced about dealing with the issue of climate change while unemployment, crime, and infrastructural shortages similarly need addressing (Runhaar et al., 2012) and elections are won on current conditions. Alternatively, it may be because the climate change signal is stronger in Northern and South Africa.

Secondly, OAGCMs are imprecise thus cannot be relied upon when making decisions (Lemos and Rood, 2010). Also, decision-makers avoid the use of climate information because of the many uncertainties it contains (Kirchhoff et al., 2013). This means that if climate information is going to be factored into investment decisions, then there should be ways of dealing with its inherent uncertainties.

2.5 Principles of Adaptation Measures

Considering the factors that bar the use of long-term climate information stated above, as far as climate change adaptation is concerned, they do not justify inaction. Decision makers ought to be cognizant of the structure of these uncertainties and barriers and create innovative ways to incorporate such information into their adaptation strategies or policy frameworks (OECD, 2009). Decision makers should be able to come up with measures that would be flexible, robust and have no-regrets despite the changing climate (Ranger, 2013). This section will briefly define critical principles that policymakers must consider when designing adaptation techniques. According to the IPCC, adaptation occurs when man and nature have to react to changes in climate (Smit et al., 2001). It can also be described as the process which seeks to ensure interventions are sustainable (Leary et al., 2008). For any adaptation measure to be successful, benefits should be substantially more than the likely costs and should be able to be applied without difficulty (Willows and Connell, 2003). Any measure chosen must be consistent with the problems or aims the decision maker seeks to solve or achieve (Willows and Connell, 2003).

First of all, an adaptation strategy should be flexible. This means that it ought to apply to different decisions across some sectors (Willows and Connell, 2003). Also, adaptation strategies must be “no or low-regret.” This means that the measure should cost little while yielding immediate economic and environmental benefits and still be useful regardless of the climate (Willows and Connell, 2003). In addition to this, strategies ought to be robust. Robust strategies are essential especially when the future is unknown or uncertain. In other words, this strategy performs well over different futures and unforeseen and unplanned circumstances (Rand, 2013). As a result of these many uncertainties that make it seemingly impossible for policymakers to take necessary decisions, various individuals and institutions have over the years developed tools and approaches to assist decision makers. This makes it possible for them to incorporate uncertainties into existing plans or formulate entirely new policies that are responsive to the impacts of climate change.

2.5.1 Decision-making Processes

Climate change uncertainty is a significant problem for both scientists and decision makers. In an attempt to deal with the issue and encourage policymakers to embrace uncertainty, various tools and processes have been introduced to assist in decision making. There is no standard or globally accepted criterion for a ‘good’ decision, particularly with regards to a ‘good’ climate-related decision (Moser and Ekstrom, 2010). A decision that might work in one context might not necessarily succeed in a different situation. Jones et al. (2014) suggest that to be able to make effective decisions, there should be sufficient information on the nature of the climate as well as the likely impacts and risks which the policy seeks to address. Similarly, (Lempert and Kalra, 2011) posits that decisions made concerning the climate should be able to accommodate and deal with expected and unexpected changes in the climate and various uncertainties. The IPCC believes decision makers make choices based on their instincts, intuition, and emotions without necessarily following a laid down step by step procedure (Jones et al., 2014). The various literature describes different methods used to make decisions with regards to climate change. For example with the "top-down model," scientific data is paramount (Murphy et al., 2009). There is reliance on the output of various climate models to shape policy.

The other process is known as the "assess-risk-of-policy" framing (Lempert et al., 2004) Different authors refer to it as, "context-first" (Ranger et al., 2010), "decision scaling" (Brown et al., 2011), "bottom-up" (Kwadijk et al., 2010) or policy-first approaches. Unlike the top-down model, this process begins with the decision-making context. In this approach, those that generate projections or provide scientific data work directly with planners to comprehend their objectives and most importantly how they intend to achieve them. When this bridge of understanding has been built between both parties, information providers can then customize or tailor various uncertainty descriptions to meet their preferences. This can be effective but might need to be framed in the way as to suit each decision context (Lempert, 2012). One method of conducting the bottom-up approach is through robust decision making. Robust decision making is seen as the most appropriate criterion when dealing with tremendous uncertainty. It is a satisfying criterion (Rosenhead 1989, cited in Jones et al. 2014, p.209) that provides solutions to accommodate various climates, differing economic systems and even political changes (Dessai and Hulme, 2007). The benefits of taking robust decisions are realized most especially when the projected future turns out differently than expected. Following the arguments made: the large level of uncertainty associated with a climate scenario led approach creates a strong case for the implementation of bottom-up approaches. This is further supported by the imperative development agenda within bottom-up strategies.

2.5.2 Tools for planning and policymaking in a changing climate

As discussed above, the bottom-up approach begins with the objectives of the decision maker and then attempts to identify the vulnerabilities or risk related to the climate. Various tools and approaches have been designed from this concept and provide the user with a detailed analysis of the economic impacts of his/her objective and how climate change can affect them.

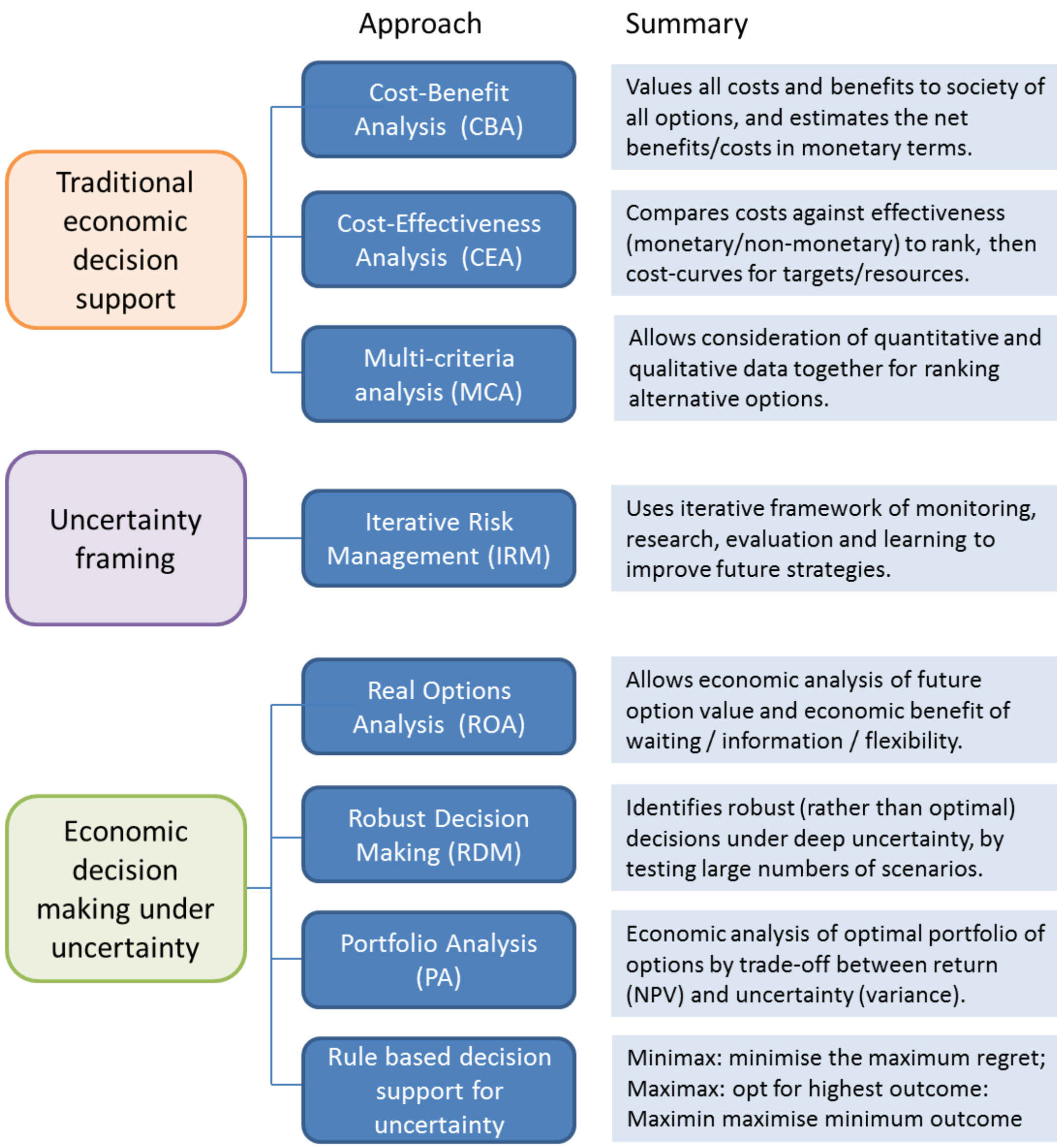


Figure 2. 7 Tools for planning and policymaking in a changing climate

Source: Watkiss et al., 2014

Table 2. 1Attributes and Application of Decision Support Methods for Adaptation

Decision-Support Tool	**Strengths**	**Challenges**	**Applicability**	**Potential use**
Cost-Benefit Analysis	Commonly used	Low sensitivity testing.	In cases where climate risks are infinitesimal.	To identify low and no regret options (short-term) in market sectors.
Cost-Effectiveness Analysis	Analysis of benefits in non-monetary terms.	It does not consider uncertainty enough	As above, but for non-monetary sectors (e.g. ecosystems) and where social objective (e.g. acceptable risks of flooding).	As above, but for market and non-market sectors.
Multi-Criteria Analysis	Analysis of costs and benefits in non-monetary terms.	Relies on expert judgement or stakeholders, and is often subjective, including analysis of uncertainty.	Where mix of quantitative and qualitative data. Can include uncertainty performance as a criteria	As above, but also use for scoping options (policy level). Can complement other tools and capture qualitative aspects.
Iterative Risk Assessment Frameworks	Iterative analysis, monitoring, evaluation and learning.	Challenging when multiple risks acting together and thresholds are not always easy to identify.	Useful where long-term and uncertain challenges, especially when clear risk thresholds.	For appraisal over medium-long-term. Also applicable as a framework at policy level.
Real Options Analysis	Value of flexibility, information.	Requires economic valuation (see CBA), probabilities and clear decision points.	Large irreversible decisions, where information on climate risk probabilities.	Economic analysis of major capital investment decisions. Analysis of flexibility within major projects.
Robust Decision Making	Robustness rather than optimisation.	High computational analysis (formal) and large number of runs.	When large uncertainty. Can use a mix of quantitative and qualitative information.	Identifying low and no regret options and robust decisions for investments with long life-times.
Portfolio Analysis	Analysis of portfolios rather than individual options	Requires economic data and probabilities. Issues of inter-dependence.	When number of complementary adaptation actions and good information.	Project based analysis of future combinations. Designing portfolio mixes as part of iterative pathways.

Source: Watkiss et al., 2014

Figure 2.7 and **Table 2.1** highlight various tools that have been developed over the years to assist decision makers draw plans and policies under a changing climate. Each have their strengths and weaknesses and can be used together with other tools to improve in some cases the accuracy of results. Most of them have been applied in actual events. The Real options analysis was conducted on the Bile Nile of Ethiopia to ascertain the viability of hydropower investments (Jeuland and Whittington, 2013). The Ethiopian government also developed its climate resilience strategy using an iterative management approach (Watkiss et al., 2014). Also, one of the most common tools used and accepted widely in economic appraisal is cost-benefit analysis (CBA). CBA compares the monetised (discounted) costs and benefits of a proposal or range of options. This helps decision makers select options which are both affordable and beneficial. For example, weather is a risk. To account for current weather variability, a decision maker could estimate the likelihood of different levels of seasonal rainfall based on historical data (Ranger, 2013). The limitation of CBA is that it does not provide any way for accounting for unquantifiable uncertainties, like those inherent in projections of long-term climate because of the difficulties assigning probabilities to future states.

Cost-effectiveness analysis (CEA) and multi-criteria analysis (MCA) are often used in the appraisal of development interventions, because they allow a decision maker to compare options where it is impossible to monetise all or some of the benefits (Ranger, 2013). With CEA, there is a comparison of how much it would cost to make identical products (Pearce et al., 2006). From here, the adviser can rank the options in terms of their cost effectiveness. MCA is similar, but it involves multiple objectives. Here, options are scored against different measures of effectiveness and then weighted based on expert's or public's preferences. These scores may also be based on expert judgement or quantitative methods. Uncertainty over future climate affects CEA and MCA in a similar way to CBA; it means that there is unquantifiable uncertainty over the effectiveness or scoring of different measures. Incorporating uncertainty into existing policies and plans can be done when there is coordination at the national level, adequate cross-sectoral planning, being integrated with existing priorities and reviewing and monitoring climatic changes (Ranger and Garbelt-Shiels, 2011). Reducing climate uncertainty would improve decision making (Kirchhoff et al., 2013) however, decision making is not solely limited to this kind of uncertainty but can be affected by culture, economics etc (Hulme and Dessai, 2007). According to Ranger (2013) it is important to consider robust adaptation strategies such as carrying out more research into climate risks before embarking on huge investments because that could ensure that changes in culture, the economy and other factors do not affect the decisions taken, however applying this method depends upon a lot of "quantitative information, computing power, and requires a high degree of expert knowledge" which unfortunately developing countries lack (Watkiss, and Dynzynski 2013, p.3). According to Dessai and Wilby (2011) when taking decisions with climate change uncertainty in long-term planning, decision makers must first accept the concept of uncertainty. The decision maker that fails to recognize the role or impact of uncertainty would end up designing plans that are not robust. Adaptation strategies should be flexible and open-ended, especially for assets with long life spans (Clarke et al., 2012).

Developing countries are more vulnerable to the impacts of climate change thus the need to shift towards building climate resilience into their economies. Research posits that increased annual temperature, and a reduction in precipitation affects economic growth (Lee, Villaruel and Gaspar, 2016). According to Dell et al. (2009) a 1°C increase in temperature has been seen to lead to a 0.5% to 3.8% decline in income in the long run. This study along with another by Nordhaus (2006) suggested that there is a correlation between heat and poverty. As a result of this, in order to deal with the menace of poverty and ensure economic progress, there is the need to pay attention to climate and disaster resilient development (World Bank, 2013). According to USAID, climate- resilient development means "ensuring that people, communities, businesses, and other organizations are able to cope with current climate variability as well as adapt to future climate change, preserving development gains, and minimizing damages"(2014, p.2). It is important to deeply consider climate risks and uncertainties when drawing up development policies. When this happens decision makers would be able to achieve development objectives regardless of the nature of the climate. In the energy sector, and the hydropower subsector specifically, when climate considerations are integrated, projects are more likely to become resilient and can perform to a satisfactory degree. Also when the energy plan is also screened for climate risks, whatever decision that is taken would be resilient to the uncertain nature of the climate.

