SYNTHESIS REPORT:

Harnessing Hydropower

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Abbreviations

BEL	Bujagali Energy Limited
CAT	Catchment Area Treatment
CDM	Clean Development Mechanism
CEA	Central Electricity Authority
CIA	Cumulative Impact Assessment
DFID	United Kingdom government Department for International Development
DRC	Democratic Republic of the Congo
EEA	European Environment Agency
EIA	Environmental Impact Assessment
EIRR	Economic Internal Rate of Return
ESCOM	Electricity Supply Corporation of Malawi
FUNAE	Fundo de Energia
GBI	Green Belt Initiative
GCM	General Circulation Model
GERD	Grand Ethiopian Renaissance Dam
GW	Gigawatts
ha	hectares
ICOLD	International Commission on Large Dams
IEA	International Energy Agency
IHA	International Hydropower Association
IPCC	Intergovernmental Panel on Climate Change
IPP	Independent power producer
IRENA	International Renewable Energy Agency
IUCN	International Union for Conservation of Nature
MEGA	Mulanje Electricity Generating Agency
MW	Megawatts
MWh	Megawatt- hours
NEA	Nepal Electricity Authority
NHA	National Hydropower Association
NPV	Net Present Value
PPA	Power purchase agreement
PPIAF	Public-Private Infrastructure Advisory Facility
RCM	Regional Climate Model
REN21	Renewable Energy Policy Network for the 21st Century
SAPP	Southern African Power Pool
SEI	Stockholm Environment Institute
TWh	Terawatt-hours
TWO	Transboundary Waters Opportunity
UN	United Nations
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United States Agency for International Development
USBR	United States Bureau of Reclamation
W	Watts
WCD	World Commission on Dams
WECS	Water and Energy Commission Secretariat

Report Summary

The Harnessing Hydropower study aimed to provide an analysis of the historical performance of hydropower in selected countries and an assessment of the risks and opportunities related to the performance of schemes under future climate change in the context of water, energy and food security. This was undertaken through a literature review and short country case study visits, consulting with as broad a range as possible of stakeholders in each country's hydropower sector. The target audience for this work is Department for International Development (DFID) staff together with other development professionals, and government officials who are interested in the performance and development of the hydropower sector in low income countries and the trade-offs between water, energy and food security in the context of climate change.

The study included four phases of activity:

- **Inception report** - This described the study's aims and objectives, candidate countries/basins for case studies and the plan for delivering the study, including an outline framework for analysis and stakeholder engagement plans.
- **Literature review** - This details how the factors that affect the performance of hydropower schemes may be influenced by climate change and interactions within the complex built, natural and social systems providing water, energy and food security. The review also set out the criteria used to select three case studies for further analysis.
- **Case studies** - Three case studies were selected as described in the Literature review - one in Africa (Malawi) and two in South Asia (India and Nepal) - as part of the study to analyse past performance of hydropower and to identify priority interventions to help improve performance in a representative range of country contexts and settings.
- **Synthesis Report** – This is a synthesis of findings that draws on the literature review and evidence from the case studies to illustrate key challenges and opportunities related to hydropower performance, including consideration of the impacts of climate change and the broader context of the water – energy – food security nexus.

This Synthesis Report addresses the following key questions and a summary of the key findings is given below:

What are the drivers for developing new and improving existing hydropower schemes?

At present 1.6 billion people worldwide, mainly in low-income countries, do not have access to household electricity. In some rural areas of countries in sub-Saharan Africa access rates can be as low as 1% (Lumbroso et al., 2014 ; World Bank, 2009). These people's use of traditional biomass, and especially fuel wood, can lead to deforestation and land degradation. Developed in an appropriate way, hydropower could play a key role in achieving the goal of halving global energy-related carbon dioxide emissions by 2050 and improving access to electricity for the rural poor. Reliable power supplies are essential for economic growth and provide important social and public health benefits (DFID, 2009). Hydropower also offers a "hedge" against volatile energy prices and risks associated with the imported supply of electricity or fossil fuels (World Bank, 2009).

How can hydropower performance be assessed, and what factors affect the performance of different types of hydropower schemes, including climate change?
There are a variety of measures that can be used to evaluate the performance of hydropower schemes. These can generally be classified under the following headings: Power generation measures; Economic measures; Social impacts; Environmental impacts; Water use; and Greenhouse gas emissions. The study found that the main issues that affect hydropower performance included: Funding mechanisms and the role that public and private finance plays; Availability of data; Physical and environmental factors; Climate change; Operation and maintenance; and Type of hydropower scheme.

Climate variability and climate change present significant challenges to existing hydropower and the development of future schemes. The recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report highlighted potential impacts on hydropower owing to a reduction in water availability in most dry sub-tropical regions, a decline in raw water quality and increased risk of flooding. Seasonal, year-to-year and longer term natural variations in climate affect hydropower performance because of the amount of power generated being reliant on river flows.

Economic benefits of hydropower are sensitive to changes in atmospheric temperature, precipitation and runoff yet recent studies claim that climate change impacts are rarely explicitly considered when planning hydropower projects. The future risks (and opportunities) that could result from climate change include: changing spatial and temporal patterns of rainfall and river flows; increased evaporation rates from reservoir surfaces; increased sediment loads in rivers, as a result of more intense rainfall and land use change; increased flood magnitudes; and increased flows in rivers fed by glacial melt water (in countries with sufficiently high mountains).

Climate change can be accounted for in the planning and design of hydropower schemes via the use of hydrological models and results from Global Climate Models (GCMs) which provide information, albeit with significant bands of uncertainty, on how climatic variables may change in the future. Over the expected lifetime of most hydropower schemes (50-100 years) it is extremely challenging to define likely climate changes as GCM outputs are subject to increasing uncertainty the further into the future they represent.

What measures are needed to improve and incentivise investment in sustainable hydropower schemes?
There are a range of economic incentives to encourage investments in sustainable hydropower schemes these include; fiscal incentives (e.g. tax incentives that include income tax, value-added tax, and customs duty incentives), non-fiscal incentives (e.g. risk cost sharing, support for land acquisition and resettlement) and capital-smart subsidies (i.e. philanthropic investment and training, see Desjardins, 2013).

In many countries the regulatory environment has changed several times in the past 30 years. This often makes private investors cautious, especially where the initial fiscal and licensing regime turns out to have been too generous to the licensees and results in changes in policies and regulations that disadvantage the original investors. The latter point is evidenced by the Himachal Pradesh case study which showed existing power producers are fighting attempts to increase the environmental levies they are required to pay. Consistency and stability in the investment environment could therefore improve and incentivise investment in sustainable hydropower schemes.

In the Lower Mekong region there a number of mechanisms, currently being applied that aim to improve the sustainability of private sector investment impacts. These include; investors use of sustainability frameworks and corporate social responsibility frameworks, benefit sharing, including development projects aimed at poverty alleviation, and the related concept of payments for ecological services, in catchments where hydropower development takes place (Foran et al., 2011).

What should the private sector role be in the development of new hydropower schemes?

In the future the private sector could play a critical role in hydropower schemes. The financing requirements of many large projects exceed funds available from governments and public sources. However, in many low income countries the lack of strong regulatory and enabling environments set against intense scrutiny of larger projects raises considerable risk for private capital. The inherent complexities of large hydropower schemes further compromise private sector investment. Private financial involvement in hydropower projects has always been on a smaller scale than publicly sponsored and financed schemes. For large hydropower projects in 2012, approximately 15,500 MW of projects with private participation reached financial closure in low income countries, with total project costs of US$21.15 billion. For small hydropower projects, the corresponding figures were 1,113 MW with a value of US$1.25 billion. In both cases, Brazil accounted for most of the activity.

In sub-Saharan Africa the scale of investment needed to achieve universal energy access is about US$15 to US$20 billion per year, every year, through to 2030. In order to achieve this objective it may prove an efficient use of public funds to leverage more extensive private sector investment.

Policies to promote private sector investment can be a step towards growing the hydropower sector, but there can also be more entrenched institutional and regulatory issues with national energy sectors which need to be addressed. There is evidence in the Malawi and Nepal case studies carried out for this study for a recent trend towards unbundling of national utilities. This will separate generation, transmission and distribution functions, with a view to introducing competition in each area. This would allow the private sector to compete for contracts in each area. It is too soon to know what the impacts will be in the countries studied.

How does hydropower compare to other power generation technologies, and how can trade-offs be evaluated?

It is currently challenging to compare hydropower with other methods of power generation because of the limited information available on technical issues such as: kWh of power generated per US$ of investment; greenhouse gas emissions over the lifetime of the scheme; water use per kWh of power generated; capital, as well operation and maintenance costs; number of beneficiaries; and social and environmental impacts. The above should be relatively “simple” to measure; however, this is often not the case and there is often a lack of consensus on the figures for the above subjects.

The role of hydropower within the water – food – energy security nexus can be assessed using a range of methods from qualitative approaches to more data driven and quantitative modelling. Tools are under development which aim to identify win-win opportunities, where all parties can gain from cooperatively managing the available resources. Where greater benefits can be achieved by cooperation, the win-win can be sustainable as there are few incentives to withdraw. In the case of transboundary catchments water resources are rarely sustainably, efficiently or equitably utilised, even though water is critical to economic growth and particularly in developing countries (Phillips et al., 2008). This often results from the perception that one party’s gain must be another party’s loss. By analysing a broader range of benefits from water resources and highlighting the potential for win-wins, it may be possible to move the perception away from a simple gain-loss situation (Phillips et al., 2008). In recent years numerical modelling techniques have been developed to carry out multi-objective trade-off analysis in developing countries (e.g. Hurford and Harou, 2014).