Table 2. 2 How hydropower projects are climate proofed

Sub-component	Key climate risk	Potential direct impacts	Intervention description	Impacts of intervention option
Climate proofing and rehabilitating large scale hydro schemes	More frequent drought	Critical and extended water availability challenges leading to decrease in generation	Structural:	
			Establish forest cover targets in critical water catchment areas, and provide the financing and capacity required to ensure achievement of these targets.	Improved water resource availability
			Expand ambition for energy generation from wind, solar, geothermal and biomass power generation, and increasing the level of feed in tariff for renewable generation to draw in private sector operators.	Improved system resilience to extended drought and other shocks
			Non-structural	
			Develop demand management plans and use incentives and instruments to level peak demand/spread demand over time.	Reduce impact of drought and strategic use of constrained power generation
			Policy	
			Regulatory: Set specific quantitative and temporal targets for a diversified renewable energy mix that is resilient and can provide base/peak load during prolonged periods of drought and hydro power suppression or absence	Improved system resilience to extended drought and other shocks
			Regulator: Innovative demand smoothing measures and instruments, such as time of use pricing/incentives.	Smooth electricity demand

Source: (Climate and Pathway, 2013)

Table 2.2 is adopted from the National Climate Change Action Plan of Kenya. This is a climate Risk Assessment of Kenya's Flagship Projects and provides an example of how climate considerations can be factored into hydropower projects to ensure their sustainability. The most likely climate risk which is the frequency of droughts was identified with its implication being a decreased generating capacity. Through this framework various intervention strategies are outlined to minimize risk. Since hydropower is very vital in the economies of developing countries, strategies to increase their resilience to climatic events should be incorporated into their planning. Decision makers ought to commit more funds into carrying out comprehensive analysis during the planning of hydroelectric projects

2.6 Summary

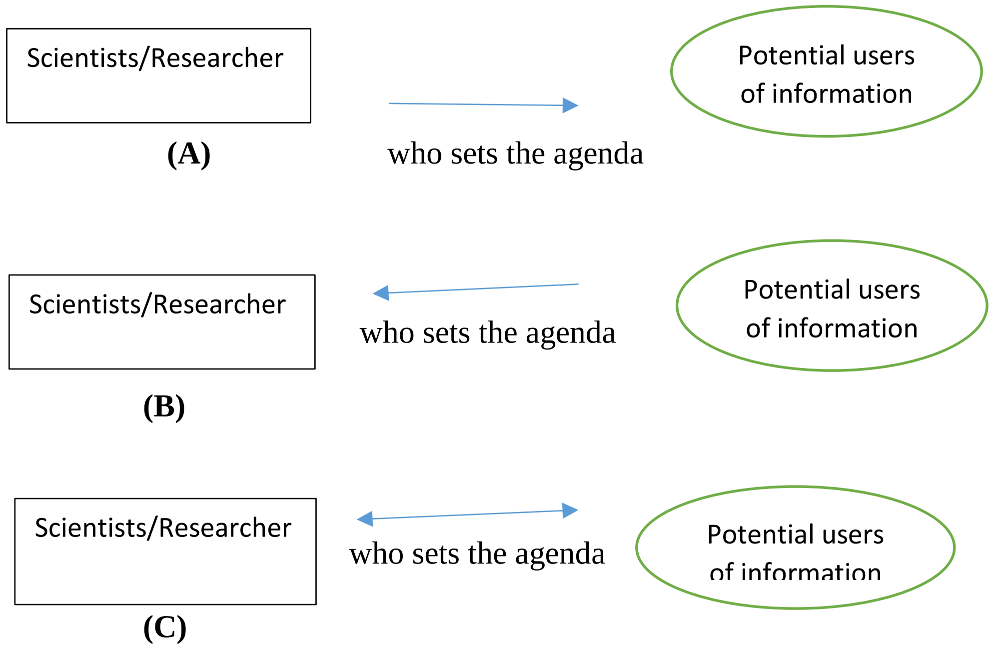
The literature reviewed the study area of the Bui Dam, the notorious West African climate and how the future climate will affect it. Studies conducted on the Volta Basin indicate rainfall has been declining and temperatures steadily increasing which could have a negative impact on hydropower generation. The section introduced the concept of uncertainty and explained the need to incorporate uncertainty in planning, when countries should adapt to climate change as well as outline how effective decisions can be made. Various tools policy makers can use to take decisions when faced with climate uncertainty were also discussed with examples showing where they have been applied. A brief description of the need for climate resilient development was also given as hydropower projects and any infrastructure or policy should be designed to be able to withstand the shocks of this uncertain climate. An example of a framework which highlights how hydropower schemes are climate proofed to ensure resilience was given to demonstrate the possibility of building such projects without the fear of the risks posed by the climate.

CHAPTER THREE: CONCEPTUAL FRAMEWORK

In recent years there has been significant progress in producing climate information in the Western World (IPCC, 2007). This can be in part attributed to the fact that institutions such as the IPCC have invested time and resources to summarize the state of art understanding of the climate and climate change (Plumer, 2013) as well as the recognition by users of the importance of considering the impacts of climate change. Another institution which has contributed to furthering climate research is the World Research Climate Programme (WRCP). Their primary focus is developing and improving on numerical models which simulate the climate system as well as understanding how sensitive the climate is to human and natural changes (Wel, 2015). The IPCC depends on the data produced by the WRCP for their various reports (Plumer, 2013). However, the question one might want to ask is whether these scientific strides are being translated into climate-resilient decision making and robust policy frameworks (NRC, 2009 a,b). The framework used in this study to understand the interaction of climate science with the development of hydropower policy in Ghana gets its inspiration from an earlier study by Lemos et al. (2012), which synthesized findings of other studies to identify the barriers of the use of climate information in decision making. Although the study of Lemos et al. (2012) considered the barriers to the use of seasonal climate forecasts, here we use it to identify the barriers to the use of climate information on a longer climate change timescale.

Put directly in the decision making context one can consider there are producers of climate information, known as the scientists and another group known as the users of the information, in this case, policymakers. Climate scientists are responsible for interpreting weather and climatic events, developing models of how the climate acts, predicting or making projections of future climate events and passing that information to various users including policymakers. This linear model of science denotes the process where scientific information flows from basic research to applied research to where it benefits people (Pielke and Byerly, 1998). Advocates of this model posit that when science conducts research, it is targeted at ensuring the people benefit (Sarewitz and Pielke, 2007: Kirchhoff et al., 2013). Critics, however, claimed that even though science is making significant discoveries, it is not necessarily informing decisions (Kirchhoff et al., 2013; Meyer, 2011).

Scientists produce information believing it is useful for policy making while decision makers might think otherwise (Lemos and Rood, 2010). Cash et al. (2003; 2005) suggest from a knowledge systems perspective that climate information is likely to be utilized if it exhibits the properties of saliency, credibility, and legitimacy. In this case, climate information is seen as credible if the "technical quality" behind its production has been tested (Cash and Buizer, 2005, p.32). Its saliency can be proven if the information is seen to be relevant; where decision makers need it and believe it is in a form, they can efficiently use (Cash and Buizer, 2005). The information can be classified as legitimate when the process of its production was seen to be fair and unbiased(Cash and Buizer, 2005). According to Sarewitz and Pielke (2007), there is the need to bring decision makers and producers of science/climate information together to develop information that is useful and usable for decision making. This section will attempt to explain how users relate to the climate information that science has produced in order to highlight the barriers that limit the use of long-term climate information. Other frameworks posit that when dealing with social problems, knowledge from science is not enough but instead, there should be some cooperation between scientists and users during the production process (Funtowicz and Ravetz, 1993, Turnpenny et al., 2010). In summary, studies seem to skew towards the fact that scientific research ought to be problem driven and that the users of information are vital during the process of producing scientific information (Kirchhoff et al. 2013; Cash and Buizer, 2005). Figure 3.1 describes the possible flow of information between producers and users of information under different conceptions of the science-policy space. In scenario (A), scientists naturally produce information with the expectation that users will use it. This is typical of the linear model where information flows to the society. In scenario (B), users determine what kind of information they need at any given time while in scenario (C), both scientists and users jointly decided the type of information to be produced.



Source : (Dilling and Lemos, 2011)

Figure 3. 1 Information flow between producers and users

(A) Researchers determine the type of information to produce and disseminate (B) Decision makers/users of the information determine what type of information they require (C) There is a joint collaboration on the information needed.

This study attempts to comprehend events that transpired during the planning of the Bui Dam from the perspectives of scientists and decision makers which led to long term climate information not being considered. In particular, two major frameworks are considered to determine the barriers of using climate information. The first as depicted in Table 3.1 was done to ascertain the barriers to the use of SCFs (Seasonal Climate Forecasts) whilst the second as described in Table 3.2 encompasses the different reasons why users are not utilizing medium to long term climate information. After describing what these two frameworks identified as the barriers, a new framework for this study is suggested. The findings found from these two major studies were derived mainly from the agriculture and water management sectors. This study will add to the knowledge in the energy and hydropower sectors as far as the barriers to the use of medium to long term climate information are concerned.

Table 3. 1Barriers of using Climate Information

	Barriers identified in the literature	
Fit	Not accurate and reliable	Not timely
	Not credible	Not useful; not usable
	Not salient	Excessive uncertainty
Interplay	Professional background	Insufficient technical capacity (for
	Previous negative experience	example lack of models)
	Value routine, established	Culture of risk aversion
	practices, local knowledge	Insufficient human or financial
	Low or no perceived risk	Capacity
	Difficulty incorporating	Legal or similar
	Information	Lack of discretion
Interaction	Not legitimate	Infrequent interaction
	One-way communication	End-user relationship

Source: (adopted from Lemos et al. 2012)

Various studies have attempted to understand the factors that prevent science from being used in policy (Rice, Woodhouse and Lukas, 2009). According to Table 3.1, there are three main factors of the barriers of using climate information (SCFs), namely, Fit, Interplay and

Interaction. Fit considers how well users perceive climate information and how they fit in with the culture of the organization. Decision makers perceive climate information as not "Fit" when they are not timely, not useful, not salient and not reliable (Cash et al., 2003; Pagano et al., 2002; Lemos and Morehouse, 2005). They tend to trust climate information less when they begin to notice some "false warnings" (Marshall, Gordon and Ash, 2011). This is because they have experienced many events where the forecasts have not been accurate; therefore it discourages them from using such information. The framework of the barriers to the use of SCFs can apply to long-term climate information because utilizing climate projections in the longer time frame is impeded because climate models cannot accurately simulate historical trends (Sabeerali *et al.*, 2014). This causes decision makers to question its accuracy and credibility.

Farmers cannot trust and rely on SCFs because they are generally unsure if information could be tailored to predict the weather patterns in their respective localities (Breuer *et al.*, 2008). What happens on, for example, farm A is different from what takes place on farm B; therefore, they believe a forecast that has been broadcast might not apply to their farms. In that sense, the information does not fit their needs. The fact that climate forecasts are inaccurate is not the only factor that limits scientific information use in decision making, procedures within the institution contribute as well (Rayner, Lach and Ingram, 2005). Interplay deals with how well the new climate information can complement or support existing information already in the organization (Bruno Soares and Dessai, 2016). In this case, the new information that comes in must agree with the setting and routines of the organization and conform to the technical expertise available(Bruno Soares and Dessai, 2016). Long-term climate information requires a high level of skills and expertise to interpret which currently many institutions in Sub-Saharan Africa do not have(Jones *et al.*, 2015). As a result of this using this information might not be appealing to them. According to the findings of the study conducted by Lemos et al. (2012) decision makers will avoid the use of climate information when they do not have the requisite skill sets to interpret it. (Lemos, 2008; Dilling and Lemos, 2011; Bolson and Broad, 2013). Also, building capacity of staff to be able to utilize climate forecasts would be both time and capital consuming/demanding. (Callahan, Miles and Fluharty, 1999). Again, when an institution has an already structured way of doing things or a particular trend of dealing with issues, and there is new information that would require management to alter their procedures they might to do so (Morss *et al.*, 2005).

Interaction means how well the producers and users of climate information communicate and liaise with one another (Lemos and Morehouse, 2005; Rayner et al., 2005).

Decision makers are less likely to use information if they were not involved in its production (Lemos, Kirchhoff and Ramprasad, 2012). This deals with how well scientists and decision makers communicate and collaborate to ensure the information produced is relevant and will meet the needs of the latter(Lemos and Morehouse, 2005). Studies show that when there is low and infrequent communication and liaison between these two groups, users might not be willing to use the information provided (Choi, 2005). Scientists may not have been able to convince decision on the need to consider the utilization of long-term climate information in their policies because their focus is with solving immediate issues(Jones *et al.*, 2015). From various studies, decision makers are critical of the role they play in the production of climate information; they do not use long term climate information because they are often left out in the production process (Bolson and Broad, 2013; Eden, 2011). Decision makers, therefore, will not be encouraged to incorporate such information in their decisions. Structures should be put in place during decision making to allow both science and policy to efficiently participate in the production of new information to ensure the goals of both parties are met.

The second theoretical framework to be considered comes from Jones *et al.* (2017). Here they conducted a study to seek out the barriers to the use of long-term climate information and placed the findings into five categories.

Table 3. 2Barriers to the use of long-term climate information

Category	Constraints	Summarized details
1.1. Disconnect between users and producers of climate information	1.1.1. Utility and relevance of climate information	Inability of available medium- to long-term climate information to address the perceived informational needs of decision makers
	1.1.2. Communication challenges between producers and users of climate information	Low accessibility of climate information. Formats and knowledge platforms are not always user-friendly. Lack of collaboration and interaction between the producers and users of climate information. Few effective boundary organizations
1.2. Limitations of climate information	1.2.1. Spatial resolution	Poor spatial resolution hinders the ability of climate information to inform local decisions
	1.2.2. Inherent uncertainty	Inherent uncertainty of climate models and the intrinsic complexity of the climate system
1.3. Financial and technical constraints	1.3.1. Limited financial resources	Lack of financial resources at national and local levels to access relevant climate information and tools to implement adaptation activates
	1.3.2. Limited scientific and technical Capacity	Limited scientific capacity to interpret and analyse climate information. Limited technical capacity to communicate climate information to decision makers in a manner that does not sacrifice the integrity of the underlying science. Limited capacity of decision makers to understand and utilize available climate information in decision-making processes, particularly relating to associated uncertainties.
1.4. Political economy and institutional constraints	1.4.1. Temporal mismatch between climate information and political cycles	Political cycles (typically 4 – 5 years in duration) are poorly matched with the timescales associated with medium-to long-term climate information (typically multi-decadal in duration)
	1.4.2. Institutional constraints	Reluctance of institutions to act on available knowledge – many relying on past information to guide decision-making. Higher priority allocated to addressing other development challenges and/or competing agendas Limited flexibility in decision-making over institutional structure, direction and budgeting
1.5. Psycho-scio constraints	1.5.1. Different perceptions of risk	Differing levels of risk perception amongst producers and users of climate information
	1.5.2. Trust and credibility	Perceived lack of accuracy, reliability, and credibility in climate information amongst many potential users and decision makers

Source: (Jones *et al.*, 2017)

As with the framework from Lemos et al. (2012), climate information is not utilized because decision makers do not see them as relevant. Governments and international bodies seem to finance climate research in order to further understand the whole system of the atmosphere whilst neglecting the issues raised by decision makers such as unemployment, poverty etc. (Jones *et al.,* 2017) Also, there is no proper communication between decision makers and the scientists/producers of climate information. Decision makers cannot interpret the findings of science into working solutions (Romdahl, 2011: Viviroli et al., 2011).

Jones et al. (2017) also state that long-term climate information is not being used because of the uncertainties associated with it. They suggest that decision makers require a high level of certainty when taking decisions especially with regards to what to invest. However, scientists cannot meet those expectations because of the nature of the uncertainties and the complexity of the climatic system. As a result of this decision makers choose to ignore climate information completely (Kirchoff et al., 2013b).

Developing countries do not have the financial muscle to access downscaled climate data some of which require historical data they do not have (Lawrence et al., 2013). As a result of insufficient funds, climate information is not used in many areas especially Sub-Saharan Africa. Climate science is complicated and the information produced requires a specific, and technical acumen before decision makers or users can understand and utilize. These technically astute individuals or groups are to communicate the strengths and weaknesses of climate information to decision makers(Jones *et al.*, 2017). In the event where these intellects are absent decision makers cannot interpret climate information thus hindering their ability to utilize them in their plans or policies.

Decision makers perceive climate information as not necessary because it does not meet their needs. Multi-decadal climate projections may provide information up to a 100 years into the future but decision makers are generally only interested in only what will happen in the next decade (Bryson et al., 2010: Agrawala and van Aalst, 2008). Developing countries have to deal with immediate issues so have little or no concern with things further into the future (Ziervogel and Zermoglio, 2009).

The structure and mandates of institutions, the case of bureaucracy and limited flexibility affect the manner in which climate information is used (Lemos and Rood, 2010). These institutions although aware of the risks and uncertainties of the climate consider financial and socio-economic issues as more important (Lemos and Rood, 2010).According to Kirchhoff et al. (2013b), when decision makers perceive that the climate information is not credible, they will not use it. Some decision makers in water resource management do not find the state of climate science presently to be accurate nor reliable enough to be utilized by them.

Considering these two frameworks, the first which centers on SCFs and the second on long-term climate information, we notice there are similarities. For example, both agree on the issue of the technical background of experts as well as the relevance of the climate information as barriers to their use and the issue of uncertainty. The researcher, therefore, proposes a framework on the barriers to the use of climate information in hydropower planning based on the second framework developed by Jones et al., (2017). This is because Lemos is more directed at SCFs while this study is skewed towards long-term climate information. Also, Lemos does not consider the relevance of policy documents as a barrier to why climate information is excluded from decision making, Jones et al., (2017) identifies the political economy and institutional constraints as a significant barrier stating that other development initiatives are placed ahead of climate change efforts. The researcher modifies the framework by Jones et al., (2017) by placing psycho-socio constraints, how producers and users of climate analysis perceive risk, under the disconnect between users and producers and climate information to help understand what the possible barriers to using climate information in hydropower planning could be. This has been summarized in **Table 3.3**

Table 3. 3 Barriers to the use of climate information in hydropower planning

Category	Constraints	Summarized details
1. Disconnect between users and producers of climate information	Utility and relevance of climate information	Decision makers did not consider climate information was necessary during the planning stage of the dam
2. Limitations of climate information	Uncertainty	Decision makers are aware of climate change but did not consider the issue of uncertainty.
3. Technical constraints	Limited scientific and technical capacity	There were few or no experts available to analyse medium to long term climate information.
4. Political economy and institutional constraints	Weak policies The need for development interventions surpass climate risks and uncertainties	Development interventions are of more importance than climate change efforts

CHAPTER FOUR: RESEARCH METHODOLOGY

4.1 Introduction

Creswell (2003) defines qualitative research as a method used to analyse social processes using themes and categories that emerge and arise from interviews, observations, videotapes, and case studies. Quantitative research, on the other hand, seeks to verify hypotheses based on quantitative numerical information typically from observation (Creswell, 1998). It is most often utilized when the researcher attempts to comprehend why people do what they do and how (Drew et al., 2008). In studies where there is the need to describe, illustrate, explain and explore behavior and events, qualitative methods are the most applicable (Drew et al., 2008).

In this study, a qualitative research method was used due to the nature of the questions being asked. In order to investigate the extent to which climate information is used in Ghana as well as explore issues which might not have been obvious, this research approach is most appropriate. According to Creswell (2003), the idea behind the qualitative research is to derive a deeper understanding of a phenomenon on a different scale from quantitative research by obtaining information from a small fragment of people. Qualitative research provides a mechanism through which the attitudes and behavioral patterns of people and how they perceive the world, instead of generalising on a larger scale (Creswell, 2003).

4.2 Research design

Mouton (1996) and Cheek (2008) suggest that a research design is intended to draw a plan and determine how it would be implemented. For this research, the case study method is used in an attempt to answer the questions posed.

4.3 Case study

According to Miles et al. (1994), "the case study approach to qualitative inquiry is focused less on discerning patterns of the group and more on an in-depth description of a process, a program, an event, or an activity." (p.163). To be able to find out how decisions concerning climate change uncertainty and hydropower projects are taken in Ghana, there is the need to examine closely a most recent case, which is the Bui Dam. This would enable the researcher to understand deeply the processes which led to the construction of the dam despite the issues of uncertainties posed by the climate. The researcher would rely on multiple forms of data such as semi-structured interviews, document analysis and archival records to describe what went on during the project and explore why certain things were issued (Yin, 2003).

4.4 Sampling

In qualitative research, purposive sampling is widely used (Creswell, 1998). This research had to rely on purposive sampling as it was the most convenient method of locating and assembling participants with adequate knowledge on the research question. Considering the aim of the research, the researcher from his own judgment selected people from the following institutions, The Energy Commission, The Environmental Protection Agency, Ghana Meteorological Agency and the Water Research Institute of the Centre for Scientific and Industrial Research. Fifteen key informants who were involved in the Bui Dam in differing capacities were therefore selected.

4.5 Data collection

In order to derive adequate information to support the case study method, semi-structured interviews and an extensive review and analysis of relevant government documents, various publications, and journals, as well as specific internet searches, would constitute the main data collection methods. In search for relevant literature from academic journals and publications, the keywords the researcher used were, “climate change”, “climate change uncertainty”, “climate change in Africa”, “climate change and hydropower”, “decision making under climate change uncertainty”, “impact of climate change on energy”, “energy in Ghana”, “climate change and the Bui Dam”. These entries formed the basis for the document search online and produced results which the researched scanned through and selected those of relevance for the study. Documents such as the energy and climate change policy were obtained from the Ministry of Energy and the Ministry of Environment, Science, Technology, and Innovation respectively. Other secondary data such as the feasibility report and Environment and Social Impact Assessment of the Bui Dam were explicitly analyzed.

Also, the semi-structured interviews would help determine the following:

- the barriers of using climate information during the Bui Dam construction.

The questions were not close-ended but left open to encourage further discussion about the issues. The questions used for the interviews are found in Appendix 1. Participants for the interviews were selected using the purposive sampling method from the following institutions, The Energy Commission, The Environmental Protection Agency, Ghana Meteorological Agency and the Water Research Institute of the Centre for Scientific and Industrial Research. The rationale for this selection is summarized in Table 4. Four people were selected from these organizations to gain insight into the research subject. The primary challenge the researcher faced was the issue of time as many participants called off appointments at the last minute and had to reschedule thus affecting the timely collection of data. Each interview lasted at least an hour and was tape recorded for transcription and analysis.

Table 4. 1 Interview schedule

DATE	INSTITUTION	PURPOSE	ROLE
October 2015	Energy Commission	To find out how risks in hydro-power infrastructure development and operations are perceived and quantified and the process by how hydropower plans are developed	The Energy Commission advises the government on energy policy and strategy
October 2015	Water Resource Commission	To understand the actual impact climate change is having on water resources in the country over the historical/present period and the projections for the future, analyse risks and uncertainties involved.	Regulates and manages Ghana's water resources and coordinating government policies in relation to them
October 2015	Ghana Meteo Agency	To gain understanding on how climate information is generated and disseminated for planning hydropower schemes	The Ghana Meteorological Services Agency (GMet) is charged with collating, analyzing, storing and disseminating meteorological data to end users for climate change adaptation measures to be carried out
December 2015	Bui Power Authority	To investigate how the Bui Dam incorporated climate risks and uncertainties	Established to oversee the development of the Bui hydroelectric power project on the Black Volta river and any other potential hydroelectric power sites on the Black Volta river.

The above table shows the summary of the various interviews conducted during the study.

4.6 Ethical protocol

The procedures for the interviews were laid out in writing, and were clearly explained to interviewees before interviews proceed. Participants signed a consent form (Appendix 2) and read a brief of the study (Appendix 3) before the interviews began. The confidentiality of interviewees were respected and were not named by their request. The interviews were conducted at a location chosen by participant.

This research was undertaken without any cause to harm to the society and the participants. Participants were given full and accurate information in regard to issues such as the background, nature and purpose of the research. Participants were given sufficient details on the research in question as to allow them to make an informed decision to participate or otherwise in a research study. Participants were not coerced to give information as part of the research and to withdraw from the research at any time. The information provided by participants has been treated as confidential and used for research purposes only. Participants were not put under undue or unnecessary risk as a result of their participation.

4.7 Limitations of the study

The researcher encountered a few challenges during the research, particularly during the interview process. Although 15 key informants were chosen, as a result of the limited time and resources the researcher had and the busy schedules of the officials, fixing appointments proved futile permitting the researcher to meet only four key personnel. For example one scheduled meeting with officials from the Environmental Protection Agency could not come on as a result of their involvement in the Climate Change conference held during Paris at the time. The failure to meet them did not affect the results of the study because the researcher got access to secondary data which contained enough material to supplement the study.

4.8 Data Analysis

The researcher transcribed all interviews, and created various pages on Microsoft word where findings from internet searches and other document analyses were collated. This began the data analysis process. The researcher grouped the findings from each interview and document review into various themes in order to understand their relationships and meanings. The framework by Lemos was used to document, organize and categorize both the primary and secondary data. Results were then interpreted inductively in order to identify and describe relationships. The data was analyzed to find recurrent themes and patterns in order to arrive at a credible Through this the researcher was able to identify the similarities the study had with previous work as well as demonstrate systematically and logically how decisions concerning the Bui Dam planning and construction were taken.

CHAPTER 5: RESULTS AND DISCUSSION

5.0 Introduction

In order to address the research aim of ‘to what extent climate information is used in hydropower planning in Africa, specifically in Ghana, the logical flow of analysis is as follows. The researcher presents results in line with the research objectives. First, to have a clear understanding of the dam planning process in Ghana, a summary of the national governance structures and institutions for the relevant sectors of energy and climate is provided. Also, the various policy documents on energy and climate are introduced and discussed. (Section 5.1). Secondly, to understand the barriers to conducting a climate risk analysis in dam planning, responses from key informant interviews are used. (Section 5.2).

5.1 What is the planning process of Dams in Ghana?

This section introduces and examines the institutions and relevant policy documents involved in the process of building dams in Ghana. This seeks to describe how dams are drawn and conceived on paper before they are finally built. This will enable one to understand the linkages between climate and policy. First of all, The National Development Planning Commission (NDPC) is the institution responsible for planning development interventions. It works together with the The Ministry of Environment, Science, Technology and Innovation (MESTI), The Environmental Protection Agency (EPA) and Ministry of Finance and Economic Planning (MOFEP) to ensure that the development policy framework which is known as the Ghana Shared Growth and Development Agenda (GSGDA II) (2014-2017) has considered climate change and its impacts in Ghana (MESTI, 2013).

The Ministry of Environment, Science, Technology, and Innovation (MESTI) is responsible for protecting the environment by creating policies and ensuring that science and technology related activities follow set out guidelines and principles as well as maintaining proper coordination for sustainable development activities. MESTI operates through the Environmental Protection Agency (EPA), the Council for Scientific and Industrial Research (CSIR); the Ghana Atomic Energy Commission (GAEC); and the

Town and Country Planning Department (TCPD). It is the lead institution for climate change activities in Ghana (MESTI, 2013).

The EPA ensures compliance with any laid down environmental impact assessment procedures in the planning and execution of development projects, including compliance in the respect of existing projects and to advise the Minister on the formulation of policies on all aspects of the environment and in particular make recommendations for the protection of the environment (EPA, 2015). The Water Resources Commission (WRC) is charged with regulating and managing Ghana's water resources and coordinating government policies in concerning them (WRC, 2015).

The Ministry of Energy and Petroleum (MoEP) is responsible for drawing and assessing energy-related policies while The Energy Commission advises the government on energy policy and strategy (Energy Commission, 2006). The institution was represented on the National Climate Change Committee (NCCC) when the National Climate Change Policy (NCCP) was being developed. The 2010 Energy Policy that was drawn by the Policy sought "to promote clean energy with less use of wood fuel and charcoal to safeguard the nation's forests that are important carbon sinks" (MESTI, 2013). The Ghana Meteorological Services Agency (GMet) is charged with collating, analyzing, storing and disseminating meteorological data to end users for climate change adaptation measures to be carried out (MESTI, 2013).

In Ghana, Non-governmental Organizations (NGOs) have been widely involved in climate change activities at various levels, however, despite NGOs being involved in climate change activities issues such as insufficient funding and low levels of technical expertise has affected their work (MESTI, 2013). As far as climate change initiatives in the country are concerned, the following organizations have over the years been instrumental: UK Department for International Development (DFID), the European Union, the French Development Agency, the World Bank, The Embassy of the Kingdom of the Netherlands, United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP). It is however unfortunate that most of these projects lack harmonization thus resulting in a duplication of efforts (MESTI, 2013).

In 2009, a National Climate Change Committee (NCCC) was founded by the President to be hosted by The Ministry of Environment Science Technology and Innovation. It was given the authorisation to deliver policy direction on climate change; to oversee activities to ensure the efficacy of policy measures; and to assess related policies and programmes (MESTI, 2013).

5.1.1 What are the policies guiding climate change and hydropower development?

The country has two critical national adaptation policy documents that recognize the need for action at all levels of the government, from national to local. These are the National Climate Change Adaptation Strategy (NCCAS), published in 2012 for the period 2010 to 2020, and the National Climate Change Policy, launched in 2013 for the period 2015-2020. With lead implementation by the Ministry of Environment, Science, Technology, and Innovation (MESTI) and support from the National Climate Change Committee, the National Climate Change Adaptation Strategy is implemented by the UNEP and the UNDP.

The goal of the NCCAS is “to enhance Ghana’s current and future development to climate change impacts by strengthening its adaptive capacity and building resilience of the society and ecosystems.” Its primary objectives are to improve societal awareness and preparedness for climate change, enhance the mainstreaming of climate change into national development planning. The NCCAS has ten priority programmes for climate change adaptation and integration into national development:

Table 5. 1The ten (10) priority programmes of the NCCAS

1. Increasing resilience to climate change impacts: identifying and enhancing early warning systems 2. Alternative livelihoods: minimizing impacts of climate change for the poor and vulnerable 3. Enhance national capacity to adapt to climate change through improved land use management 4. Adapting to climate change through enhanced research and awareness creation 5. Development and implementation of environmental sanitation strategies to adapt to climate change 6. Managing water resources as climate change adaptation to enhance productivity and livelihoods 7. Minimizing climate change impacts on socio-economic development through agricultural diversification 8. Minimizing climate change impacts human health through improved access to healthcare 9. Demand- and supply-side measures for adapting the national energy system to impacts of climate change 10. Adaptation to climate change: sustaining livelihoods through enhanced fisheries resource management

Source: (Mensah, Anderson and Nelson, 2016)

Table 5.1 highlights the ten priority areas of the NCAAS. The strategy document, however, does not describe how each would be implemented. However the most pertinent issue is whereas this document was published in 2012, the Bui Dam construction began in 2009. This is critical as it indicates the country began consideration of climate change in its various policy documents after the Bui Dam was under construction.

The second document which guides climate change efforts in the country is the National Climate Change Policy (NCCP). The vision of the NCCP is to ensure a climate-resilient and climate-compatible economy while achieving sustainable development through equitable low-carbon economic growth for Ghana" (MESTI, 2013). The NCCP is in line with the aims of the Ghana Shared Growth and Development Agenda (GSGDA) 2010-2013 (MESTI, 2013). Table 5.2 describes the areas which the NCCP focuses.

Table 5. 2 The National Climate Change Policy priority areas

Policy area	Focus area
Agriculture and Food Security	Develop climate-resilient agriculture and food security systems
Disaster Preparedness and Response	Build climate-resilient infrastructure Increase the resilience of vulnerable communities to climate-related risks
Natural Resource Management	Increase carbon sinks Improve management and resilience of terrestrial, aquatic and marine ecosystems
Equitable Social Development	Address the impact of climate change on human health Minimize the impact of climate change on access to water and sanitation Address gender issues in climate change Address climate change and migration
Energy, Industrial, and Infrastructural Development	Minimize greenhouse gas emissions

Source: MESTI, 2013

The discussion till now is seeking to lay down the various institutions and documents that guide climate change initiatives in Ghana. It is important to note that The NCCP was developed in 2013, years after the Bui Dam (2009) construction began. In the actual sense, there was no climate change policy document to guide the planning process or any general climate change mitigation or adaptation efforts. There is evidence of the commitment of policymakers in Ghana to engage and deal with the climate change issue. However, efforts to ensure a climate-change-proof economy have not quite materialised. This perhaps could be due to inadequate capacity (both technically and financially) at all levels of the national development planning processes (EPA, 2010). Ghana has yet to mobilise national sources of funding and to tap into global opportunities for financing for climate change adaptation.

This relates back to a limited understanding and knowledge of the climate change impacts and how these will affect sectoral development, and consequently a limited ability to budget for adaptation actions (EPA, 2010).

The NCCP is more skewed to mitigation efforts than adaptation especially with regards to energy, and industrial development. It seeks to reduce emissions but does not disclose how energy sources affected by climate change can be sustained. It also does not describe how the negatives of climate change can be dealt with to ensure sustainability of the energy sector and hydropower projects. For a country that depends on hydropower for most of its electricity, it is quite disturbing the climate change policy does not say much about how to adapt to climate change especially with future development projects.

The NDPC developed the Ghana Shared Growth Development Agenda I, II (GSDGA). The medium-term strategy is founded with the aim of achieving macroeconomic stability and the efficient utilization of Ghana's natural resources in agriculture, minerals and oil and gas supported by strategic investments in human capital, infrastructure, human settlements, science, technology and innovation to drive industrialization (NDPC, 2010). The strategy delineates the various policies and strategies that will be used to manage the economy between 2010 and 2017 (NDPC, 2010). In order to properly manage the economy, more significance will be placed on human development, infrastructural development, housing, and energy for accelerated employment creation and income generation for poverty reduction. (NDPC, 2010). The framework also seeks to promote measures that would ensure environmental sustainability as well as lower the impacts of climate change (NDPC, 2010).