Conclusions and recommendations

The following can be concluded from the case studies and literature review:

Hydropower will play an increasingly important part in supplying electricity in low income countries in Africa and Asia over the next 30 years

Hydropower offers a range of advantages over alternative methods of generation. It is a renewable source of energy and well selected sites can generate low cost power. Storage hydropower schemes can usually be operated flexibly, providing a rapid response to changes in demand. In an integrated power system, reservoir and pumped storage hydropower could be used to reduce the frequency of start-ups and shutdowns of thermal plants, better balancing supply and demand under changing patterns thereof. Hydropower offers a “hedge” against volatile energy prices and risks associated with the imported supply of electricity or fossil fuels (World Bank, 2009). Under the right circumstances, schemes can be designed to provide additional water-related benefits, such as irrigation and municipal supplies.

Existing hydropower schemes should be “re-operated”, improved and rehabilitated before investing in new infrastructure

Generally, existing hydropower schemes should be rehabilitated, refurbished or upgraded before new facilities are constructed. Adding new or more efficient turbines generally has a much lower social and environmental impact than building new schemes. It is important to note that hydropower is a mature technology hence even very old hydropower equipment is only likely to be 5% to 15% less efficient than the most modern (when able to run at full capacity and not suffering from lack of maintenance or turbine damage). Hence the largest increase in hydropower performance will be in cases where the equipment has deteriorated (e.g. to such a degree that there are significant efficiency gains simply by replacing it with traditional designs and solutions.

New hydropower schemes need to be assessed within the context of comprehensive catchment-wide and national planning

New hydropower schemes should be considered in the context of the whole catchment taking into account how climate change will influence flows, and how future river flows will meet competing and perhaps increasing demands for power generation, the environment, and water supply for domestic, agriculture and industrial uses. Community- and ecosystem-based adaptation approaches that integrate the use of biodiversity and ecosystem services into an overall strategy aimed at empowering people to adapt to climate change must be central to any comprehensive planning efforts with respect to new hydropower dam developments.

Comprehensive analysis needs to be undertaken at national level to define the best way of addressing the specific water – energy – food security challenges faced by particular countries. For example, should international funding agencies invest US$80 billion in the proposed Grand Inga hydropower project on the River Congo in the Democratic Republic of the Congo (DRC) that will generate 40,000 MW and potentially foreign exchange from export sales of electricity, or would it be more sustainable and advantageous to use these funds to put in place small-scale, off-grid, power generation (e.g. wind, solar, small-scale hydropower) that are more likely to directly benefit the 94% of the DRC’s population that do not have access to electricity? Such questions remain difficult to answer and involve highly political issues with potentially different sections of the population benefitting, depending on the investments selected.

There is a paucity of suitable hydrological data with which to plan new hydropower schemes in many low income counties, so monitoring should be improved with some urgency
Hydropower schemes based on limited and unreliable hydrological data have the potential to underperform and not to attain the benefits the infrastructure is designed to generate. Generally, in the past two decades hydro-meteorological networks in low income countries have deteriorated.

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

Climate change scenarios should be incorporated into the planning and design of new hydropower schemes to ensure their performance is resilient to changes
Hydropower is so fundamentally reliant on river flows that it is wise to consider the risk of future variations or changes in flows being sufficient to impact on the performance of existing or planned schemes.

There is evidence in the research literature and from the case studies undertaken by this study to suggest that the possible effects of climate change are not being taken into account when new hydropower schemes are being planned. Climatic uncertainty as the result of climate change should be incorporated into planning and design of hydropower schemes as a matter of course to help to avoid over- or under-designed infrastructure and financial risk, and to improve the resilience of such schemes.

There is some limited work that suggests that planned investment for hydropower in Africa is in regions that are unlikely to experience the worst effects of climate change and hence are fairly low risk in terms of being non-performing or not meeting targets for returns on investment. However, there are also other studies that contradict these findings. Some research has been published that indicates flows in major Asian rivers fed by melt water from the Himalayas may increase at least up to the year 2050, thus increasing the potential for hydropower generation.

Evaluations of proposed new hydropower schemes should include an assessment of their water footprint and greenhouse gas emissions
It would appear that the water footprint and greenhouse gas emissions have in many cases in the past not been estimated at all when hydropower schemes have been evaluated . There is a growing body of evidence to suggest that in “hot” countries that these are larger than previously anticipated. Hence there is a need to evaluate these additional factors when new hydropower schemes are planned and the performance of existing ones are assessed to reduce unintended consequences.

Technological innovations can improve environmental performance and reduce operational costs of hydropower schemes
Although hydropower technologies are mature, recent research into the following areas will help to improve the economic efficiency and lessen the negative impacts of future hydropower schemes: variable-speed turbines; fish-friendly turbines; new sediment management techniques; more efficient tunnelling methods; use of models to assess and optimise the trade-offs between energy, irrigation and water supply needs as part of integrated river basin management.

Environmental and social issues will continue to play a significant part in the development of new hydropower opportunities

Potential negative social and environmental impacts of hydropower projects vary depending on the project's type, size and local conditions. Experience gained over the past 80 years, together with recently developed sustainability guidelines and criteria, and innovative planning approaches based on stakeholder engagement and technical innovations should be used to help to improve the sustainability performance of future projects. Such approaches are only just beginning to be demonstrated by projects such as WISE-UP to Climate (IUCN, 2014).

The benefits of large hydropower schemes often do not reach the poorest communities

Although hydropower has contributed to economic development worldwide, in many low income countries the electricity produced has failed to reach the rural poor for a variety of reasons including a lack of distribution infrastructure. The benefits of supplying a small amount of electricity are generally greatest for the people currently without access to electricity, usually the rural poor.

Improvements are required in the understanding of the water – energy – food nexus and the place of hydropower within it

There is no harmonised 'nexus database' or analytical framework that can be used for monitoring or trade-off analyses. Hence the effects of increasing energy or water scarcity on food and water or energy security, as well as potential synergies between land, water and energy management, are not well understood. One question that needs to be addressed is the extent to which the higher availability of one resource in the nexus (i.e. water, energy or food) can sustainably reduce scarcity of another, and how might this work at different spatial scales (e.g. local, regional and national).

Investments in new hydropower schemes should ensure that they increase the climate resilience of poor and vulnerable communities

Investments in new hydropower schemes should aim to enhance climate resilience by helping poor and vulnerable communities prepare for, withstand, and recover from the negative effects of climate change. However, there have been some cases where large hydropower dams can decrease, rather than enhance, climate resilience, especially for the rural poor, by increasing evaporative water loss, prioritising power generation over other demands for water and changing the hydrological regime which supports food production. For example, in 1992 it was estimated that the modified seasonal flows caused by hydropower schemes on the Zambezi River in southern Africa reduced the value of shrimp fisheries in the estuary by US$10 million dollars per year.

Regional pools of sustainable power should be diversified to reduce the dependency on energy sources that can be affected by climate change

Diverse methods of power generation are critical for climate change adaptation in water stressed regions. Regional power supply grids such as the one developed by the Southern African Power Pool (SAPP) provide a means for diversifying power production and reducing dependency on energy sources that can be affected by climate change, which in some cases will include hydropower. SAPP could play a key leadership role in adapting the regional power grid to the realities of climate variability and water scarcity through promotion of decentralised energy technologies, energy efficiency standards, demand-side management, and feed-in tariffs to support renewable technologies. In practice to date however, SAPP has emphasised large-scale coal and hydropower development to feed the regional grid, without serious consideration of climate change impacts and risks.

Recommended research and further studies to enhance the evidence base

There are a number of knowledge gaps related to the performance of hydropower and its role within the water –energy - food security nexus under climate change. These are briefly detailed below.

Assessment of the performance of hydropower under future climate change

More work is required to assess the impacts of climate change uncertainty on proposed hydropower schemes in low income countries relative to other variables (e.g. capital costs, operation and maintenance costs, internal rates of return). This could help to:

- Develop guidance for rehabilitation, upgrading or uprating existing hydropower plants to increase efficiency, output, capacity and value.
- Identify opportunities to redevelop very old hydropower plants, having obsolete equipment and less than optimum use of the water resource.
- Identify dams originally developed for flood control, irrigation, navigation or drinking water and assess the feasibility of adding hydropower generation.

Estimation of greenhouse gases from hydropower scheme reservoirs

Hydropower is often cited as a green form of energy with "low" greenhouse gas emissions; however, recent research indicates that for hydropower schemes with large reservoirs located in tropical and semi-tropical regions, the greenhouse gas emissions in grammes equivalent of CO_2/kWh may be similar to other "dirty" energy sources such as coal fired power stations. There is disagreement amongst researchers concerning the quantities of greenhouse gases emitted by reservoirs. The Kyoto Clean Development Mechanism now limits funding for hydropower projects with less than 10W of installed capacity per m2 of reservoir surface area, in recognition of potential for greenhouse gas emissions. Further research is required in tropical and sub-tropical low income countries to enable a more accurate methodology for defining lifecycle emissions from hydropower schemes to be put in place.

Minimisation and utilisation of greenhouse gases generated by hydropower scheme reservoirs to generate power

Methane could be extracted from the water in reservoirs and burnt as a renewable source of energy. There is some limited research describing the potential for extracting methane from reservoirs to be used as a renewable energy source. However, further work is needed to investigate methods to minimise the emissions from hydropower schemes including understanding the processes via which these gases are generated.

Water consumption and footprinting tools for different power generation technologies

There are limited data on consumptive water use in the energy sector for different power generation techniques (e.g. hydropower, thermal, nuclear), compared to the data for the actual water withdrawn from the aquatic environment (e.g. surface or ground waters). Existing data on the consumptive use of different power generation techniques are often not consistently traced throughout the full lifecycle. In order to compare the water use of different power generation techniques a widely accepted water footprinting tool is required.

Uniformly applicable water footprinting frameworks do not yet exist that allow the comparison of water use efficiency for different forms of energy or food production. Such water footprinting frameworks would have to consistently integrate water productivity with water scarcity and opportunity costs in any particular location. This is not a simple task. Water footprinting of hydropower schemes in relation to the amount of hydropower they generate could serve as a useful differentiator in selecting from a range of options for development

Impacts of hydropower on ecosystem services including their cumulative effects

There is still insufficient knowledge on the impacts of hydropower schemes on ecosystem services including the relationships between river flows, the state of aquatic ecosystems and terrestrial flora and fauna. There is also a need to improve the assessment of environmental risks associated with cumulative impacts, resulting from development of cascades of dams for hydropower schemes in the same basin.

There are suggestions that there is a need for a publicly available clearinghouse to store existing data on environmental impacts and environmental mitigation measures for hydropower schemes covering areas such as: the passage of fish; environmental flow releases; and water quality. This would require clear criteria for inclusion of data and information (e.g. recent, peer-reviewed journal papers and credible web sites). These data could help to reduce the cost of mitigation decisions and support comprehensive reviews of environmental issues.

For hydropower schemes that store water behind a dam there is a need to carry out more research in order to separate the environmental impacts of the dam from the impacts of hydropower operation itself.

Role and impacts of small-scale hydropower schemes in low income countries

It is widely reported that small scale hydropower is “environmentally friendly”. However, more work is needed to accurately assess the environmental impacts caused by small hydropower so that such schemes can be compared with other forms of electricity generation (e.g. large scale hydropower, thermal, wind, solar) on the scale of the impacts per kW of power generated. It is possible that the impacts of the widespread use of small scale hydropower may be no less numerous or less serious, per kW generated, than those from hydropower produced from large storage dams.

No accurate statistics on the potential for small scale hydropower are available for Africa. Their rates of development are commonly thought to be lower than for large-scale hydropower. Currently, grid connected small hydropower is mostly constructed and operated by either national utilities or Independent Power Producers. To increase the deployment of small hydropower, as well as isolated mini-grids and off-grid electrification different implementation models will be required. This is an area that requires further research, although positive examples are available from the Malawi and Nepal case studies in particular.

Financing of small-scale hydropower schemes in low income countries

Small hydropower projects (<10 MW) are often less profitable and thus more difficult to finance than larger schemes. Part of the reason for this may be that they cannot serve large industrial demands which commonly provide contracts for power purchase which a developer can then use to support loan requests to banks. Several of the cost components involved in developing hydropower do not change proportionally with the project’s size. However, small scale-hydropower can have a number of environmental and social advantages where they are not part of a national grid they are particularly likely to provide greater local benefits. There is a need to carry out more research into sustainable financing and business models that are required to facilitate the development of off-grid small hydropower in the low income countries, , although positive examples are available from the Malawi and Nepal case studies in particular.

Private sector participation in the development and operation of new hydropower schemes

There is need to carry out more research into how the private sector can effectively participate in hydropower scheme development and operation. Research is needed into how to devise an appropriate “enabling environment” (i.e. providing enough inducements without creating excessive rewards), how to compensate private partners for the provision of public goods and price in the degradation or loss of existing public goods resulting from a development. Methods must also be developed to allocate the “correct” proportion of the risks to private sector partners.

SECTION 1

Introduction

1.1 Aims of the study

The Harnessing Hydropower study aims to provide an analysis of the historical performance of hydropower in selected case study countries and an assessment of the risks and opportunities related to the performance of hydropower under future climate change in the context of the water, energy and food security. This synthesis report brings together evidence from a literature review (Lumbroso et al., 2014) and three country case studies on hydropower performance in Malawi, Nepal and the state of Himachal Pradesh in northern India (see Hurford et al., 2014a, b, c). The literature review outlines the selection process for the case study countries.

The report is aimed at Department for International Development (DFID) staff together with other development professionals, government staff and interested stakeholders who are engaged in countries with existing hydropower schemes and/or plans to increase hydropower production and aiming to achieve energy, water and food security within the context of climate change. This report has been written so that the reader does not need to be an expert in the field of hydropower or the trade-offs between water, energy and food security to be able to understand the pertinent issues. The report has been structured as a series of questions covering the following topics:

- A global overview of hydropower including:
    - Regions where hydropower is currently being developed.
    - Hydropower potential.
    - The drivers for developing new and improving existing hydropower schemes.
- The guiding principles of the water – energy – food security nexus including:
    - The guiding principles of the nexus.
    - The assessment of hydropower performance with the water – energy – food security nexus.
- Hydropower performance including:
    - The performance of hydropower schemes in terms of: power generation; economic measures; tariff levels; social impacts; environmental impacts; water use; greenhouse gases
    - The factors that affect the performance of hydropower schemes including: funding mechanisms; regulatory factors; physical and environmental factors; climate change; operation and maintenance.
    - The impacts of climate change on the performance of hydropower schemes.
- Development of new hydropower schemes including:
    - Measures to incentivise investments in sustainable hydropower.
    - Improving the planning process for hydropower schemes.
    - The policies required to develop sustainable hydropower schemes.
    - The private sector's role in the development of new schemes.
- Hydropower and the water – energy – food security nexus including:
    - A comparison of hydropower with other power generation technologies.

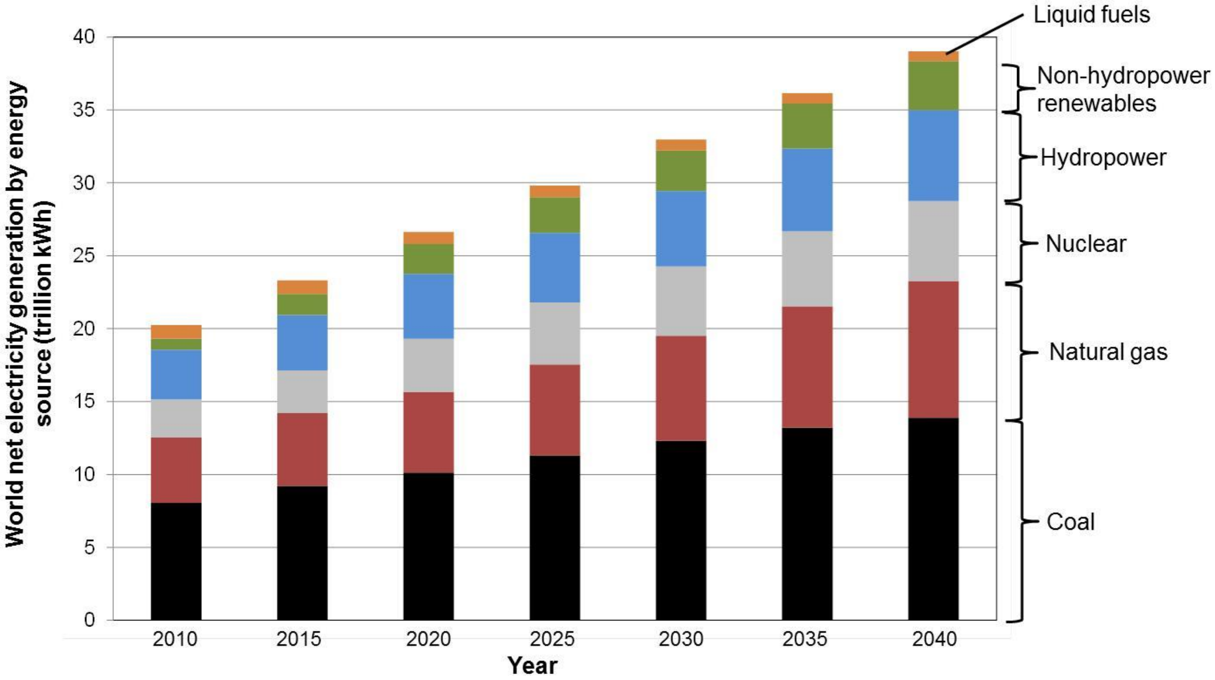
- How issues related to food, energy and water security affect hydropower schemes.
- Methods that can be used to "trade-off" the benefits of hydropower within the water – energy – food security nexus.

This report also brings together conclusions and knowledge gaps related to the above topics.

1.2 Background to renewable energy sources

Increasing population and economic growth, primarily in emerging markets, is strengthening the demand for water, energy and food. Global energy consumption, relative to 2011, is projected to increase by nearly 35% by 2035 (IEA, 2013), with emerging economies such as China, India, and Brazil doubling their energy consumption in the next 40 years. By 2050, Africa's electricity generation is projected to be seven times as high as it is today. In Asia electricity generation will more than triple by 2050 (Rodriguez, 2013). Figure 1 shows the world net electricity generation by energy source.

Figure 1 World net electricity generation by energy source



Source: Adapted from USEIA, 2013

In 2012 renewable energy sources accounted for approximately 19% of the world's total energy consumption (REN21, 2014). Of this total, traditional biomass[1], which currently is primarily burned for cooking and heating in remote and rural areas of developing countries, accounted for about 9%. Modern renewables, which generate electricity, increased their share to approximately 10%. Hydropower is one such modern renewable source of energy. In 2012 hydropower provided 3.8% of the world's energy consumption (REN21, 2014), but approximately 16% of the world's electricity supply, and was the world's predominant source of renewable electricity as shown in Figure 2 (REN21, 2014).

[1] Wood fuels, agricultural by-products and dung

Hydropower has increasingly been seen by international funding agencies as a solution to meeting increasing energy demands from a renewable, low-carbon source. Approximately two-thirds of economically viable hydropower potential worldwide is yet to be tapped and 90% of this potential is in developing countries (UN, 2004). Global hydropower generation capacity has been increasing steadily over the last 30 years, and the past few years have shown an increased growth rate (Hamududu and Killingtveit, 2012). However, hydropower is one of the energy sources most likely to be affected by climate change and climate variability because the amount of electricity generated is directly related to water quantity and its timing (Harrison and Whittington, 2001). The recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report highlighted potential impacts on hydropower owing to a reduction in water availability in most dry sub-tropical regions (IPCC, 2014).