The GSGDA identifies the absence of climate change mitigating and adaptation policies for the energy sector, and unreliable and inadequate supply of energy to households and industry (NDPC, 2010). As this was identified, the only reaction was to introduce mitigating efforts in the NCCP which was to minimize greenhouse gas emissions; however, it was silent on adaptation issues. The GSGDA highlights the urgency of climate proofing the nation's infrastructural assets as well as reinforce energy security as these two are pivotal towards economic growth and poverty reduction (MESTI, 2013). The policy document does not show how infrastructure should be climate-proofed though that is what it advises. It would be appropriate if the documents could provide a plan for action/implementation to guide the processes of climate proofing any form of infrastructure.

Energy policies by different administrations have been developed over the years to enable progressive economic development through reliable energy supply (Kemausuor et al., 2011). The Volta River Scheme was conceived during the colonial era, but it was under the governance of the late Dr. Kwame Nkrumah, the first president of Ghana that the Volta River Project was a reality (Botchway, 2000). In 1962, the Akosombo dam began construction and was commissioned in 1965 at around $200 million (Gridco, 2010). A year earlier The Volta River Authority was formed to oversee the construction of the dam, building a power station close to Akosombo and making sure to relocate residents (VRA, 1961).

In 1982, after decades of increasing demand for electricity, the VRA commissioned the second dam, Kpong hydroelectric project (Asante and Clottey, 2007). During the 1990s the government drew up the National Energy Strategy (NES) with the aim of expanding electricity to the entire nation by the year 2020 (Energy Commission, 2004). The NES was planned to proceed in six 5-year phases over the period 1990–2020. Between 2000 and 2005, the government adopted a formal energy policy, with the intention of providing adequate energy for meeting development objectives of poverty reduction as well as stimulate economic growth (NDPC, 2007).

The Energy Commission prepared the Strategic National Energy plan (SNEP) in 2006 to outline the potential energy resources of the country which could be harnessed to facilitate growth by 2020 (Energy Commission, 2006). SNEP was merely a comprehensive plan to identify the optimal path for the development, utilization and efficient management of energy resources available to the country. It is in this document that the premise for the Bui dam project is outlined. Table 5.3 outlines the sources of electricity generation in Ghana in 2013 while Figure 5.1 shows a more recent electricity outlook in Ghana.

Table 5. 3 Electricity Outlook in Ghana

NAME OF PLANT	INSTALLED CAPACITY (MW)	EFFECTIVE CAPACITY	OPERATING AUTHORITY
AKOSOMOBO	1020	1001	VRA
KPONG	160	120	VRA
BUI	400	133	BPA
SUB-TOTAL	1580	1254	
THERMAL	1,234	1,234	VRA, IPP's, CENIT, TAPCO. TICO
TOTAL	2,814	2,492	

Source: VRA, 2013

Table 5.3 highlights the contribution of hydropower facilities in the country as at 2013. Hydropower accounted for 56% whilst thermal sources provided 44% of the nations' electricity. MW represents Megawatts.

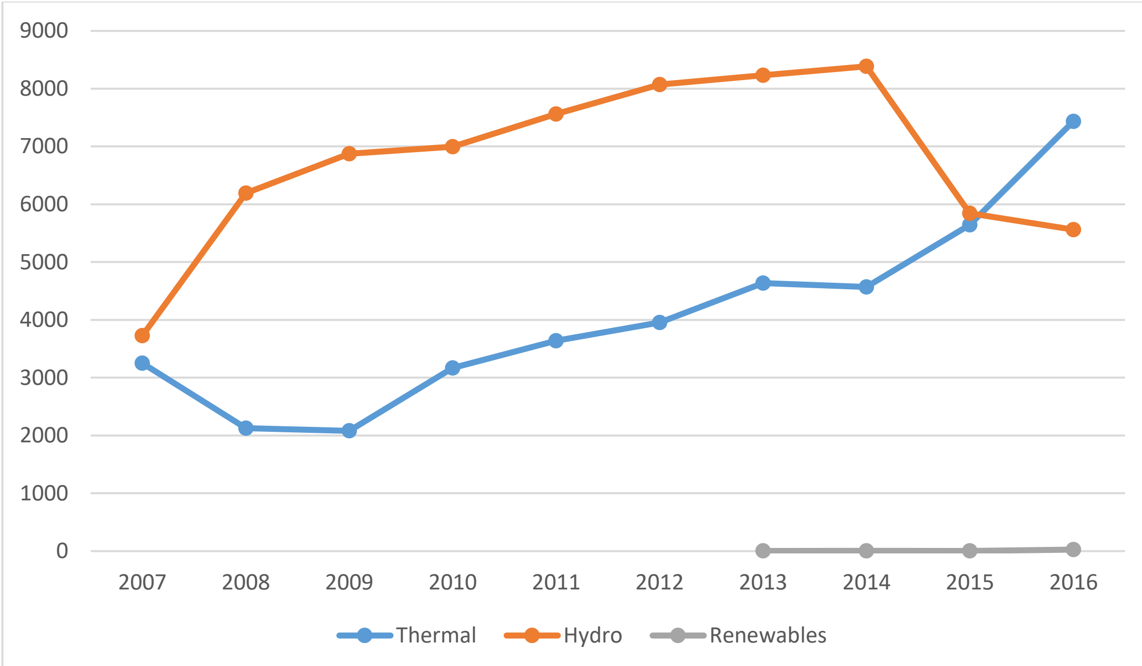


Figure 5. 1 The electricity generation by plant (GWh) per installed capacity (MW).

Source: (Energy Commission, 2017)

From 2007, hydropower has been the number one source of power till some few years ago when thermal power's use has risen significantly. This shows that there is an ongoing gradual shift from hydropower.

5.1.3 Planning process of the Bui Dam.

After considering the various institutions and the specific policies needed in Dam planning, this section briefly describes how the most recent Bui Dam was planned and eventually implemented. **Table 5.4** shows this and indicates the various timelines were possible.

Table 5. 4 A step by step process of how the Bui Dam was finally built

PLANNING PROCESS

- It begun at National Development Planning Commission (NDPC) where a policy was formulated in an attempt to address the deficit in energy supply. (March, 2005)

• After agreeing to build the dam, the NDPC monitored to ensure strict following to the plan.

• The Bui Power Authority (BPA) (project owner) got an environmental permit from the Environmental Protection Agency (EPA) after carrying out the Environmental and Social Impact Assessment (ESIA). After the permit was issued, the Energy Commission set up a committee to assess the dam site. (April, 2007)

• The BPA then sought a permit from the Water Resources Commission (WRC) for a permit. (August, 2007)

• The EPA sets up a technical review team, with the WRC included, for the ESIA study however that did not happen with the Bui Dam project mainly due to the following reasons:

  - Government had already approved the contract with Sinohydro (dam builders) and the loan agreement with China Exim Bank. (September, 2007)

• The WRC became involved after the EPA issued the environmental permit and when BPA wanted to begin diverting the river. The WRC ensured in its permit that there was no water pollution during construction, enough water, no upstream flooding when it rains as well as regulated flows downstream. (October, 2007)

• WRC monitored the project to ensure adherence to water standards and regulations. However, in the case of the Bui Dam, it could not organize frequent visits to the site due to low staff availability. (April, 2008)

• The BPA then provided the Energy Commission with the environmental permits from the EPA and permits from the WRC before work began. (December, 2009)

Source: (Hensengerth, 2014) Secondary data

From this section, these critical issues have been identified:

1. The climate policies were published after the Bui Dam had begun construction. This could explain why there were not any climate risk assessment conducted during the planning phase since there was no document to guide the process.

2. The NCCP although published years after the Bui Dam is still weak and does not state how hydropower which is a climate-sensitive infrastructure can be climate proofed.
3. The NCCAS although mentioning the vulnerability of hydropower does not explicitly state how the sector can be climate-proofed
4. During the planning process of the Dam leading towards its implementation, some procedures were hastened because of the 'urgency' of the project. The NDPC had already identified the Bui Dam as key in fixing the deficit in energy supply. Therefore the project had to be implemented despite the potential risks and uncertainties posed by the climate.

5.2 What are the barriers to climate risk analysis in hydropower planning?

In summary, the following issues were raised. The various institutions responsible for climate change adaptation and energy development, their respective policy frameworks, the electricity outlook in the country highlighting the contribution of hydropower in the country. This was done to demonstrate the roles and responsibilities of government institutions in the process of hydropower development to understand how the Bui Dam was built. It was pointed out that the plan for the Bui Dam was conceived before the climate change policies were published. This proves that there was no guideline to follow to ensure the impact of climate change on the Bui Dam was extensively explored. However, after examining the policy documents that were released, they do not indicate any strategies for ensuring how climate change risks and uncertainties would be factored into future hydropower projects. The researcher now considers the extent to which climate information is used hydropower planning and attempts to explain why a climate risk analysis might not be conducted in subsequent hydropower projects.

5.2.1 Climate information needed for hydropower projects

According to (Jones and Walmsley, 2014), the viability of any hydropower scheme is dependent on the following climate information/ services,

- Flow data: a flow series of about 30 years is needed for analysis however in most African nations, access to such data is limited.
- Rainfall data: These records are needed to perform a rainfall-runoff analysis before the construction of the facility

- Temperature and solar radiation data: These are necessary to estimate evaporation from the reservoir
- Climate change scenarios – This is needed to be able to connect global scale predictions and regional dynamics to generate specific forecasts.

According to the feasibility study of the Bui Dam, the energy generation capacity of the project was reviewed using historical records of monthly inflow of the Black Volta (Coyne and Bellier, 2006). Majority of hydropower plants have been built using historical flow data of about 30 years with the belief that the future would be the same; however it is unlikely that such plants would last their lifespan (Beilfuss, 2012). This is because these plants were designed with the data provided from the past, therefore, considering the nature of climate change and its uncertainties there is no guarantee that in about 50 years from now they would still be operational.

From the feasibility studies and the ESIA reports of the Bui Dam, it was clearly shown that historical information relating to rainfall, hydrology as well as temperature was utilized, however climate change scenarios were not used. As such, there was no risk assessment to demonstrate the vulnerability to future climate and thus the possibility that climate change could affect the viability of the project. Some institutions tried lobbying for more analysis to be conducted but the project speedily went on (International Rivers, 2008). Again, since all the climate policies were drafted after the Bui dam had begun construction, it only means they could not have influenced it. However, the Pwalugu dam has been lined up and has even undergone a scoping report. This section, therefore, captures the factors that could impede the running of a climate risk analysis in future hydropower plants. Results here are from the responses given by participants of the study which are matched to the conceptual framework on the use of climate information introduced in Chapter 3

Limitations of climate information

This mainly considers the issue of uncertainty inherent in climate information.

Data we collect from synoptic stations are both inaccurate and insufficient. Insufficient data stems from the fact that historical data especially during the 1980s – 1990s have many gaps. (15112015-1). In the previous section, it was discovered that in Sub Saharan Africa access to such data is limited. Synoptic stations are vital because they can provide various meteorological data for research. In adapting to climate change, it is necessary to have data concerning the meteorological pattern of the area in question to adopt adaptation strategies. For the measures to be successful, the data has to be accurate, and this is a typical reason why climate information might not be used in huge infrastructural projects such as hydropower. When scientists cannot rely on the data they have, it can affect their ability to conduct a proper analysis for use by decision makers. This means that for climate information to be used there is the need for data to be accurate and sufficient for the purpose for which it is needed. Where there are gaps in the data, it would profoundly affect the outcome of decisions. *Satellite data is rarely used due to the cost involved in getting access to them* (15112015-1).

Many of the synoptic stations have been abandoned mainly due to funds and inadequate personnel to man them. According to the World Meteorological Organization, stations ought to be 20km apart, but in Ghana, they are 90km apart (15112015-1). This poses serious difficulty in collating data for extensive analysis during hydropower projects. In the situation where there are few synoptic stations, and they are abandoned, would it be judicious to construct more? The more synoptic stations, the more accurate and area-specific the data becomes hence the WMO's suggestion of building them 20km apart. The absence of enough stations compromises the accuracy and reliability of the data provided. Figure 5.2 clearly shows the 22 synoptic stations in the country.

*We are aware of climate change, and we know that forecasts and those predictions are not 100% accurate. Just like saying it will rain today and it does not, they are not always accurate. We need climate information but know it is limited, so we do not put our complete hope in it. Some decisions need to be made, and we have to take them regardless of the information we have. In other words, the climate is not the only other factor (*15112015-2).

From the responses of respondents, the three main issues they raised were insufficient data, inaccurate data as well as the issue of uncertainty. This explains the limitation inherent in climate information and why decision makers will not want to use them in making decisions with long-term implications. Decision makers cannot rely on inaccurate data to make critical decisions.

Question: Are you resourced and knowledgeable with the tools that are used to take decisions under climate change uncertainty.

We are not aware of these tools and techniques (15112015-1). Producers of climate information had no clue about the various tools that have been developed to incorporate climate change uncertainty in decision making such as Multi-criteria analysis and others. As there is no education on these tools, they cannot be used unless they receive some training to upgrade and enhance their skill sets.

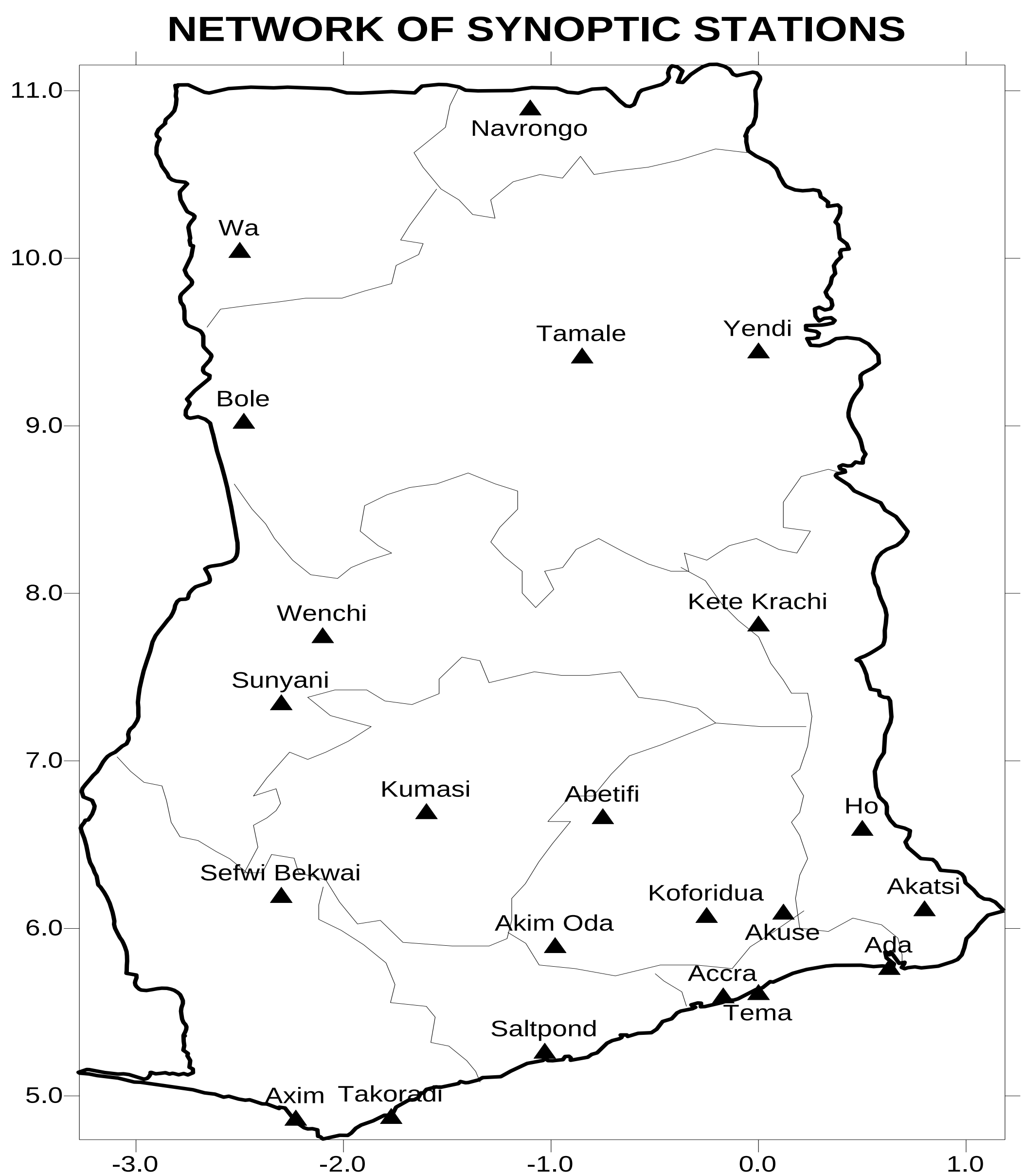


Figure 5. 2 The 22 synoptic stations in the country.

Source: GMet, 2012

Technical constraints

This deals with how limited the technical expertise in the research institutes is.

What barriers do you face in using climate information, both seasonal and decadal?

In my organization, we only recently acquired a high-speed computer from Japan to aid meteorological activities, so some of our technical staff are currently being trained to operate it. We cannot handle short-term forecasts let alone add long-term information (A21102015-1). The information that is currently collated cannot be adequately analysed as they do not have the requisite skill set to do so. Before, the scientists could not make good use of the sparse information they were able to collect because they lacked the logistics as well as the technical acumen to do an extensive analysis. They do not focus on decadal forecasts with the farthest being the long-term forecast (i.e., three to nine months) which has implications for long-term planning.

What are the challenges your institution faces in dealing with climate information?

> The challenging nature of the notorious climate of West Africa is difficult to predict, and this is worsened by the fact that the climate models we used are very Eurocentric. One disadvantage is that most of the parameters requested by the models do not conform to the climate and nature of Africa since they were designed mainly by and for the western nations. Most of these models are very expensive to acquire while the free, and public domain ones are not sophisticated enough for extensive analysis. Some require too much data based since they were designed to suit or mimic the climate of foreign nations. (A21102015-1).

In this case, the main issues raised here are the Eurocentrism of the models and the low technical abilities of staff. Since models are difficult to use and acquire there is not enough motivation to conduct a comprehensive analysis of climate change issues. Also, the use of long-term climate information would require sophisticated logistics and trained staff to be able to interpret thus resulting in a barrier.

Disconnect between users and producers of climate information

This deals with how fluid the relationship between producers of the information and the users are as well as how useful, and relevant the climate information is to decision makers.

> The government does not take climate information seriously even with seasonal forecasts that are released. Whenever there are dramatic changes in climate which could affect development, attempts to contact government is made but no response comes from them. For example, current conditions are similar to 1983, so it was necessary to send information to the government but, they have not responded. Agriculture and water resources would be affected significantly. (A21112015-1).

There is no clear communication channel between government and institutions charged with releasing such information although they are supposed to be working together.

During the construction of the Bui Dam we were contacted by the main contractors to undertake some studies which we did for them; however we cannot dictate how that information should be used. Our institution runs some hydrological studies for them (A21112015-1).

This is interesting and shows that climate information produced is not always going to be used by recipients. Several reasons could account for this with one being the political will of the users of the information. Decision makers since they control resources and wield power can decide to disregard the suggestions of scientists if the information provided is not satisfactory or encouraging. The government formed the Bui Power Authority to enable the flow of information among the affected stakeholders. This body acted as the project owner and was responsible for interacting with the Ministry of Finance and Economic Planning, The Ministry of Environment and Science and Technology and The Ministry of Energy, as well as other institutions that were involved in the project. This to an extent proves that there was some level of interaction and communication among institutions. In that respect, we might conclude that there was no problem with communication and that the decision that was finally taken through discussions and various deliberations rests with the government. One should note that, at the time, the government needed to provide electricity and had to solve the current power crises although reports suggest from decision makers that was not the case (Petersson, 2015).

One can argue that even though the Bui Dam was stated in the energy plan, there should have been a climate risk analysis conducted. However, it is not certain that a negative result from the analysis would have halted decision makers from proceeding. This is because, in developing nations, these hydropower plants are viewed as a tool for sparking and maintaining economic growth (Harrison and Whittington, 2001). Considering the benefits hydropower offers to the economy, it might not be judicious to halt the construction of future plants due to the fear of climate change. A way of dealing with this uncertainty might be to simply redesign the plants to accommodate the possibility of the changing climate.

One respondent also said, *there is a lack of support from the government to conduct research hence the impossibility to run a proper analysis during the Bui Dam planning* (15112015-1). The respondent added that, his institution could only get access to regional scale data from the National Aeronautics Space Administration if there are foreign-funded projects because it is costly to acquire (15112015-1). Critics called for more analysis before the construction of The Bui Dam, but it was ignored. Again, the bottom line is that even if the scientists had carried out an extensive analysis of the climate risks involved in the project, would the government heeded? One might also argue that even with the short term forecasts that required action, the government did nothing, therefore, it might be futile to expect them to discuss issues with long-term significance.

Science-policy linkages

Considering the NCCP and NCCAS documents, most of the scientific information analysed are based on past statistics and very little projections into the future. This confirms the government's stance towards long term plans. Without climate projections being factored into any of the climate policies guiding the nation, it is difficult to have a fair idea of how the future climate and its uncertainties would impact various sectors of the economy, specifically hydropower. In summary, there should be a progressive coordination between producers of climate information (science) and users of climate information (policy makers) whereas long term climate information would be used to advise long term plans. This would mean for example, that the government would use climate projections beyond the year 2050 to ensure that policy choices today made would not jeopardize future development.

Political economy and institutional constraints

This analyses the vital documents used in the planning of the dam.

Politics plays an essential part of every economy and is often at the heart of every decision taken in a country. The government would take decisions that would ensure it wins the next election thereby ensuring that basic amenities such as portable water and electricity are provided. In such a political climate decisions would be taken irrespective of the amount of opposition faced. The request to halt a developmental drive that would provide electricity, in order to check for climate risks would be ignored. From this understanding and after examining documents from key institutions central to this discourse, Energy commission and MESTI, it is evident that whilst the Bui Dam had backing in the energy plans, there was no such guideline for conducting a climate risk analysis in the NCCP or NCCAS. This might have given the government the impetus to carry out the project. Perhaps the presence of such a clause or statement in the policy documents would have tied them to conduct one.

From the literature review, it was indicated that before the construction, two hydrological assessments were conducted over the Black Volta, the main source of inflow for the Bui reservoir indicated a reduction river flow (Kunstmann and Jung 2005: WRI 2000). According to Kumar et al. (2011), rainfall trends are likely to change, become uncertain as a result of climate change; therefore assessments should be conducted during project planning. In assessing the feasibility of hydroelectric projects, technical analyses are used to evaluate how cash flows would be generated, ascertain the costs as well as the revenues the project might produce as shown in the feasibility study of the Bui Dam prepared by Coyne and Bellier (2006). They do not analyse how climate change would impact revenue and power generation associated with climate change probably because when climate considerations are incorporated, the financial risks may significantly undermine the feasibility of existing and future hydropower projects (Beilfuss, 2012). Also in the report, there was no mention of the risks of the climate on the Bui Dam.

To understand the extent to which the Bui project considered climate change, we examine the ESIA and feasibility study reports. The ESIA refers to climate change by this statement:

> Conversely, a changing climate, in turn, holds significant implications for the safety and performance of dams. Increases in the severity and frequency of droughts would

> reduce the capacity for hydropower production, and may increase reservoir sedimentation. This will, however, only happen over the very long term (i.e., thousands of years). Potentially, increased floods can also threaten dam safety; however, for the Bui Project the design parameters include provision for the worst possible maximum flood event (PMF) to occur, above the 10,000 year return period (Environmental Resources Management, 2007, p.176).

Even though it clearly stated the possible impacts of climate change, droughts, and flooding, it does not provide an extensive analysis but rather posits the potential impacts on very long time horizons. This confirms Rydgren et al. (2007) finding which said presently, EIA guidelines for hydropower projects around the world do not include aspects of hydrological variability beyond that dealing with dam safety issues, i.e., extreme flood peaks. According to the ESIA of the Bui Dam, “This study has been carried out per the policies, safeguard procedures, and guidance of the World Bank Group” (Environmental Resources Management, 2007, p.4). The World Bank Group’s ‘safeguard’ policies include thorough examinations in the following areas, “Projects in Disputed Areas, Projects in International Waters, Safety of Dams, Involuntary Resettlement, Indigenous Peoples, Cultural Property, Pest Management, Forestry, Natural Habitats and Environmental Assessment” (Environmental Resources Management, 2007,p.4). Though it conducts an environmental assessment, it does not state or describe how a climate analysis should be undertaken. As highlighted by Byer and Yeoman (2007) one major limitation of EIAs is their inability to determine how the uncertainties about changing climatic conditions can affect projects and how these uncertainties could be incorporated into the analysis.

The fact that the government’s EIA regulations did not make room for climate change analysis does not mean it should not have been done. Although in developing countries such as Ghana who are seeking for economic development, the provision of electricity is essential and hydropower sources if available would always be utilized considering the immense benefits it offers. In this case, it is evident that supplying electricity might perhaps be more important than considering climate risks. Also at the time the country drew the energy plan, climate change was not an “issue.” Even though it was stated that it might affect hydropower generation, alternate or adaptation plans to minimize climate risks were not drawn up. The climate policies that were published afterwards do not detail how hydropower projects ought to be climate-proofed, and this might affect future dams.

Considering the issues raised by respondents, the researcher discovered a few of the following

- Climate information is being used in managing and operating hydropower projects to in the form of seasonal climate forecasts.
- Climate information used in planning hydropower projects are limited to river flow, rainfall, and temperature data.
- Data used in the projects are based on only historical records which are incomplete and insufficient.
- The government does not support institutions financially to conduct detailed climate risk assessments.
- Institutions usually produce short to medium term forecasts, as, in the case of the Bui Dam, long-term (decadal) projections were not provided.
- Climate information is often not accessible because it is seen as expensive to acquire.
- Producers of climate information believed access to more data would help deal with uncertainty. They believe if the government purposely funds climate research they would have more data that could enable them to manage uncertainty.
- Producers of climate information did not know about decision making under climate change uncertainty methods.
- Governmental policies do not state how to climate-proof the hydropower sector.

Table 5.5 summarizes the barriers of using long-term climate information in hydropower projects as discovered from this study. These if not adequately managed might be encountered during the planning and construction of the Pwalugu multipurpose dam.

Table 5. 5 Barriers of performing climate risk analysis in hydropower projects

Category	Constraints	Details
Limitations of climate information	• Insufficient data • Inaccurate data • Uncertainty	The data provided by climate science is not reliable. Therefore when considering the future of the Bui Dam, it was ignored.
Technical constraints	• Eurocentric models • Lack of competent technical staff	Few trained experts can conduct proper climate risk analysis
Disconnect between users and producers of climate information	• Lack of government support • Lack of stakeholder communication	The government is not concerned about what the climate is saying but the need to build the Dam.
Political economy and institutional constraints	• Weak climate policies • The need for development interventions surpasses climate issues.	Weak climate policies that do not explicitly describe how to climate-proof the hydropower sector. The advantages of building the dam supersede the impacts climate change might pose to its sustainability.

Source: Fieldwork, 2015

As stated in the SNEP (2005), the Pwalugu Dam is scheduled to be built by 2020, and the scoping report has shown the government's desire of climate proofing hydropower projects by incorporating climate change risks and uncertainties. In the report it states:

> Climate change is expected to have significant implications for both existing and proposed new infrastructure assets, particularly those with long design lifetimes. This makes such assets sensitive not only to the existing climate at the time of their construction but also to climate variations over the decades of their use. Decisions made now will shape the resilience of design and development of infrastructure systems. Action is therefore needed to ensure that new infrastructure is efficient, robust and resilient to climate conditions in the long term, through considered planning and design (MacDonald, 2014, p.90).

CHAPTER SIX: RECOMMENDATION

This study has briefly described how dams are planned in the country and the barriers to the use of climate risk analysis in hydropower. This section attempts to provide solutions to surmount some of these barriers and how the hydropower sector can be climate-proofed. Participants of this study's interview mainly agreed the level or the use of climate information in the country is limited to seasonal forecasts and the only sector that seems to make use of them are located within the agricultural industry. Considering how decisions are taken, there is the need to make sure future projects thoroughly incorporate climate change. It is encouraging that the next hydropower project is scheduled to undertake a climate risk assessment. The Climate change risk assessment would be undertaken as part of the Pwalugu Dam ESIA to:

1. Determine how the project can deal with climate risks while being viable. However, there has not been a clear indication or description of the methods that would be used to determine this.
2. Establish the impacts of the project on its surrounding climate and environment.
3. Draft measures which can ensure the project would last its expected lifespan (MacDonald, 2014).

Various studies have suggested methods by which this can be done, some were discussed within the literature review. The research revealed that decisions taken on hydropower are based on already prepared energy plans, while climate change was not a key determinant in assessing the environmental impacts on the proposed interventions. The study does not seek to blame any party but attempts to offer practical solutions to prevent future occurrences. The government has disclosed a climate risk assessment for the next project, and before it can produce usable information, it must endeavour to support and finance further climate research. Also, local scientists, especially within West Africa, should be encouraged to develop climate models that can represent the region appropriately to reduce its continued reliance on the European based software which most often are not usable. Again, a climate risk assessment of the energy or the power sector of the country could be conducted as in Albania (World Bank, 2009). One might think it irrelevant on the basis that Ghana's hydropower resource is almost depleted. Ghana has some small to medium hydropower projects planned, and such an analysis would help make a more informed decision. There is the need to describe all risks associated with the climate and how it might affect future hydropower projects, although the future is shrouded with varying degrees of uncertainties it could enable decision makers to take the best possible choice. Decisions taken should, therefore, be free from political pressure and should be solely based on empirical analysis. As the European Commission and other international organisations have begun to improve their EIA guidelines by incorporating climate change in more depth, the government is also showing it is keen to adopt and modify a suitable tool for the country. For example in this report by (Clarke et al., 2012) and European Commission (2013) project managers have been given various procedures through which climate change issues can be factored into the EIA process.

First of all, there should be a clear understanding of the dynamics of climate change and its uncertainties by decision makers. Scientists should also understand the fact that though they must perhaps disseminate climate information to decision makers, the decision making context is more complicated and does not only involve the issue of climate. In the case of The Bui Dam, the government was facing an electricity crisis and had to solve it quickly. It is possible that if scientists are generally aware of the other issues that surround decisions they might be able to provide solutions that decision makers might be willing to utilize. In short, there should be more collaboration between these two groups as well as the training of experts in both climate science and policy making to help bridge the gap.

In climate proofing the hydropower sector, the solution is to ensure the entire energy sector is climate proof and robust enough against the changing climate, political changes, economic conditions. Climate information has many limitations however this should not be the reason why action should not be taken. Climate science is still evolving and improving while the need for decisions about various social issues is prevalent. Decisions should not only be focused on the long-term but also on the immediate and short-term as well. This means that there should be a balance where decisions should not entirely be delayed or even disregarded because of the adverse effect it could have on the future. This means that if the decision meets a short-term need, it should be taken with the plan of ensuring the decision does not negatively impact long-term goals. Regarding the energy sector, though critics would criticize the building of the Bui Dam, it has added to the energy mix thus becoming a vital source of electricity, meeting a pressing need. In ensuring the energy sector or the electricity subsector is robust, the researcher recommends the following.

As established in this study and other literature, hydropower is at risk and is vulnerable to climate change and its uncertainties. As a result, there should be more research into other diverse sources of electricity. The government should intensify its efforts to increase the energy mix. Thermal plants have their limitations as they are more expensive to run than hydropower. As the ratio of thermal plants has increased, this could be financially stressful. Any problems with the West African Gas supply pipelines could affect the supply of gas to some plants and in turn, affect the ability to provide electricity. The current mix of thermal and hydropower is not diverse enough. There should be other sources integrated. More studies should be conducted in this regard. Studies on how the government can invest in solar, tidal and even wave energy should be conducted.