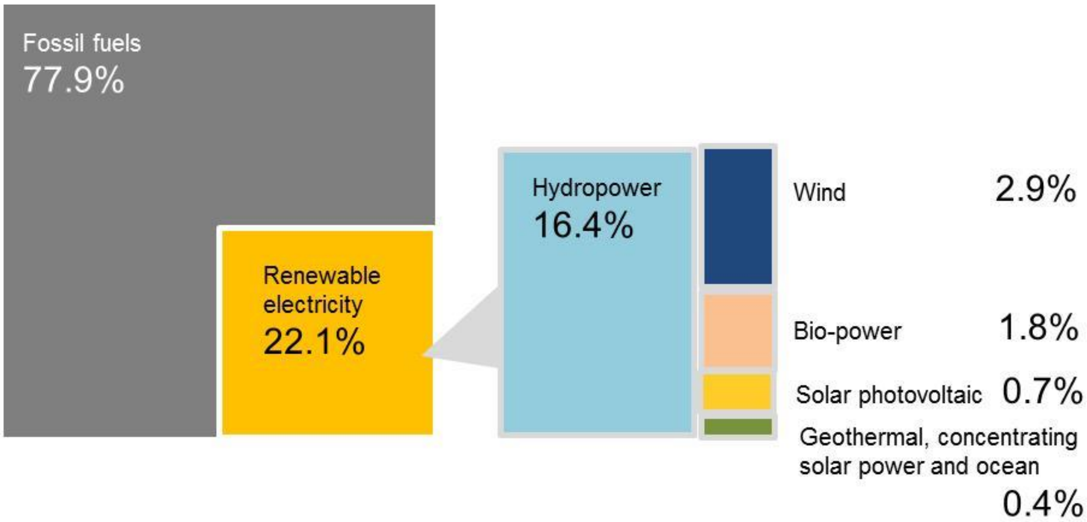
1.3 Background to hydropower generation

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

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

Hydropower is a technically efficient form of electricity generation, typically the efficiency of a modern day hydropower plant in converting potential energy to electrical energy is about 90% (USBR, 2005).

Figure 2 Estimated renewable electricity share of global energy use at the end of 2013



Source: Adapted from REN21, 2014

There are three main types of hydropower schemes:

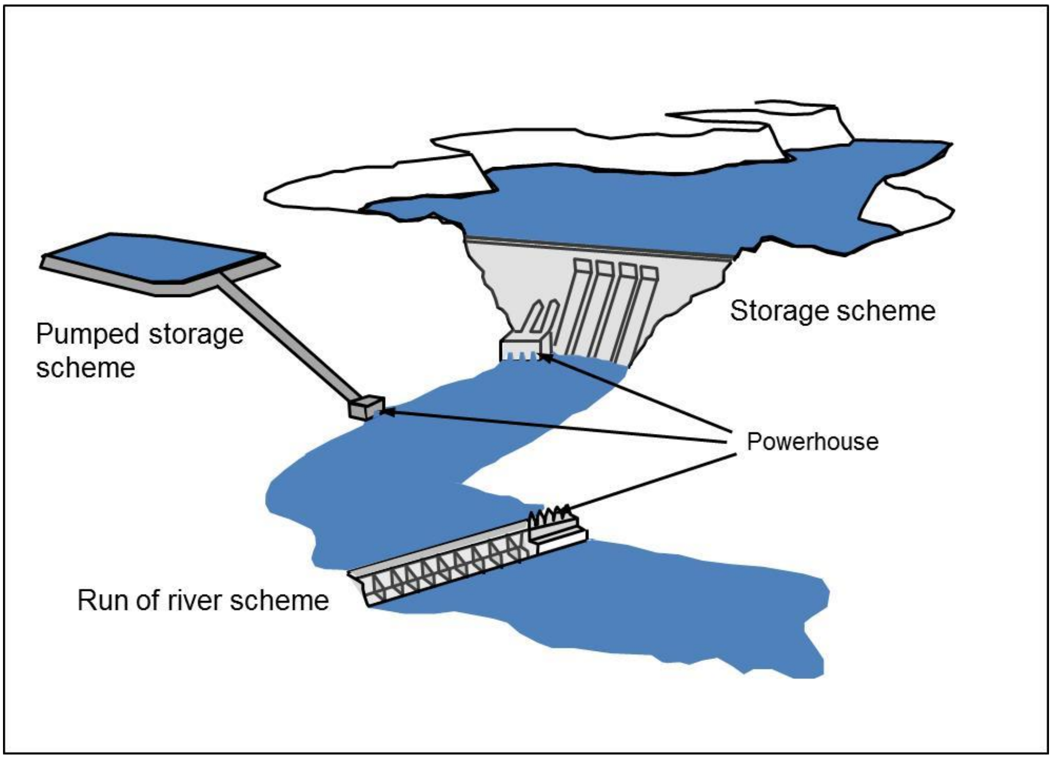
- **Storage schemes** – These have a dam that impounds water in a reservoir that feeds the power plant. Storage schemes generally have higher environmental and social costs than pumped storage or run of river schemes because more land is inundated and the natural flow regime is disrupted.
- **Run of river schemes** – These have either no storage at all, or a limited amount of storage, referred to as pondage. Run of river plants alter the flow regime of a river to a lesser degree than storage schemes. They are generally considered to have a

lower environmental impact than storage schemes (Lindström and Granit, 2012). Run of river plants are generally only appropriate for rivers with a sufficiently high minimum dry weather flow or those regulated by a much larger reservoir or lake upstream.

- **Pumped storage schemes** – These are designed solely to store energy to provide power during peak loads and they offer the flexibility to supplement other electricity supplies at very short notice. This form of hydropower can balance load differences on power grids more effectively than technologies (e.g. thermal power stations) that typically supply base load (Levine, 2003). During off-peak hours excess electricity produced by other power plants is used to pump water from lower- to higher-level reservoirs. During periods of highest demand, the water is released from the upper reservoir through turbines to generate electricity. This has the additional benefit of using electricity to pump uphill when it is available at a relatively low cost and to generate when it is higher cost, generating revenue through the cost differential.

Figure 3 shows the three types of hydropower schemes.

Figure 3 Diagram illustrating the main types of hydropower schemes



SECTION 2

A global overview of hydropower

2.1 Where have hydropower schemes been developed?

The use of hydropower and its potential for expansion varies between countries. The five countries with the greatest potential for hydropower expansion are China, USA, Russia, Brazil and Canada (REN21, 2014). Europe, America, and Asia have a sizable share of hydropower capacities. The installed capacity for Europe and Northern America, though large, has not increased much over the past 30 years, whilst during the same period the installed hydropower capacity in Southern/Central America and Asia/Oceania has increased by around 50% (Hamududu and Killingtveit, 2012).

Between 2009 and 2010 the global use of hydropower increased by around 5.3% reaching 3,427 TWh by the end of 2010 (Lucky, 2012). The world's total consumption of hydropower increased each year between 2003 and 2010. It also increased by at least 3.5% annually during five of the seven years between 2003 and 2010 (Lucky, 2012). A total of US$40 to US$45 billion was invested in large hydropower projects worldwide in 2010 (Lucky, 2012).

Table 1 shows regional hydropower characteristics in terms of hydropower in operation, total potential, under-construction, planned and countries with more than 50% of their total electricity demand supplied by hydropower.

Region	Hydropower in operation (MW)	Percentage of total potential hydropower (%)	Hydropower under construction (MW)	Hydropower planned (MW)	Number of countries with 50% of electricity supplied by hydropower
Africa	23,482	9.3	5,222	76,600	23
Asia	401,626	17.8	125,736	141,300	9
Europe	179,152	53.9	3,028	11,400	8
North and Central America	169,105	34.3	7,798	17,400	6
South America	139,424	26.3	19,555	57,300	11
Australasia/ Oceania	13,370	20.1	67	1,500	4

Source: Hamududu and Killingtveit, 2012

Table 1 World hydropower in operation, under construction and planned

There are 27 DFID priority countries. Table 2 gives an overview of the installed hydropower capacity in each of these countries and the percentage of electricity that has been produced by hydropower over the past 30 years. In many of these countries there is significant potential for the development of hydropower resources over the next 30 years.

Country	Current installed capacity	Electricity production from hydropower over the previous 30 years (% of the total)			
		1980	1990	2000	2010
Afghanistan	400 MW	No data	No data	No data	35.6
Bangladesh	230 MW	24.8	11.4	4.7	1.7
Burma	1.54 GW	53.5	48.1	37.0	67.7
Democratic Republic of Congo	2.41 GW	95.5	99.6	99.9	99.6
Ethiopia	2,000 MW	70.2	88.4	98.3	99.0
Ghana	1.18 GW	99.2	100.0	91.5	68.8
India	38.1 GW	39.0	24.8	13.3	11.9
Kenya	761 MW	65.0	76.6	31.6	45.7
Kyrgyzstan	2.91 GW	No data	63.5	85.9	91.8
Liberia	64 MW	No data	No data	No data	No data
Malawi	300 MW	No data	No data	No data	94.0
Mozambique	2,000 MW	65.2	62.6	99.5	99.9
Nepal	660 MW	93.5	99.9	98.4	99.9
Nigeria	6,000 MW	38.8	32.6	25.2	24.4
Pakistan	6.48 GW	58.2	44.9	25.2	33.7
Palestinian Territories	0 MW	0.0	0.0	0.0	0.0
Rwanda	55 MW	No data	No data	No data	55.0
Sierra Leone	50 MW	No data	No data	No data	No data
Somalia	5 MW	No data	No data	No data	No data
South Africa	661 MW	1.0	0.6	0.5	0.8
South Sudan	8 MW	No data	No data	No data	No data
Sudan	1,593 MW	70.0	63.2	46.0	80.0
Tajikistan	5.5 GW	No data	90.9	98.4	96.6
Tanzania	561 MW	86.4	95.1	86.4	50.4
Uganda	340 MW	No data	No data	No data	98.0
Yemen	0 MW	0.0	0.0	0.0	0.0
Zambia	1.73 GW	98.9	99.0	99.4	99.7
Zimbabwe	754 MW	88.3	46.7	37.5	73.5

Note: It is important to note that various publications have different figures for the installed capacity and the potential undeveloped hydropower potential for the same country. For consistency the figures in the table have been taken from the same source.