More research can be conducted with regards to how the government could further exploit the remaining hydropower sources. Further studies should also be done concerning the ratio each electricity source should contribute. Questions such as should thermal contribute 30%, how much should solar contribute, is wind energy feasible, how much should it contribute must be asked. This would ensure all potential energy sources in the country are effectively harnessed to promote the efficient and constant supply of electricity regardless of the growing population or the future climate.

An essential factor of this recommendation is the need to ensure balance. Currently, with thermal power contributing about 60%, any issue with the supply of gas or light crude oil will massively affect electricity supply. For example, when hydropower was the number one source of electricity, droughts significantly affected supply causing power outages and the importation of electricity from neighbouring countries. As a result of this more studies should be conducted to ascertain the right combination of each possible electricity source to ensure constant supply regardless of climate, financial limitations. The overdependence on one source of electricity might cause power outages when they are not operational.

In summary, when climate change uncertainty issues arise in any decision making context, it is essential that climate change not be made the focus. The problem that needs to be solved must be central to the discussion. Afterwards, an assessment of how climate risks and uncertainties can affect the problem should be done. Even if climate change is the cause of the problem the contribution of other variables should not be underestimated but thoroughly examined. This would grant the decision maker a clearer and broader view of the entire issue and the tools needed to solve them.

CHAPTER SEVEN: SUMMARY AND CONCLUSION

The climate is changing, and although scientific research and knowledge have dramatically increased over the years, it is still shrouded with uncertainties. In this era and dispensation of governance, with many countries seeking to meet medium to long-term goals such as the MDGs, the issue of climate and its uncertainties must be considered. The effects of drought cause problems with water availability and supply and as far as this study is concerned will affect hydropower plants. Ghana has been dependent on hydropower, and recent low levels of water in the dams albeit caused by droughts led severe power outages that affected both individuals and industries. Despite these happenings, the government decided to build a 400MW hydropower plant with many analysts and stakeholders calling for more analysis which was inadvertently ignored. Even after the construction, the country was still plagued with power outages thus sparking this study. The researcher believed that Ghana should not experience ‘blackouts’ due to droughts but the entire energy sector ought to be climate proof. The study attempted to find out the why a climate risk analysis was not conducted before the Bui Dam construction and discovered that

Considering the various climate change policy and strategy documents developed by the Government of Ghana and other multinational organizations, there has not been much emphasis on adapting energy sources to climate change instead, the objectives within the energy sector are to reduce greenhouse gas emissions. In a country which utilizes a significant amount of hydroelectricity, it is not encouraging. The two climate documents for the country, NCCP, and NCCAS which were published after the Bui Dam had commenced construction do not describe how to climate-proof the hydropower sector, specifically future projects.

The research identified that plans for hydropower are contained in the country’s energy policy. The Bui Dam and other hydropower projects are contained in the plan, but there is no detailed consideration of climate change. The Bui Power Authority was established to oversee the planning process of The Bui Dam. This study has been able to give a step by step process showing what went on during the planning of the Dam as well as the functions of organizations involved. Before the construction, two hydrological assessments conducted over the Black Volta, the main source of inflow for the Bui reservoir indicated a reduction river flow (Kunstmann and Jung, 2005: WRI, 2000). This did not slow construction, other organizations called for more analysis to be conducted, but the government ignored them. This indicates the government's desire to meet the shortfall of electricity instead of critically examining the extent to which the climate could impact the project. With the Pwalugu multipurpose dam, however, as contained in its scoping study, a climate risk assessment would be conducted as part of the ESIA. This is a positive indication that climate uncertainties are beginning to be factored into such projects. The mode of this assessment was not disclosed but one is hopeful it would be comprehensive enough, and any decision that would develop from it would be robust and resilient.

Analysts claim the data gap in Africa is a factor which prevents climate information from being used in the long run. In Ghana, and in Africa generally, dams are built using historical data, which are even incomplete. The government has not been able to solve the data problem because of the few synoptic stations present. Respondents revealed that more data can help deal with the uncertainty that climate change poses and more support from the government should be given so they could have access to more satellite data.

The researcher discovered from the framework developed that the use of climate information during the planning of the Bui Dam is low mainly because decision makers believe it is uncertain and cannot be relied upon. Organizations responsible for producing climate information admitted their focus was primarily on short-term forecasts. In this regard, the ability to plan for long-term investments is compromised. When the government does not support a government founded institution, it is quite difficult to operate effectively. The study revealed some institutions are lacking the funds needed to access quality data as well as improve the body's capacity to produce enough data for various research. The findings were consistent with other studies conducted by Lemos et al. (2012) as well as Jones et al. (2017) proves that if data is not accurate, lack of technical staff to interpret available data as well as the absence of proper communication channels between information providers and decision makers it could affect the latter's decision of using climate information. This is a snapshot of what could have happened during the Bui Dam construction though the influence of politics cannot be entirely downplayed. This means that despite the limitations of using climate information at that time, their use was not the issue but the government's desire to meet the shortfall in electricity supply.

With the country facing severe power crises at the final planning stages of the Bui Dam, an analysis was not necessary according to participants of this study. The government was indeed aware of climate change but did not explicitly consider it, because the outcome of the analysis was not going to affect their decision to build their dam, the power of political will. With the country's significant hydropower resources almost being depleted and the need to supply cheap power, a negative assessment by a climate analysis which is also subject to uncertainty was not worth it. Also, the ESIA that was conducted before the construction did not allow for a climate analysis. It is therefore quite interesting that international organizations are now seeking to integrate climate risks in the EIA process. This is a step in the right direction to ensure that governments have adequate information about climate risks and uncertainties before deciding to undertake a massive investment such as hydropower. The government must therefore accordingly adjust and modify its existing guidelines and principles to ensure that for any project that is undertaken especially hydropower it ought to undergo various climate risk analysis. As the country's GSGDA and NCCP are both seeking to build and promote a climate-resilient economy, it is necessary that even from the planning stage and before specific projects are approved, the relevant safeguards are put in place to ensure that they can withstand the shocks of the climate and other societal pressures such as population growth.

The government has stated its intention to conduct a climate risk assessment as part of feasibility studies for the Pwalugu multipurpose dam (MacDonald, 2014). The question remains, what will the government do when results show possible low levels during the uncertain lifetime of the plant? It is important to note that these projections are uncertain. What does the government do? The country needs power and hydro is a vital source, but it cannot do away with it because an uncertain analysis produced negative results. Various tools have been developed over the years to help decision-makers deal with uncertainty. Each of them has their strengths and weaknesses and have been utilized in different parts of the world. To deal with climate change uncertainty in hydropower, while risk assessments are good and necessary, they should not be the end. While cost-benefit analysis is useful, they might not entirely solve the problem. To be able to deal with climate change and its uncertainties, it is must be addressed holistically. Hydropower is a piece of the puzzle which should not be dealt with in isolation, preferably the entire energy/ power sector should be seen as one whole and configured to ensure it is resilient. This study attempts to provide a framework describing how the government can climate-proof the energy sector so that the past electricity outages do not recur. The researcher recommends the addition of more energy sources to the mix, not just thermal and hydro. Further studies which could identify how to combine each possible energy source and in which ratio should be conducted to ensure the continuous supply of electricity regardless of the outcome of the climate, population, crude oil prices, gas shortages. Decisions that are taken should be dual focal, both short-term and long-term responsive.

Other studies do not look at the issue holistically. Although this study is mainly about the barriers to the use of climate risk analysis in hydropower, the overall objective is to climate-proof the hydropower sector. Studies indicate that climate science has many limitations and decision makers have not embraced the idea of using them in their decisions because of their irrelevance, uncertainty, and credibility. The study utilized data from primary and secondary sources to establish the barriers that prevented climate information from being used in the planning of the Bui Dam as well as why a climate risk analysis was not conducted before the project commenced. It discovered that climate information is being used in managing and operating the Dam but no climate projections were considered before projections. The main reasons are, climate information is generally uncertain. Decision makers cannot trust the accuracy of the information thus were not ready to use it. The second barrier the study discovered was that there is a disconnect between users and producers of climate information. This means that decision makers did not find the need to engage long-term climate information when planning for the Bui Dam. Also, there were few or no experts available at the time to provide the kind of long-term information needed to make decisions.

These barriers all connect to the underlying issue the study discovered. This had to deal with the fact that in the ESIA which was done based on the procedure by the World Bank Group there was no clear indication as to how a climate analysis should be done. In other words, there is no accommodation for a climate assessment within the ESIA which the Bui developers used, therefore, it was not done.

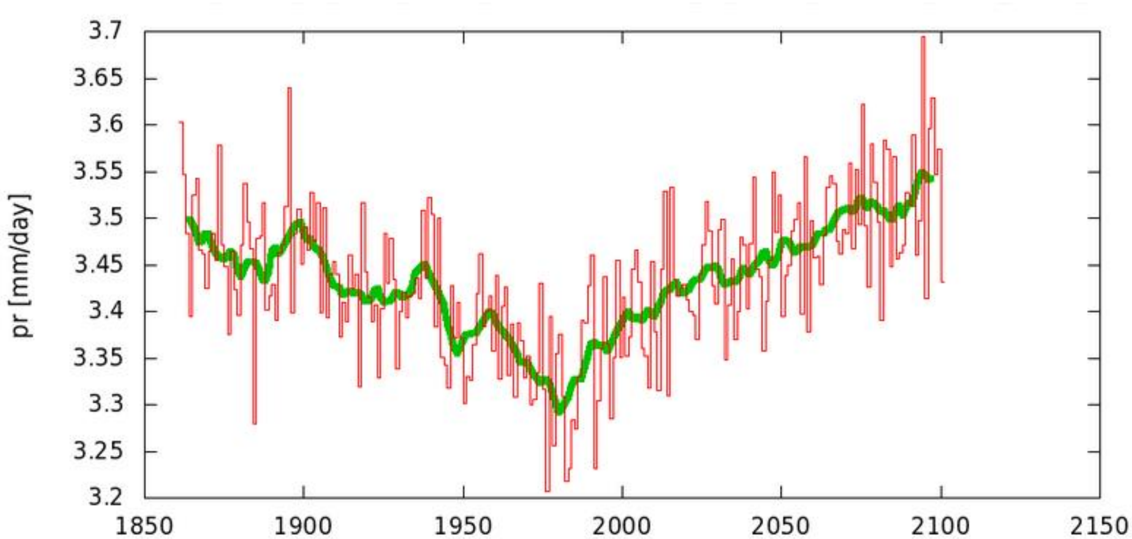
It is not until recently that international institutions such as the European Commission have amended their EIA guidelines to allow for climate change studies. The government of Ghana has demonstrated its willingness to be consistent with global practices and procedures as it has stated within the scoping report of the next proposed hydropower project at Pwalugu the need to carry out a climate risk assessment. These are all positive signs, however, the issues remain when these assessments are conducted, and the results are negative what would decision makers do? Would they ignore the reports and go ahead to construct the dam?

Ghana has been dependent on hydropower but has been slowly shifting to thermal power as a result of poor output from hydropower due to low water levels. The contribution of hydropower over the years cannot be denied and its relevance tomorrow will not be underrated, however with the changing climate along with its uncertainties, more attention should be given. This study, therefore, recommends that to climate-proof the hydropower sector it is expedient to see the energy sector as joined together and as a whole. Studies should be conducted to examine how much each energy source ought to contribute, hydropower, thermal as well as increase the mix to solar and wind if possible. This would spread the risks and ensure that even with low water levels in the dam it would not affect power generation.

APPENDIX 1

Semi- Structured Interview Questions for the Various Institutions

VOLTA RIVER AUTHORITY, BUI POWER AUTHORITY AND ENERGY COMMISSION/ MINISTRY OF ENERGY



1. Various research by analysts foresee a substantial changes to P and T (CMIP5 models suggest increase with high uncertainty, other analyses suggest decrease in river flow) in Ghana over next several decades of 21st C. What does this mean for hydro development in Ghana?

2. Such climate and hydrological impact projection data existed before the recent Bui Dam was built. Why do you think such information was/is either relevant or irrelevant for past dams and future ones?

3. Weather and climate patterns are generally uncertain. What do you think are the risks (climate and non-climate) in investing in such infrastructure?

4. How are the risks from climate variability and change compared with other risks?

5. How do these risks advise the planning process?

<u>Primary Research Question</u>

What are the barriers to the use of climate information in recent and planned hydropower developments in Ghana?

With reference to the Bui Dam Project and future planned investments such as the Pwalugu Dam;

1. How informed was/is the ministry/ institution with regards to Climate Change issues?
2. How accurate do you feel information on climate variability and change is?
3. How does the information you receive on climate variability and change match your needs for this information (e.g. in terms of format and content)?
4. How was/is this information used to plan and operate hydropower schemes?
5. Is the climate information readily available and easy to use?
6. What can be done to improve the flow and quality of information?
7. Do you have the capacity(e.g. skills and tools) to consider climate variability and change in planning for the hydropower sector?

8. Why was not a climate risk assessment conducted in the Bui Dam project?

   Was it as a result of uncertainty in climate information or other factors such as political, financial, time, etc.?
9. How does inadequate and uncertain information on the climate bar its use in long term decisions in Ghana?

GHANA METEOROLOGICAL AGENCY

Various research by analysts foresee a change, mostly a reduction in precipitation in
Ghana over several decades.

1. Considering data from 20 years ago till now what changes have you observed? How significant are the changes? What are your projections for the next twenty years?
2. In your opinion, what does this mean for hydro development in Ghana?
3. How do you generate climate information?
4. Which models do you use for projections?
5. How do you deal with uncertainty?

Primary Research Question

What are the barriers to the use of climate information in recent and planned hydropower developments in Ghana?

With reference to the Bui Dam Project and future planned investments such as the Pwalugu Dam;

1. What roles did you play in their planning?
2. Is climate information generated from consultation with the possible users of such information?
   Which bodies/ institutions benefit? What about the VRA/BPA and Energy commission, are they recipients of your data? How do you collaborate with them in this activity?
3. For what time periods do you provide data? Both in the past and projections for the future?
4. What is your opinion on providing long term climate information?
5. How do you feel this impacts hydropower projects?
6. How does your agency offer assistance to help them interpret the data and use in their planning activities. (be specific using institutions mentioned in Q1, ask how VRA etc uses it, if they do)

WATER RESOURCES COMMISSION

The IPCC believes water resources are going to be adversely affected as a result of climate change.

1. What are your thoughts on this statement?
2. How evident is this with respect to the Volta Basin in Ghana?
3. Considering data from 20 years ago till now what changes have you observed? How significant are the changes? What are your projections for the next twenty years?
4. How do you generate your information?
5. How are river flow analysis generated? What were your results for The Black Volta as far as Bui Dam was concerned? What have you discovered about projections for the White Volta, Pwalugu Dam?
6. Which hydrological models do you use for projections?
7. How do you deal with uncertainty?
8. In your opinion, what does this mean for hydro development in Ghana?

Primary Research Question

What are the barriers to the use of climate information in recent and planned hydropower developments in Ghana?

With reference to the Bui Dam Project and future planned investments such as the Pwalugu Dam;

1. What roles did you play in their planning?

IMANI GHANA

1. Various research by analysts foresee a change, mostly a reduction in precipitation in
Ghana over several decades and a severe impact on water resources due to climate change. In your opinion, what does this mean for hydro development in Ghana?

2. Such data existed before the recent Bui Dam was built. Why do you think such information was/is either relevant or irrelevant for past dams and future ones?

3. Weather and climate patterns are generally uncertain. What do you think are the risks (climate and non-climate) in investing in such infrastructure?

4. How do these risks advise the planning process?

Primary Research Question

What are the barriers to the use of climate information in recent and planned hydropower developments in Ghana?

With reference to the Bui Dam Project and future planned investments such as the Pwalugu Dam;

1. How do you think the issue of climate change is being managed among the key institutions?

2. Considering the Energy Commission, Water Resources Commission and Volta River Authority, do they have the capacity(e.g. skills and tools) to consider climate variability and change in planning for the hydropower sector? Why do you think so?

3. What significance do you perceive these institutions place on climate information?

4. What can be done to improve the flow and quality of information?

5. Why was not a climate risk assessment conducted in the Bui Dam project?

6. Was it as a result of uncertainty in climate information or other factors such as political, financial, time, etc.?
7. How is this affecting the Bui Dam?
8. What do you think the fate of the Pwalugu Dam is?