Source: World Energy Council, 2014; World Bank, 2014

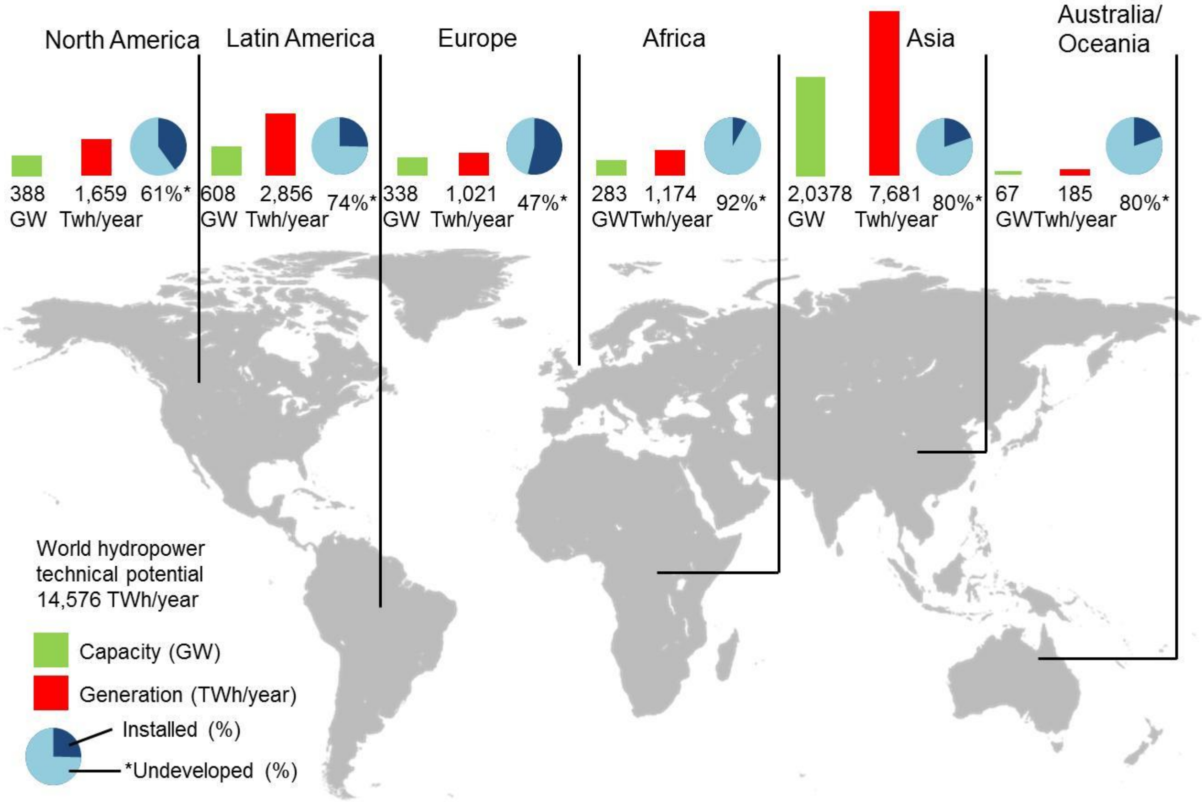
Table 2 Current installed capacity and electricity production from hydropower in DFID priority countries

2.2 Where is there potential to develop new hydropower schemes?

At the end of 2008, over 160 countries had hydropower schemes, with an estimated total of approximately 11,000 hydropower schemes worldwide (World Energy Council, 2014). Hydropower capacity is often categorised as "gross theoretical capacity", this is the capacity of hydropower generation possible if all watercourses had hydropower schemes with a 100% efficiency installed on them. The "technically exploitable capacity", which is shown in Figure 4, is the hydropower capacity possible within the constraints of current technology and local economic conditions.

Figure 4 shows that in global terms Africa has been relatively slow in taking advantage of its hydropower generation potential. Reports indicate that Africa is only using 5% to 10% of its technically viable hydropower potential (Sirte, 2008). Box 1 provides further details of countries in South Asia and Africa with significant hydropower potential.

Figure 4 Regional installed and undeveloped technically exploitable hydropower capacity



Source: Adapted from Hydroworld.com, 2013

Box 1 Examples of hydropower potential in South Asia and Africa

There is substantial untapped hydropower potential in the Ganges River Basin in South Asia. The potential value of hydropower produced in Nepal alone would be around US$5 billion annually (World Bank, 2012). One of Nepal's biggest challenges is finding ways to harness its enormous 42,000 MW of economically viable hydropower resources to stabilise and to increase power availability and drive broad and inclusive development. The currently installed capacity is 660 MW, which is 1.5% of the viable total. Of the current installed capacity, 28% is in small plants and 72% in medium sized plants. Some 28% is under private ownership and 97% is grid-connected (Molden et al., 2014).

In Africa the following countries have the most potential to become important generators of hydropower:

- Democratic Republic of Congo: The total technically feasible hydropower potential is estimated at 100,000 MW; however, only 2,400 MW has been developed. Projects currently under development include the 40,000 MW Grand Inga scheme, which will cost around US$80 billion, with an interconnection cost of US$10 billion. Construction of this facility is to be completed by 2025.
- Ethiopia: The total technically feasible hydropower potential is 37,000 MW. The Gilgel Gibe III hydropower dam is currently under construction. Once completed it will be the largest hydropower scheme in Africa with generating capacity of some 1,870 MW. Grand Ethiopian Renaissance Dam (GERD), currently under construction, will have a capacity of 6,000 MW when it is completed in July 2017.
- Cameroon: There is an estimated 23,000 MW of exploitable hydropower resources, of which only 3% is developed.
- Uganda: The hydropower potential is estimated at 3,000 MW of which only 10% has been exploited.

Source: Hydroworld.com, 2013

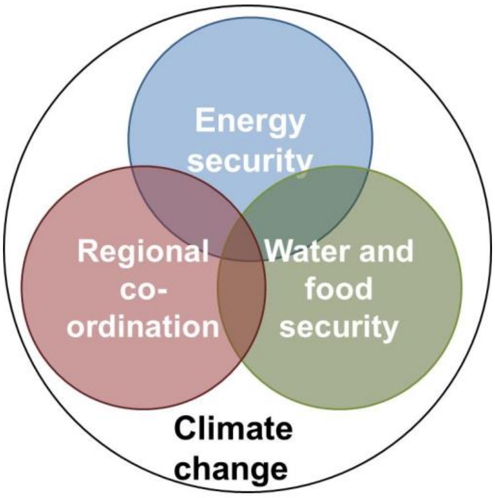
2.3 What are the drivers for developing new and improving existing hydropower schemes?

At present 1.6 billion people worldwide, mainly in low-income countries, do not have access to household electricity. In some rural areas of countries in sub-Saharan Africa access rates can be as low as 1% (Lumbroso et al., 2014; World Bank, 2009). These people mostly rely on traditional biomass, including fuel wood, which can lead to deforestation and land degradation. Reliable power supplies are essential for economic growth and provide important social and public health benefits (DFID, 2009). Investment in hydropower also offers a "hedge" against volatile energy prices and risks associated with the imported supply of electricity or fossil fuels (World Bank, 2009).

Hydropower lending from international financial institutions such as the World Bank has increased in recent years, driven by demand from low-income countries for sustainable energy sources and multi-purpose schemes that can be used for irrigation, water supply and flood management (World Bank, 2009). This follows a period of lower growth when the World Bank scaled-back investments in hydropower after the World Commission on Dams published its review of the development impacts of large dams (WCD, 2000). The World

Commission on Dams report created a lot of uncertainty around the future of dam building, but this has now largely been superceded by the drivers for increased electricity production identified above. The four main drivers for the development of multi-purpose hydropower schemes and the interactions between them are shown in Figure 5.

Figure 5 Drivers for the development of multi-purpose hydropower schemes



Developed in an appropriate way hydropower could play a key role in achieving the goal of halving global energy-related carbon dioxide emissions by 2050 (IEA, 2010) and improving access to electricity for the rural poor. The International Energy Agency (IEA) has recently set out the following future prospects for hydropower:

- Large hydropower can be a major contributor of renewable energy to the world's energy growth.
- Small hydropower will supply a growing market especially in low income countries and will also adapt technology and applications to meet new opportunities.
- Pumped storage will grow in importance as a low-cost and reliable integrator of non-firm renewables, with improved technology.

IEA, 2014

Some of the drivers and potential for developing hydropower based on evidence from the case studies undertaken as part of this study are detailed in Box 2.

Box 2 Drivers and potential for developing hydropower in Malawi, Nepal and India

Some of the drivers for developing hydropower found from the cases studies are summarised below:

- In Malawi 85% of the 15 million population live in rural areas, of which only 1% has electricity. The rural electrification programme is under-resourced and most rural areas have little hope of gaining access to grid electricity in the near future. Micro-hydropower schemes such as the Mulanje Energy Generation Authority (MEGA) based on a social enterprise model offer a means to provide affordable energy to rural customers in sub-Saharan Africa (Practical Action, 2014).
- In Nepal around 56% of the population have access to electricity (Samuhik Abhiyan, 2011). However, while excess power is produced in the coincident monsoon and snowmelt seasons, outages of 18 hours per day are common in the dry season. With an annual growth in electricity demand of 7% to 9% (Water and Energy Commission Secretariat (WECS), 2011), Nepal faces an urgent need for a more reliable electricity supply. Nepal has 42,000 MW of economically viable hydropower resources, but current installed capacity is 660 MW, only 1.5% of the viable total (Nepal Electricity Authority (NEA), 2013).