DATE	INSTITUTION	PURPOSE
September 2015	Energy Commission	To find out how risks in hydro are perceived, how hydropower plans are carried out considering climate change

October 2015	Water Resource	To understand the actual impact climate change is having on water resources in the country, analyse risks and uncertainties involved.
	Ghana Meteo Agency	To gain understanding on how climate information is generated and disseminated for planning hydropower schemes
November 2015	Imani Ghana	To understand how the risks and uncertainties of climate change on the Bui Dam and future dams are considered through the lens of a Think Tank
December 2015	Volta River Authority	To investigate how the Pwalugu dam is incorporating climate risks and uncertainties
December 2015	Bui Power Authority	To investigate how the Bui Dam incorporated climate risks and uncertainties

APPENDIX 2

CONSENT FORM FOR PROJECT PARTICIPANTS

PROJECT TITLE: Climate change and Bui Dam in Ghana

Project Approval ER/JA376/1

Reference:

I agree to take part in the above University of Sussex research project. I have had the project explained to me and I have read and understood the Information Sheet, which I may keep for records. I understand that agreeing to take part means that I am willing to:

- Be interviewed by the researcher
- Allow the interview to be audio taped
- Make myself available for a further interview should that be required

I understand that any information I provide is confidential, and that no information that I disclose will lead to the identification of any individual in the reports on the project, either by the researcher or by any other party.

The following clauses should be included in all consent forms:

I understand that my participation is voluntary, that I can choose not to participate in part or all of the project, and that I can withdraw at any stage of the project without being penalised or disadvantaged in any way.

I consent to the processing of my personal information for the purposes of this research study. I understand that such information will be treated as strictly confidential and handled in accordance with the Data Protection Act 1998.

NB The participant/s agrees that the information provided can be used in further research projects which have research governance approval as long as their name and contact information is removed before it is passed on.

Name:

Signature

Date:

APPENDIX 3

PARTICIPANT INFORMATION SHEET TEMPLATE

STUDY TITLE: CLIMATE CHANGE AND BUI DAM IN GHANA

INVITATION PARAGRAPH

You are being invited to take part in a research study. Before you decide whether or not to take part, it is important for you to understand why the research is being done and what it will involve. Please take time to read the following information carefully.

WHAT IS THE PURPOSE OF THE STUDY?

The background of the study is based on the fact that climate change is occurring, with science confirming increased temperatures but are uncertain with rainfall predictions. Hydropower, which is Ghana's highest source of electricity is dependent on water. Low rainfall has been recorded over the years, however it is interesting that more hydropower sites have been identified and might be built in the near future. The aim of the study is to determine how decision making under climate change uncertainty within the hydropower sector is done in Ghana. The study will run from September till January. A review of the documents like the Energy Policy and National Climate Change Policy would be conducted. The final part of the research involves semi-structured interviews with stakeholders from Government and think tanks to ascertain the

WHY HAVE I BEEN INVITED TO PARTICIPATE?

The intention of the study is to interview people from Government, as well as Think Tanks.

You belong to one of these categories that is basically why you have been asked to take part.

DO I HAVE TO TAKE PART?

'It is up to you to decide whether or not to take part. If you do decide to take part you will be given this information sheet to keep and be asked to sign a consent form. If you decide to take part you are still free to withdraw at any time and without giving a reason'.

WHAT WILL HAPPEN TO ME IF I TAKE PART?

Your interview will be recorded and information about decision making under climate change uncertainty will be inferred from your responses. Your name and organization details or information about specific projects and activities of your organization will be kept confidential. Only conclusions based on your interview will be published as the opinion of the stakeholder from your category.

WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART?

The research would enable people further understand how decisions concerning hydropower developments are taken in view of climate uncertainties in Ghana.

Decision Making Under Climate Change Uncertainty in Hydropower in Ghana.

Version 1

20/08.2015

WILL MY INFORMATION IN THIS STUDY BE KEPT CONFIDENTIAL?

All information collected about the individual will be kept strictly confidential (subject to legal limitations) and privacy and anonymity will be ensured in the collection, storage and publication of research material as no names of the respondents will be mentioned.

WHAT SHOULD I DO IF I WANT TO TAKE PART?

You should sign the consent form and agree to a time for the interview to be conducted.

WHAT WILL HAPPEN TO THE RESULTS OF THE RESEARCH STUDY?

The results of the study will be an essential part of the researcher's project and he would attempt to get it published afterwards.

WHO IS ORGANISING AND FUNDING THE RESEARCH?

The research is self-funded.

WHO HAS APPROVED THIS STUDY?

The study has been approved by Martin Todd (m.todd@sussex.ac.uk) and Dom Kniveton d.r.kniveton@sussex.ac.uk.

CONTACT FOR FURTHER INFORMATION

Supervisors:

Prof. Martin Todd, email: m.todd@sussex.ac.uk

Prof Dom Kniveton, email : d.r.kniveton@sussex.ac.uk

"University of Sussex has insurance in place to cover its legal liabilities in respect of this study."

THANK YOU

DATE

20/8/2015

BIBLIOGRAPHY

Agrawala, S., van Aalst, M., 2008. Adapting development cooperation to adapt to climate change. Climate Policy 8, 183–193. doi:10.3763/cpol.2007.0435

Allotey, G.A. (2015) Karpower: First power barge to be delivered in September 2015. Available at: http://citifmonline.com/2015/04/29/karpower-first-power-barge-to-be-delivered-in-september-2015/#sthash.pOgNazP7.dpbs (Accessed: 20 June 2015

Arntzen, E., Miller, B. and O'Toole, A. (2013) 'Evaluating greenhouse gas emissions from hydropower complexes on large rivers in Eastern Washington', (March). Available at: http://www.pnl.gov/main/publications/external/technical_reports/PNNL-22297.pdf.

Asante FA, Clottey EA (2007) Ghana's electricity industry. Accessed 3 July 2015. Available at: http://www.esi-africa.com/ghana-s-electricity-industry/.

Balmer, M. and Spreng, D. (2012) 'Hydroelectric Power', Fuel, pp. 193–209. doi: 10.1016/B978-0-08-054808-1.00011-9.

Barker, T. (2008) 'The economics of avoiding dangerous climate change. An editorial essay on the stern review', Climatic Change, 89(3-4), pp. 173–194. doi: 10.1007/s10584-008-9433-x

Bekoe, E. O. and Logah, F. Y. (2013) 'The Impact of Droughts and Climate Change on Electricity Generation in Ghana', *Environmental Sciences*, 1(1), pp. 13–24. doi: 10.1039/c3cc39212k.

Biney, C. a (2010) Connectivities and Linkages within the Volta Basin.

Bolson, J., & Broad, K. (2013). Early adoption of climate information: lessons learned from South Florida Water Resource Management. Weather, Climate, and Society, 5(3), 266-281

Botchway FN. (2000). The state, government and the energy industry in Ghana. Verfassung und Recht in Ubersee, Baden-Baden 2000;33:135–211

Bremond, A. de, Preston, B.L. and Rice, J. (2014) 'Improving the usability of integrated assessment for adaptation practice: Insights from the U.S. Southeast energy sector', Environmental Science & Policy, 42, pp. 45–55. doi: 10.1016/j.envsci.2014.05.004

Breuer, N. E. et al. (2008) 'AgClimate: A case study in participatory decision support system development', Climatic Change, 87(3–4), pp. 385–403. doi: 10.1007/s10584-007-9323-7.

Bruno Soares, M. and Dessai, S. (2016) 'Barriers and enablers to the use of seasonal climate forecasts amongst organisations in Europe', Climatic Change, 137(1), pp. 89–103. doi: 10.1007/s10584-016-1671-8.

Buytaert, W. et al. (2010) 'Uncertainties in climate change projections and regional downscaling in the tropical Andes : implications for water resources management', pp. 1247–1258. doi: 10.5194/hess-14-1247-2010.

Byer, P.H. and Yeomans, J.S. (2007) 'Methods for addressing climate change uncertainties in project environmental impact assessments', Impact Assessment and Project Appraisal, 25(2), pp. 85–99. doi: 10.3152/146155107x205841

Callahan, B., Miles, E. and Fluharty, D. (1999) 'Policy implications of climate forecasts for water resources management in the Pacific Northwest', Policy Sciences, 32(3), pp. 269–293. doi: 10.1023/A:1004604805647.

Cameron, C. (2011) 'Climate Change Financing and Aid Effectiveness Ghana Case Study', (April).

Cash, D. W. and Buizer, J. (2005) Knowledge-Action Systems for Seasonal to Interannual Climate Forecasting, Roundtable on Science and Technology for Sustainability Policy and Global Affairs. doi: 10.17226/11204.

Cash, David W, William C Clark, Frank Alcock, Nancy M Dickson, Noelle Eckley, David H Guston, Jill Jaeger and Ronald B Mitchell (2003), "Knowledge systems for sustainable development", Proceedings of the National Academy of Sciences, 100(14), pages 8086–8091.

Cheek J (2008) 'Research Design' in LM Given (Ed) The Sage Encyclopedia of Qualitative Research Methods Vol 2 London: Sage, p761-3

Choi, B. C. K. (2005) 'Can scientists and policy makers work together?', Journal of Epidemiology & Community Health, 59(8), pp. 632–637. doi: 10.1136/jech.2004.031765.

Chowdhury, A. R. and Kipgen, N. (2013) 'Deluge amidst conflict: Hydropower development and displacement in the North-east region of India', Progress in Development Studies, 13(3), pp. 195–208. doi: 10.1177/1464993413486545.

Chronicle, G. (2015) Ghana electricity crisis (dumsor) - the causes, disadvantages and solutions. Available at: http://allafrica.com/stories/201503051476.html (Accessed: 5 August 2015

Clarke, I. et al. (2012) 'Guidelines for Project Managers: Making vulnerable investments climate resilient (Report for the European Commission)', (September).

Climate, L. N. L. and Pathway, R. D. (2013) Long-term National Low-carbon Climate Resilient Development Pathway Climate Risk Assessment of Kenya ' s Flagship Projects : Energy Scale up Programme and Rural Electrification: Generation of 23,000 MW and Distributed at Competitive Prices February Urban .

Cole, M., Elliott, R. and Strobl, E. (2013) Climate change, hydro-dependency and the African dam boom. Department of Economics Discussion Paper 14-03. University of Birmingham

Collins, J. (2011) 'Temperature Variability over Africa', American Meteorological Society, 24, pp. 3649–3666. doi: 10.1175/2011JCLI3753.1.

Condappa, D. De, Chaponnière, A. and Lemoalle, J. (2009) 'A decision-support tool for water allocation in the Volta Basin', 8060. doi: 10.1080/02508060802677861.

Coyne et Bellier (2006). *Updating of the 1995 Feasibility Study*. Bui Hydroelectric Project. Ministry of Energy, p.119.

Creswell, J. (1998). Research design: Qualitative, quantitative, and mixed methods approaches (2nd ed.). Thousand Oaks, CA: Sage

Creswell, John W. (2003). Research design: Qualitative, quantitative, and mixed methods approaches (2nd ed.). Thousand Oaks: Sage

Dell, B. M. et al. (2009) 'Temperature and Income : Reconciling New Cross-Sectional and Panel Estimates', 02142, pp. 198–204.

Deser, C., R. Knutti, S. Solomon, and A. Phillips. 2012. "Communication of the role of natural variability in fu- ture North American climate". Nature Climate Change 2: 775-9, DOI: 10.1038/NCLIMATE1562.

Dessai, D. S. and Wilbe, R. (2011) 'How Can Developing Country Decision Makers Incorporate Uncertainty about Climate Risks into Existing Planning and Policymaking Processes ?', World, p. 12. doi: Dessai, Suraje and Robert Wilby. "How Can Developing Country Decision Makers Incorporate Uncertainty about Climate Risks into Existing Planning and Policymaking Processes?" World Resources Report, Washington DC. Available online at http://www.worldresourc.

Dilling, L. and Lemos, M. C. (2011) 'Creating usable science: Opportunities and constraints for climate knowledge use and their implications for science policy', Global Environmental Change. Elsevier Ltd, 21(2), pp. 680–689. doi: 10.1016/j.gloenvcha.2010.11.006.

Drew, C. J., Hardman, M. L., & Hosp, J. L. (2008). Designing and Conducting Research in Education. LA: Sage Publications

Eden, S. (2011). Lessons on the generation of usable science from an assessment of decision support practices. Environmental science & policy, 14(1), 11-19

Energy Commission (2017) National Energy Statistics.

Energy Commission. Energy review. Official Journal of the Energy Commission of Ghana 2004;(November–December).

Energy Commission. Energy statistics 2005. Accra, Ghana: Energy Commission; 2005.

Energy Commission. Strategic national energy plan 2006–2010. Accra, Ghana: Energy Commission; 2006.

Environmental Resources Management [ERM]. (2007). Environmental and social impact assessment of the Bui Hydropower Project. Prepared by Environmental Resources Management, in association with SGS Environment for the Ministry of Energy/Bui Development Committee, Ghana

EPA (2010) 'Ghana's National Development Planning, Climate Change and Disaster Risk Reduction; policy advise series 1', pp. 1–12.

EPA (2010) 'Ghana's National Development Planning, Climate Change and Disaster Risk Reduction; policy advise series 1', pp. 1–12

EPA (2015) Functions of EPA. Available at: http://www.epa.gov.gh/web/index.php/about-us/functions-of-epa (Accessed: 11 August 2015).

ERM (2007) Environmental and Social Impact Assessment of the Bui Hydropower Project. Available at: http://library.mampam.com/Final ESIA - Bui HEP.pdf.

EU Commission (2009) White Paper. Adapting to climate change: Towards a European framework for action. Downloaded January 2011 from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri0COM:2009:0147: FIN:EN:PDF

Flavin, C. and Hull Aeck, M. (2005) 'Energy for Development, The Potential Role of Renewable Energy in Metting the Millennium Development Goals', REN21 Network, pp. 4–39

Funtowicz, S.O., Ravetz, J.R., 1993. Science for the post-normal age. Futures 25 (7), 739–755

Ghana Wholesale Power Reliability Assessment (2010) Final report. Power Systems Energy Consulting, GRIDCo.

GhanaWeb, 2015 AMERI deal is a rip off. Available at: http://www.ghanaweb.com/GhanaHomePage/NewsArchive/AMERI-deal-is-a-rip-off-401200 (Accessed: 25 January 2016).

Gjermundsen, T. and L. Jenssen. 2001. Economic risk-and sensitivity analyzes for hydropower projects. Pages 23-28 in Hydropower in the New Millenium: Proceedings of the 4th International Conference on Hydropower Development. Bergen, Norway, June 20-122, 2001.

Gjermundsen, T. and L. Jenssen. 2001. Economic risk-and sensitivity analyzes for hydropower projects. Pages 23-28 in Hydropower in the New Millenium: Proceedings of the 4th

Green, M. and Weatherhead, E. K. (2014) 'Coping with climate change uncertainty for adaptation planning: An improved criterion for decision making under uncertainty using UKCP09', Climate Risk Management, 1, pp. 63–75. doi: http://dx.doi.org/10.1016/j.crm.2013.11.001

Hahn, M. and Fröde, A. (2010) 'Climate Proofing for Development', Development.

Harrison, G., Whittington, H. and Gundry, S. (1998) 'Climate change impacts on hydroelectric power', Proc Univ Power Eng Conf, 1(1), pp. 391–394. Available at: http://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:CLIMATE+CHANGE+IMPACTS+ON+HYDROELECTRIC+POWER#0.

Harrison, G.P. & Whittington, H.W., 2001. Edinburgh Research Explorer. The Impact of Climatic Change on Hydropower Investment Impact of climatic change on hydropower investment.

Hawkins, E. and Sutton, R. (2011) 'The potential to narrow uncertainty in projections of regional precipitation change', Climate Dynamics, 37(1), pp. 407–418. doi: 10.1007/s00382-010-0810-6..

Hensengerth, O., 2014. Interaction of Chinese Institutions with Host Governments in Dam Construction: the Bui Dam in Ghana.

Holm, D., Banks, D., Schaffler, J., Worthington, R. and Afrane-Okese, Y. (2008) Renewable energy briefing paper: Potential of renewable energy to contribute to national electricity emergency response and sustainable development. (http:// earthlife.org.za/www/wp-content/uploads/ 2008/12/rebriefingpaperfinal5aug08.pdf);

Hoppe, R. (2005) 'Rethinking the science-policy nexus: From knowledge utilization and science technology studies to types of boundary arrangements', Poiesis und Praxis, 3(3), pp. 199–215. doi: 10.1007/s10202-005-0074-0.

Huang, C., Vaneckova, P., Wang, X., Fitzgerald, G., Guo, Y. & Tong, S., 2011. Constraints and barriers to public health adaptation to climate change: a review of the literature. American Journal of Preventive Medicine, 40(2), 183-190. Doi: org/10.1016/j.amepre.2010.10.025

IFC (2011) 'Climate Risk and Business: Hydropower'.

International Conference on Hydropower Development. Bergen, Norway, June 20- 122, 2001.

IRENA (2012) 'Hydropower', Renewable Energy Technologies: Cost Analysis Series, 1: Power s(3/5), p. 44. Available at:

http://www.irena.org/documentdownloads/publications/re_technologies_cost_analysis-hydropower.pdf.

Jones, L. et al. (2017) 'Constraining and enabling factors to using long- term climate information in decision-making'. Taylor & Francis, 3062. doi: 10.1080/14693062.2016.1191008.

Jones, L., Carabine, E., Roux, J.-P. and Tanner, T. (2015) 'Promoting the use of climate information to achieve long-term development objectives in Sub-Saharan Africa', SSRN Electronic Journal, . doi: 10.2139/ssrn.2646814.

Jones, L., Champalle, C., et al. (2015) Identifying constraining and enabling factors to the uptake of medium- and long-term climate information in decision making, CCAFS Working Paper.

Jones, L., Dougill, A., et al. (2015) 'Ensuring climate information guides long-term development', Nature Climate Change. Nature Publishing Group, 5(9), pp. 812–814. doi: 10.1038/nclimate2701.

Jones, R.N., A. Patwardhan, S.J. Cohen, S. Dessai, A. Lammel, R.J. Lempert, M.M.Q. Mirza, and H. von Storch, 2014: Foundations for decision making. In: Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Field, C.B., V.R. Barros, D.J. Dokken, K.J. Mach, M.D. Mastrandrea, T.E. Bilir, M. Chatterjee, K.L. Ebi, Y.O. Estrada, R.C. Genova, B. Girma, E.S. Kissel, A.N. Levy, S. MacCracken, P.R. Mastrandrea, and L.L. White (eds.)]

Kabo-Bah, A. et al. (2016) 'Multiyear Rainfall and Temperature Trends in the Volta River Basin and their Potential Impact on Hydropower Generation in Ghana', Climate, 4(4), p. 49. doi: 10.3390/cli4040049.

Kankam-Yeboah, K. Amisigio, B. and Obuobi, E. (2010) Climate Change Impacts on Water Resources in Ghana, Climatic Change. doi: 10.1007/bf00138847.

Kemausuor, F. et al., 2011. A review of trends, policies and plans for increasing energy access in Ghana. Renewable and Sustainable Energy Reviews, 15(9), pp.5143–5154. Available at: http://dx.doi.org/10.1016/j.rser.2011.07.041.

King, D. et al. (2015) 'Climate Change: A Risk Assessment', p. 79. doi: 10.1016/j.ecocom.2014.11.002.

Koehn, J. (2010) Homes, businesses hit by water from dam. Available at: http://www.nbcnews.com/id/38395404/ns/weather/t/homes-businesses-hit-water-dam/ (Accessed: 15 February 2016)

Køltzow, M. (2012). *Abilities and limitations in the use of Regional Climate Models Morten*. Ph. D. Department of Geosciences University of Oslo.

Kunstmann, H. and G. Jung, 2005. Impact of regional climate change on water availability in the Volta basin of West Africa. In: Regional Hydrological Impacts of Climatic Variability and Change. IAHS Publ. 295.

Lawrence, J., Reisinger, A., Mullan, B., Jackson, B., 2013. Exploring climate change uncertainties to support adaptive management of changing flood-risk. Environmental Science & Policy 33, 133–142. doi:10.1016/j.envsci.2013.05.008

Leary, N., J. Adejuwon, V. Barros, I. Burton, J. Kulkarni, and R. Lasco (eds.), 2008: Climate Change and Adaptation, Earthscan, London, UK, 381 pp.

Lee, M., Villaruel, M. L. and Gaspar, R. E. (2016) 'Effects of Temperature Shocks on Economic Growth and Welfare in Asia', (501), pp. 0–41. doi: 10.2139/ssrn.2894767.

Lemos, M. C. (2008). What Influences Innovation Adoption by Water Managers? Climate Information Use in Brazil and the United States. Journal of the American Water Resources Association, 44 (6), 1388-1396.

Lemos, M. C. and Morehouse, B. J. (2005) 'The co-production of science and policy in integrated climate assessments', Global Environmental Change, 15(1), pp. 57–68. doi: 10.1016/j.gloenvcha.2004.09.004.

Lemos, M. C., & Morehouse, B. J. (2005). The co-production of science and policy in integrated climate assessments. Global environmental change, 15(1), 57-68.

Lemos, M. C., Kirchhoff, C. J. and Ramprasad, V. (2012) 'Narrowing the climate information usability gap', Nature Climate Change. Nature Publishing Group, 2(11), pp. 789–794. doi: 10.1038/nclimate1614.

Lempert, R. and Kalra, N. (2011) 'Managing Climate Risks in Developing Countries with Robust Decision Making', World Resources Report, World Reso, p. 9. Available at: http://www.wri.org/sites/default/files/uploads/wrr_lempert_and_kalra_uncertainty_.pdf.

Lim, B., Rector, I., Angell, P. S., Nuttall, N., Leach, A., Barton-dock, M. and Evans, W. (2011) Decision Making in A Chalenging Climate: Adaptation challenges and choices, Design. doi: 978-1-56973-774-3.

Lumbroso, D. M., Woolhouse, G. and Jones, L. (2015) 'A review of the consideration of climate change in the planning of hydropower schemes in sub-Saharan Africa', Climatic Change, 133(4), pp. 621–633. doi: 10.1007/s10584-015-1492-1.

MacDonald, M., 2014. Pwalugu Multipurpose Dam Environmental and Social Impact Assessment, Accra.

Marshall, N. A., Gordon, I. J. and Ash, A. J. (2011) 'The reluctance of resource-users to adopt seasonal climate forecasts to enhance resilience to climate variability on the rangelands', Climatic Change, 107(3), pp. 511–529. doi: 10.1007/s10584-010-9962-y.

Mensah, A., Anderson, K. and Nelson, W. (2016) 'Review of Adaptation Related Policies in Ghana', (November). doi: 10.13140/RG.2.1.3873.1924.

MESTI (2013) Ghana National Climate Change Policy.

Meyer, R. (2011). The public values failures of climate science in the US. Minerva, 49(1), 47- 70.

Miles, M. B., & Huberman, A. M. (1994). Qualitative data analysis: An expanded source book (2nd ed.). Thousand Oaks, CA: Sage

Mo, C. et al., 2015. World Energy Resources: Charting the Upsurge in Hydropower Development. , p.55

Moller, L.C., 2005. Transboundary Water Conflicts over Hydropower and Irrigation : Can Multilateral Development Banks Help ?

Morss, R. E. et al. (2005) 'Flood risk, uncertainty, and scientific information for decision making: Lessons from an interdisciplinary project', Bulletin of the American Meteorological Society, 86(11), pp. 1593–1601. doi: 10.1175/BAMS-86-11-1593.

Mouton, J. (1996) Understanding social research, Pretoria: Van Schaik.

NDPC (2010) 'Medium-Term National Development Policy Framework: Ghana Shared Growth and Development Agenda(GSGDA), 2010-2013, Volume I: Policy Framework, Final Draft', Government of Ghana, National Development Planning Commission, I, pp. 1–278.

NDPC. Implementation of the growth and poverty reduction strategy 2006–2009, annual progress report. Accra, Ghana: National Development Planning Commission; 2007.

Niang, I. et al. (2014) 'Africa', Climate Change 2014: Impacts, Adaptation and Vulnerability - Contributions of the Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change., pp. 1199–1265. Available at: https://ipcc-wg2.gov/AR5/images/uploads/WGIIAR5-Chap22_FINAL.pdf.

Nordhaus, W. D. (2006) 'Geography and macroeconomics : New data and new findings'.

NRC (National Research Council). 2009. Informing Decisions in a Changing Climate—Panel on Strategies and Methods for Climate-Related Decision Support. National Academies Press, Washington, DC

Oecd (2009) Integrating Climate Change Adaptation into Development Co-operation. Policy Guidance. doi: 10.1787/9789264054950-en.

OECD (2009) Integrating climate change adaptation into development Co-operation: Policy guidance. Paris: Organization for Economic Co-operation and Development (OECD)

Oguntunde, P. G., Abiodun, B. J. and Lischeid, G. (2017) 'Impacts of climate change on hydro-meteorological drought over the Volta Basin, West Africa', Global and Planetary Change. Elsevier, 155(July), pp. 121–132. doi: 10.1016/j.gloplacha.2017.07.003.

Owusu, K., Waylen, P. and Qiu, Y. (2008) 'Changing rainfall inputs in the Volta basin: Implications for water sharing in Ghana', GeoJournal, 71, pp. 201–210.

Pagano, T. C., Hartmann, H. C., & Sorooshian, S. (2002). Factors affecting seasonal forecast use in Arizona water management: a case study of the 1997-98 El Niño. Climate Research, 21(3), 259-269

Petersson, E. (2015) We didn't expect such severe rainstorm– GMA. Available at: http://www.ghanalive.tv/2015/04/11/bui-dam-is-not-a-solution-to-dumsor/ (Accessed: 2 February 2016).

Pielke, R. A. and Byerly, R. (1998) 'Beyond Basic and Applied', 42(1998).

Pielke, Roger A., Jr., and R. Byerly. 1998. Beyond basic and applied. Physics Today 51(2): 42-46.

Rand (2013) 'Making Good Decisions Without Predictions', RAND Corporation Research Highlights, pp. 1–7. Available at: http://www.rand.org/pubs/research_briefs/RB9701/index1.html?utm_campaign=rand_socialflow_twitter&utm_source=rand_socialflow_twitter&utm_medium=socialflow.

Ranger, N. (2013) 'TOPIC GUIDE : Adaptation : Decision Making under Uncertainty', Evidence on Demand, (June). doi: http://dx.doi.org/10.12774/eod_tg02.june2013.ranger.

Rayner, S., Lach, D. and Ingram, H. (2005) 'Weather forecasts are for wimps: Why water resource managers do not use climate forecasts', Climatic Change, 69(2–3), pp. 197–227. doi: 10.1007/s10584-005-3148-z.

Reilly, J., Stone, P. H., Forest, C. E., Webster, M. D., Jacoby, H. D. and Prinn, R. G. (2001) 'Uncertainty and Climate Change Assessments', Science, 293(5529), p. 430 LP-433. Available at: http://science.sciencemag.org/content/293/5529/430.1.abstract.

Rice, J. L., Woodhouse, C. A. and Lukas, J. J. (2009) 'Science and decision making: Water management and tree-ring data in the western United States', Journal of the American Water Resources Association, 45(5), pp. 1248–1259. doi: 10.1111/j.1752-1688.2009.00358.x.

Riede, J. O. et al. (2016) 'What ' s on the 5th IPCC Report for West Africa ?', pp. 7–24. doi: 10.1007/978-3-319-31499-0.

Romsdahl, R.J., 2011. Decision support for climate change adaptation planning in the US: why it needs a coordinated internet-based practitioners' network. Climatic Change 106, 507–536. doi:10.1007/s10584-010-9947-x

Rummukainen, M. (2009). State-of-the-art with regional climate models. *Wiley Interdisciplinary Reviews: Climate Change*, 1(1), pp.82-96.

Rydgren, R., Graham, P., Basson, M. and Wisaeus, D. (2007) Addressing climate-driven increased hydrological variability in environmental assessments for hydropower projects: A scoping study. World bank, Washington D.C. Available at: http://www-wds.worldbank.org/external/default/WDSContentServer/WDSP/IB/2012/07/31/000333037_20120731015331 /Rendered/PDF/715290WP0Box370077B00PUBLIC00IHV0Final.pdf [Accessed 14 August 2015]

Sabeerali, C. T. et al. (2014) 'Why ensemble mean projection of south Asian monsoon rainfall by CMIP5 models is not reliable ?', Climate Dynamics. Springer Berlin Heidelberg, pp. 161–174. doi: 10.1007/s00382-014-2269-3.

Sarewitz, D. and R. A. Pielke. 2007. The Neglected Heart of Science Policy: Reconciling Supply of and Demand for Science. Environmental Science & Policy 10 (1): 5–16.

Singh, C., Daron, J., Bazaz, A., Ziervogel, G., Spear, D., Krishnaswamy, J., Zaroug, M. and Kituyi, E. (2017) 'The utility of weather and climate information for adaptation decision-making: current uses and future prospects in Africa and India', Climate and Development. Taylor & Francis, 0(0), pp. 1–17. doi: 10.1080/17565529.2017.1318744.

Sood, A., Muthuwatta, L. and McCartney, M. (2013) 'A SWAT evaluation of the effect of climate change on the hydrology of the Volta River basin', Water International, 38(3), pp. 297–311. doi: 10.1080/02508060.2013.792404.

The World Bank, 2014. Understanding the Impact of Climate Change on Hydropower: the case of Cameroon. , (87913).

Times, G. (2013) The effects of 'dumsor' on small and medium scale enterprises the case of Kwame Nkrumah circle enclave - the Ghanaian times. Available at: http://www.ghanaiantimes.com.gh/the-effects-of-dumsor-on-small-and-medium-scale-enterprises-the-case-of-kwame-nkrumah-circle-enclave/ (Accessed: 25 May 2015).

Tremblay, A., Varfalvy, L., Roehm, C. and Garneau, M. (2006) 'the Issue of Greenhouse Gases From Hydroelectric Reservoirs : From Boreal To Tropical Regions', Environmental Protection, 2006. Available at: http://www.scopus.com/inward/record.url?eid=2-s2.0-33846219988&partnerID=40&md5=e80d8d98ec8a1ec939b6155cd9717c3e.

Turnpenny, J., Jones, M., & Lorenzoni, I. (2010). Where now for post-normal science? A critical review of its development, definitions, and uses. Science, Technology & Human Values, 0162243910385789

Viviroli, D., Archer, D.R., Buytaert, W., Fowler, H.J., Greenwood, G.B., Hamlet, A.F., Huang, Y., Koboltschnig, G., Litaor, M.I., López-Moreno, J.I., Lorentz, S., Schädler, B., Schreier, H., Schwaiger, K., Vuille, M., Woods, R., 2011. Climate change and mountain water resources: overview and recommendations for research, management and policy. Hydrol. Earth Syst. Sci. 15, 471–504. doi:10.5194/hess-15- 471-2011

Volta River Development Act (Act 46) (1961) Volta River Authority, Ghana

von Winterfeldt, D. (2013) ‘Bridging the gap between science and decision making’, Proceedings of the National Academy of Sciences, 110(Supplement 3), p. 14055 LP-14061. Available at: http://www.pnas.org/content/110/Supplement_3/14055.abstract.

Watkiss, P. and Dynzynski, J. (2013) ‘Robust Decision Making: Decision Support Methods for Adaptation, MEDIATION Project, Briefing Note 3. Funded by the EC’s 7FWP’, pp. 1–10.

Wel, N. (2015). Mission. [online] Wcrp-climate.org. Available at: https://www.wcrp-climate.org/about-wcrp/wcrp-overview [Accessed 10 Sep. 2017].

Wilby, R. L. and Dessai, S. (2010) ‘Robust adaptation to climate change’, Weather. Chichester, UK: John Wiley & Sons, Ltd., 65(7), pp. 180–185.

Willows, R. and Connell, R. (2003) Climate adaptation: Risk, uncertainty and decision-making, Policy. doi: 10.1016/j.molcel.2011.04.017.

World Bank (2014) Fact sheet: Infrastructure in sub-Saharan Africa Available at: http://qo.worldbank.org/SWDECPM5S0 [Accessed 4 May 2015]

WRC (2015b) Water resources commission of Ghana. Available at: http://www.wrc-gh.org/about-us/ (Accessed: 11 August 2015).