Hydropower makes up approximately 16% of India's installed generating capacity (Pargal and Banerjee, 2014). In the financial year 2011/2012 India suffered from electricity shortages of around 8.5% overall and 11% of peak demand (World Bank, 2012). More than 300 million Indians live without electricity, and those with power must cope with unreliable supply, pointing to huge unsatisfied demand and restricted consumer welfare (Pargal and Banerjee, 2014). The lack of reliable power is a leading concern for industry and a potential constraint to growth (Pargal and Banerjee, 2014). India has significant hydropower potential; however, 68% of this potential has yet to be fully harnessed. After independence India adopted a five year planning process which comprises integrated national economic programmes. Under the 11th plan (2007 to 2012) only 5.5 GW of hydropower, of a targeted 15.0 GW, was added, with most projects delayed three years or more (Pargal and Banerjee, 2014). The 12th Plan (2012 to 2017) aims to add 9 GW of hydropower capacity, 28% of this is planned to be implemented by the private sector (Pargal and Banerjee, 2014).

2.3.1 Transboundary drivers

A benefit-sharing approach has the potential to help develop strategic hydropower infrastructure that serves the needs of countries both within and outside the river basin in which the scheme is constructed. Examples could include construction of hydropower schemes in the Democratic Republic of the Congo that would be able to provide electricity to countries as distant as Egypt and South Africa or schemes in Ethiopia which could provide cheap electricity to the whole Horn of Africa region. The energy produced could also support much greater processing of raw materials within Africa, increasing added value and supporting macro-economic growth. Such developments, however, need also to deliver benefits for local communities.

2.3.2 Environmental and social impacts

Large hydropower schemes have high initial capital costs and can have significant environmental and social impacts in their vicinity and downstream. Local rural communities can be located far from electricity grids, which means they do not benefit from the electricity generated by large schemes unless this is specifically required as part of a scheme. Drivers for the construction of small and micro hydropower schemes are the generally low capital costs, less arduous planning processes and relatively short period of time before they can be operational. Evidence also suggests they can stimulate local economic development and increase energy and food security.

SECTION 3

Guiding principles of the water – energy – food security nexus

3.1 What are the guiding principles of the nexus approach to water, energy and food security?

The water, energy and food sectors have traditionally been planned and managed in isolation. To date water, energy and food security have been mainly constrained by unequal access; however, humanity is now also approaching limits of global resource availability owing to population growth and unsustainable development (SEI, 2011). This has led consideration of the interdependencies between the three sectors to become more relevant. A nexus approach involves integrating the management of the three sectors, taking account of the trade-offs and synergies between them and aiming to maximise the benefits across the whole system. Such an approach is required to support the transition to a green economy, which aims at resource use efficiency and greater policy coherence (SEI, 2011). There is much work to do in order to achieve water, energy and food security for all the world's people. In hotspot regions such as South Asia and sub-Saharan Africa, large portions of the population remain marginalised and deprived of their human rights and development opportunities (SEI, 2011).

The following guiding principles are central to the nexus approach:

- Investing to sustain ecosystem services.
- Creating more with less.
- Accelerating access, integrating the poorest.

Figure 6 shows the water - energy - food security nexus. According to Jägerskog et al. (2013) *"The Water – Energy – Food nexus can be assessed using methodologies in a continuum, running from qualitative approaches at the start of the continuum, to more data driven and quantitative modelling approaches further along it. A range of factors can determine which approach is chosen, including the goal of the analysis, the level of capacity and trust between competing stakeholders at different scales, sectoral integration, access to data, and capacity for analysis.*" (Jägerskog et al. 2013).

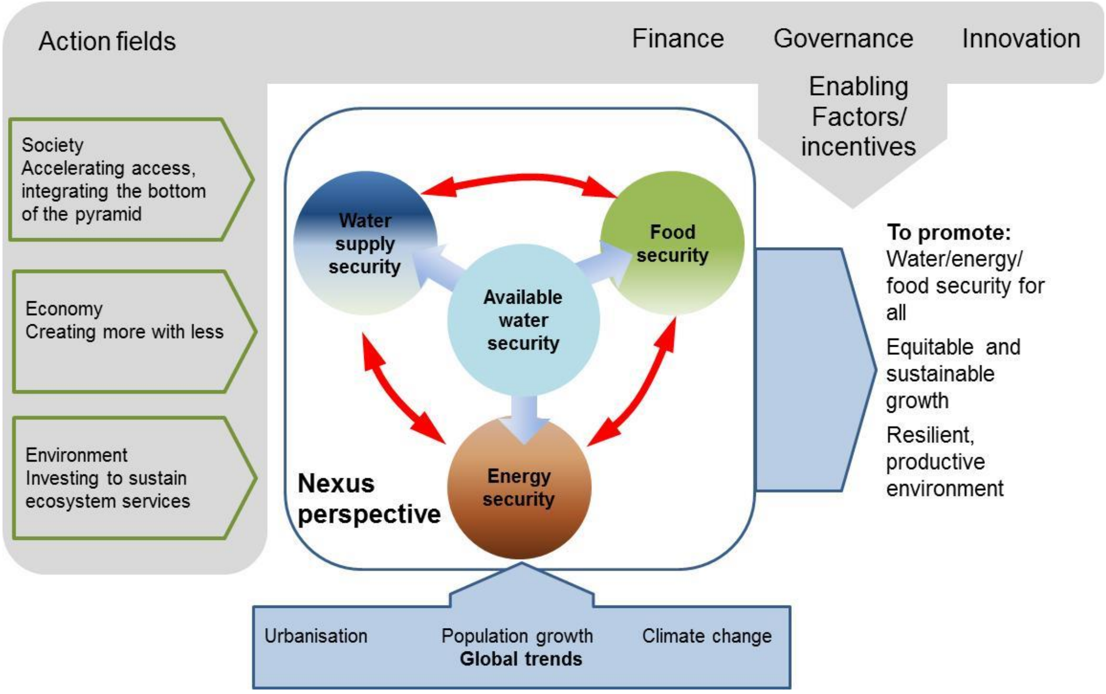
3.2 How can hydropower performance be assessed in the context of the water – energy – food security nexus?

In many river basins hydropower and multi-purpose dams play an important role in the water – energy – food security nexus as integrators and potentially optimisers of the water resources system for greater sustainability. Examples of interactions include:

- Water is used to drive turbines of hydropower schemes, as well as to cool thermal power plants.
- Water and energy are important inputs to agriculture, especially irrigated agriculture, that contribute to food security.
- Energy availability and prices affect the costs of treating drinking and wastewater.

- Biofuel crops can compete for land and water with food crops, impacting on both energy and food security.

Figure 6 The water – energy – food security nexus



Source: Adapted from SEI, 2011

Specific interactions between hydropower schemes and other uses of water and land include:

- Increased consumption of water upstream of a hydropower dam for irrigation or major public water supplies may reduce the amount of power which can be generated.
- Large hydropower schemes alter the hydrological flow regime of a river. This can have a negative impact on ecosystem services and stakeholders who depend on downstream flows (e.g. for flooding of agricultural land with water and nutrients, or to maintain productive fisheries).

3.2.1 Assessing the sustainability of dams

In 1998, in the face of escalating pressure, the World Commission on Dams (WCD) was established by the World Bank and the International Union for Conservation of Nature (IUCN) to review the development effectiveness of large dams. Through the publication of its final report in 2000 (WCD, 2000) it established a comprehensive set of guidelines for the design, implementation, and operation of dams, including hydropower dams, and their decommissioning. The hydropower industry initially rejected the specific recommendations of the WCD but has moved to a position of pro-actively moving towards sustainability guidelines which it feels should provide a degree of predictability (of outcomes and costs) to the planning and construction of hydropower or multi-purpose dams (Bosshard, 2010).

The International Hydropower Association (IHA) first developed Sustainability Guidelines for hydropower development in 2003. This led to a Sustainability Assessment Protocol in 2006 and later the Hydropower Sustainability Assessment Forum (HSAF) – a process aimed at further developing the Protocol in partnership with governments, NGOs and the financial sector. This represents an attempt to take ownership of the need to change the industry, increasing potential performance of the sector in the future (Locher et al., 2010). Since 2008, IHA has been training assessors to use the protocol in assessing proposed developments.

In 2011 the International Hydropower Association's (IHA) Hydropower Sustainability Assessment Protocol was launched (IHA, 2012). The protocol is a tool for measuring the environmental, social, technical, financial, and economic aspects of a hydropower project's performance. It was developed by a multi-stakeholder forum featuring representatives from industry, civil society, donors, developing country governments and the finance sector over a three-year period (IHA, 2012). This has the potential to be used to assess hydropower performance in the context of the water – energy – food security nexus; however, it does not appear to be being widely used to assess hydropower schemes in low income countries. IHA has recently received Norwegian funding to demonstrate the IHA Sustainability Assessment Protocol in three low income countries or river basins (IHA, 2014).

There has been some criticism levelled at the IHA Hydropower Sustainability Assessment Protocol since the inception of its development in 2006. The main one is that unlike the recommendations of the World Commission on Dams the IHA protocol does not define any clear minimum standards that dam developers must comply with or rights that must be respected (Lawrence, 2009; Bosshard, 2010). Further issues are summarised below:

- A catchment-wide approach to decision-making on water and energy projects is not required (i.e. the protocol works on a site or project level).
- There is no need to provide access to information and legal support for stakeholders.
- There is no obligation to include a clear compliance framework, which is subject to independent review, that includes both sanctions and incentives with necessary costs built into the project budget.
- Many of the principles of the IHA protocol are not measurable.
- It requires consulting with dam-affected populations without conferring any rights on them
- There is no requirement to comply with binding standards, laws or international conventions

Source: Lawrence, 2009 and Bosshard, 2010

The World Bank has recently published a review of the Hydropower Sustainability Assessment Protocol providing recommendations on its usage (see Liden and Lyon, 2014). The main findings of this review were that:

- The protocol is a useful tool for guiding the development of sustainable hydropower in low-income countries.
- It is suitable for the identification of areas of improvement in hydropower projects in a variety of localities and at various stages of project development.
- The Protocol could potentially be used in capacity building, however the tool's manuals are complex and insufficient. A training programme should be built around them, including other materials relevant to the topic of sustainable hydropower.
- The Protocol has a range of other potential uses, including incremental improvement in project components and providing a transparent framework for stakeholder dialogue and conflict resolution.
- Assessor experience and training are essential in maintaining the quality and consistency of assessments and capacity building. Given the Protocol documents' complexity and the extreme site-specificity of hydropower development, the use of Accredited Assessors having participated in previous assessments is essential for quality assurance. Despite the rigid methodology of the Protocol, assessor judgment

and discretion is very important for the scoring of topics, especially when dealing with overlapping issues and the double counting of gaps.

Source: Liden and Lyon, 2014

Box 3 gives an example of assessing the water – energy – food security nexus in Malawi.

Box 3 Assessing the water – energy – food security nexus in Malawi

Owing to Malawi's water resources system being primarily focussed on Lake Malawi, its tributaries and the downstream Shire River, there is potential for conflicts to emerge between different uses and users of this system. In 2009, the Malawi government announced the Green Belt Initiative (GBI) that enables large scale local and foreign investors to get land concessions for agricultural irrigation around Lake Malawi that extends from the northern most to the southern most point in Malawi (Semu, 2013). The GBI is targeting a coverage of about one million hectares compared with the 96,000 ha currently under irrigation (CISANET, 2014). Trade-offs exist between different uses of water and it is important to understand these in order to make best use of available resources at basin scale, ensuring sustainability of environmental and social systems. Consideration of the broader impacts of any development may improve sustainability and could foster increased cooperation locally, regionally and internationally.

SECTION 4

Hydropower performance

4.1 How can the performance of different types of hydropower schemes be assessed?

There are a variety of measures that can be used to evaluate the performance of hydropower schemes. A number of authors and organisations including: World Commission on Dams (WCD) (2000); International Hydropower Association (IHA) (2012); March et al. (2008), Krahenbuhl (2008), United States Department of Energy (2011), Vovk-Korže et al. (2008); Jha et al. (2007) have proposed ways in which the performance of hydropower schemes can be measured or assessed. The measures can generally be classified under the following headings:

- Power generation.
- Economic measures such as cost - benefit analysis and internal rate of return.
- Tariff levels.
- Social impacts.
- Environmental impacts.
- Water use.
- Greenhouse gas emissions.

These are detailed below.

4.1.1 Power generation

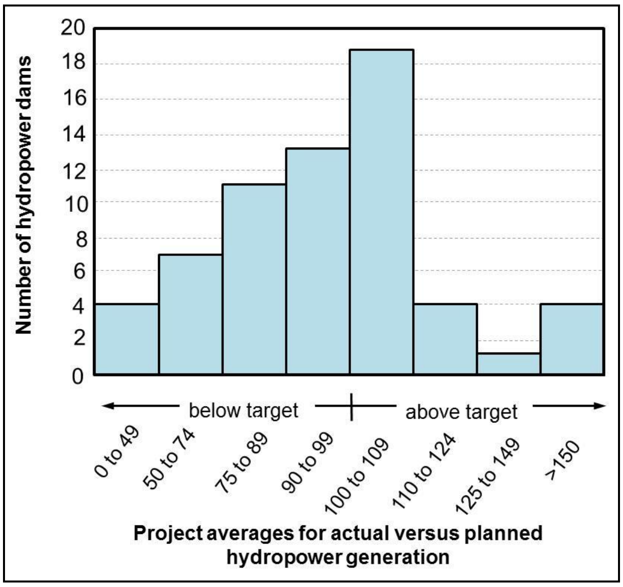
Power generation is one variable against which the performance of hydropower schemes can be measured. However, there have been few studies that have looked at hydropower schemes worldwide with respect to their power generation performance. In 2000 the World Commission on Dams (WCD) considered the power generation performance of 63 large hydropower dams worldwide (WCD, 2000).

The variance in performance with respect to power generation across the schemes was high, as shown in Figure 7. On average, almost 50% of the sample exceeded the set targets for power generation, with about 15% exceeding targets by a significant amount. Figure 7 also shows that around 20% of the schemes in the sample achieved less than 75% of the planned power targets and that over 50% of the projects in the sample fall short of their power production targets (WCD, 2000). Thus the average performance in the sample is sustained by a few over-performers and should not mask the variance in performance that is weighted towards shortfalls in power delivery (WCD, 2000).

Delays in the construction phase of projects, in reservoir filling (e.g. because rainfall was lower than average) and in installing and bringing turbines on-line often explain shortfalls in performance of power generation in the first few years of operation of hydropower schemes (WCD, 2000). For example, Tarbela Dam in Pakistan experienced major structural damage in commissioning trials that led to a two year loss of power generation (WCD, 2000).

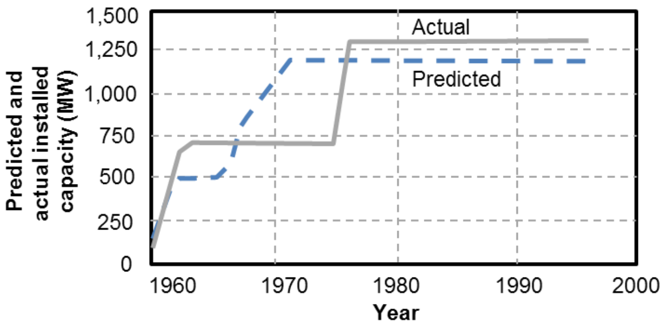
The WCD carried out a number of case studies one of which was for the Kariba Dam hydropower scheme on the Zambezi River in southern Africa. Figure 8 shows the actual and forecast installed capacity and power generation for Kariba Dam. It can be seen that installed capacity has exceeded the forecast installed capacity, mainly as a result of additional capacity being installed after the scheme was completed. The effect of drought years can be easily seen in the large swings in annual power generation from Kariba Dam, particularly over the last two decades.

Figure 7 Project averages for actual versus planned hydropower generation

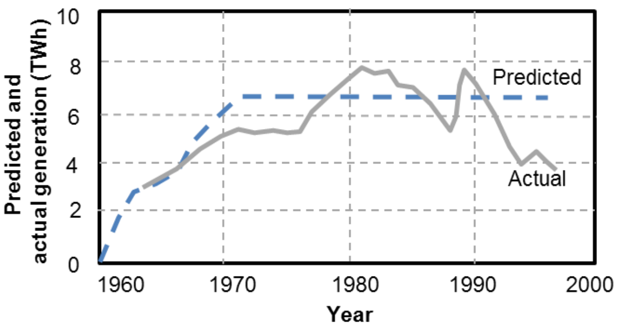


Source: Adapted from WCD, 2000

Figure 8 Actual and forecast installed capacity and power generation for Kariba Dam



View a Kariba – Predicted and actual installed capacity



View b Kariba – Predicted and actual power generation

Adapted from WCD, 2000

Box 4 gives examples of the performance of hydropower schemes in terms of their power generation from Nepal and India.

Box 4 Examples of hydropower generation performance from Nepal and India

The case studies found that some run of river hydropower schemes in Nepal are operating below maximum power generating capacity owing to turbine damage caused by sediment, cavitation[2] or a lack of maintenance (Hurford et al., 2014c). In Himachal Pradesh in India annual flushing of sediment trapped behind the dams is carried out so that there is little or no impact on overall power generation performance as a result of a reduction in storage volume behind barrages and dams (Hurford et al., 2014a).

India's largest hydropower scheme, the 1,500 MW Nathpa Jhakri run of river plant on the Sutlej River was completed in March 2004. The Central Electricity Authority (CEA) reported that the power generated in 2006/2007 was reduced owing to the high silt content in the Sutlej River flows during the monsoon (CEA, 2007). Following below target performance in the two years immediately after it was commissioned, the plant has recently generated more energy than expected, consistently exceeding its targets. This is reported to be due to higher than expected flows on the river (Case study consultee, 2013).

2 The formation and collapse of air bubbles on the surface of submerged turbine blades owing to low pressure effects within the moving water, leading to damage over time.

4.1.2 Economic measures

Economic performance of a hydropower project is often measured via an economic appraisal that takes into account the costs and benefits of the scheme, denominated in monetary terms. The Economic Internal Rate of Return[3] (EIRR) is often used to assess the performance of planned and constructed hydropower schemes (World Bank, 2009; WCD, 2000). Hydropower dams appear to meet pre-determined economic targets more than irrigation dams based on the knowledge base compiled by the World Commission on Dams (WCD). Almost 50% of the projects within the knowledge base exceeded targets (Lindström and Granit, 2012). Forbes recently reported that the world average EIRR for hydropower was 7% to 8%; however, in China they are generally 15% (Forbes, 2011).

There are also cases where outputs are lower than expected, with 5% of examined hydropower dams in the WCD knowledge base falling well below expected outcomes. The reasons for lower than expected results differ. In general, the time for hydropower dams to reach expected outcomes are shorter than with irrigation dams, averaging 80% of the expected capacity reached within the first year of operation (Lindström and Granit, 2012). This subsequently increases in years two-to-five to come close to 100% realisation of expected targets (Lindström and Granit, 2012).

Regarding the profitability of hydropower dams, conclusions can be drawn from a variety of case studies performed by the WCD. Even if a number of projects fall short of predicted targets very few projects can be considered economically unprofitable (WCD, 2000). The number of projects falling slightly short of planned profitability is matched by a number of projects that outperform their original estimates of profitability, with specific projects reaching respectable EIRR values even after decades in operations (WCD, 2000). The Kariba dam located on the border between Zambia and Zimbabwe on the Zambezi river basin, which boasts an EIRR value of 14.5%, is a prime example (Lindström and Granit, 2012).

A recent paper by Ansar et al. (2014), based on a sample of 245 large dams of a total 50,000 world wide (according to Nombre, 2014) concluded that large hydropower projects experience cost and time over runs with low EIRRs and that "*in most countries large hydropower dams will be too costly in absolute terms and take too long to build to deliver a positive risk-adjusted return*" (Ansar et al., 2014). Ansar et al., concluded that small projects are to be preferred to large ones. The small sample of hydropower schemes used by Ansar et al. and the fact that this sample appears to be biased towards certain hydropower projects with large overruns (see Nombre, 2014) means that the conclusions of this paper are unlikely to be justifiable (see Water and Dam Construction, 2014; ICOLD, 2014).

4.1.3 Tariff levels

One common factor identified in the case studies in India, Malawi and Nepal as hindering the performance of the sector was the setting of electricity tariffs for full cost recovery (see Hurford et al., 2014a, b, c). The structure of the energy sector in many countries dictates that tariffs which can be charged by utility companies are set by a separate regulatory authority. Public utilities with generating capacity, as well as transmission and distribution responsibilities, generally do not recover their full costs at these tariff levels. Private power producers then suffer from the integrated public utility's lack of financial capacity to honour power purchase agreements. For the public utility there are also no funds to be invested in

[3] The EIRR is the discount rate that makes the net present value of all cash flows from a particular project equal to zero. Generally speaking, the higher a project's internal rate of return, the more desirable it is to undertake the project.

maintenance or new infrastructure. This is the single biggest issue in current hydropower performance at individual plant and sector-wide levels (see Hurford et al., 2014a, b, c).

This study uncovered few examples of innovative pricing mechanisms to ensure full cost recovery without penalising the poor, although tariff reviews were said to be needed in all the case study countries (see Hurford et al., 2014a, b, c). Tariffs could be set to provide an initial low cost to all, with increasing prices for increasing quantities consumed beyond this. Pricing could also vary by time, or with smart-metering directly in relation to demand, to encourage a more even load distribution through the day, week or year. Demand management such as this and the use of energy efficient technologies could reduce the need for additional peak demand capacity. This could potentially allow hydropower facilities to be used to increase the available base load. Peak power generation can trade off against base load or firm energy[4] generation owing to the different use of the same volume of water (Hurford and Harou, 2014).

4.1.4 Social impacts

The performance of hydropower schemes, in terms of social impacts can be measured by the following:

- Size of the involuntary population displacement and how, if this has to take place, the effects can be ameliorated.
- The number of affected people and vulnerable groups especially with respect to groups that might be considered vulnerable with respect to the degree to which they are marginalised or impoverished and their capacity and means to cope with change.
- Changes in public health as a result of any development.
- Loss or protection of cultural heritage.
- Sharing of development benefits.

Box 5 details ways in which some of the social impacts of hydropower schemes are ameliorated in Nepal and Himachal Pradesh.

Box 5 Dealing with social impacts of hydropower schemes in Nepal and Himachal Pradesh, India

In Nepal since 1999 the government shared 10% of royalties from electricity sales to District Development Committees in the District where the hydropower scheme is located in order to assist in compensating families affected by the project (Ministry of Law and Justice, 1999; Ministry of Federal Affairs and Local Government, 1999). In 2004 this increased to 12% of the royalties. In addition 1% of royalties are shared with Village Development Committees to promote rural electrification (WaterAid, 2014). It was not prossible for this study to verify the impacts of these royalty schemes.

In Himachal Pradesh, India hydropower developers face challenges with obtaining the approval of local communities for their schemes and an increasing array of charges levied by the state government aiming to counter negative social and environmental impacts:

- IPPs are required to deposit 1% of project capital expenditure with the Local Area Development Fund to be used for local infrastructure projects.

4 The amount of energy reliably generated at a specified percentage reliability level, required by a specific system.

- A 2.5% levy is charged for Catchment Area Treatment (CAT), i.e. catchment improvement.
- A further 1% of operating revenue must be provided as a cash incentive to project affected families, for the lifetime of the project.

In relation to the acquisition of land for hydropower development, the Indian Land Acquisition Act, 2013 requires an expert group to assess whether:

- The project will serve any public purpose.
- The potential benefits outweigh the social costs and adverse social impacts.
- The amount of land required is the bare-minimum for the project.
- There are any other options which would displace less people.

Where the land acquired totals more than 100 acres, a Resettlement & Rehabilitation (R&R) Committee will be formed to monitor and review progress of the R&R scheme implementation. The Committee must include women, all castes represented in the area affected, a voluntary organisation working in the area, a nationalised bank representative, the Member of Parliament for the area concerned, the chair of the local planning committee, the land acquisition officer and the chair of the communities.

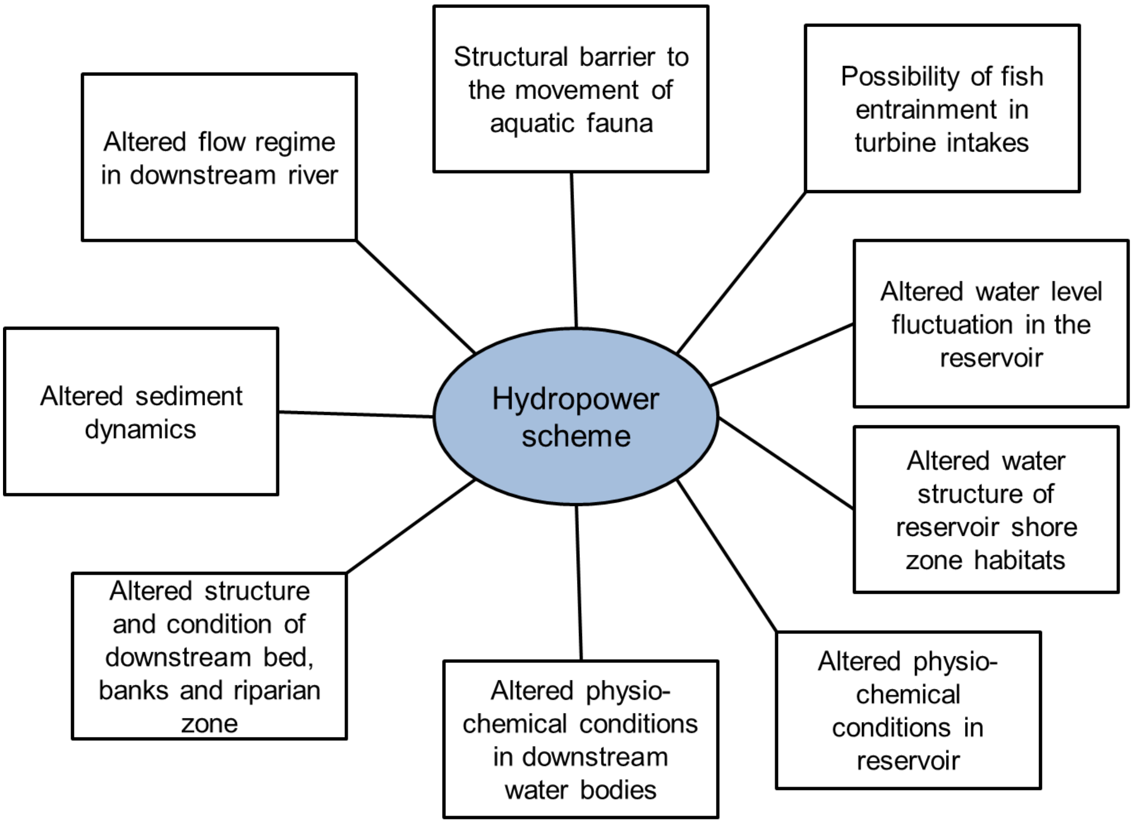
4.1.5 Environmental impacts

The main environmental impacts of hydropower schemes are summarised in Figure 9. With respect to new dams the most effective environmental mitigation measure is good site selection, to minimise the potential impacts in the first place (NHA, 2010). In general, the most environmentally benign hydropower dam sites are on upper tributaries, while the most problematic ones are on the large rivers further downstream of the headwaters (Ledec and Quintero, 2003).

Ledec and Quintero (2003) present a number of quantitative, easily calculated indicators that are especially useful for hydropower scheme site selection from an environmental point of view, which have a high predictive value for likely adverse environmental impacts. These indicators are summarised below:

- **Reservoir surface area** – The area flooded by the reservoir is a strong proxy variable for many environmental impacts (Goodland, 1997). A useful measure of environmental costs relative to economic benefits is the ratio of inundated hectares per Megawatt (ha/MW) of electricity. The global average for large hydropower dams constructed is about 60 ha/MW (Ledec and Quintero, 2003).
- **Water retention time in reservoir** – Mean water retention time during normal operation (the shorter, the better) is very useful in estimating the extent to which reservoirs will have long-term water quality problems.
- **Flooded biomass** in terms of tonnes per hectare.
- Length of river impounded.
- **Length of river left dry** – This is the length of river left dry (i.e. with less than 50% of dry season mean flow) below the dam as the result of diverting water.
- **Number of undammed, downstream tributaries** – The more large, undammed tributaries downstream of the dam site, the better, in terms of limiting environmental damage.

Figure 9 Overview of the environmental impacts of hydropower schemes



Source: Adapted from Vovk-Korže et al., 2008

- **Likelihood of reservoir stratification** – This occurs when the lake's upper zone is thermally divided from the deeper zone and the latter becomes stagnant and lacking in dissolved oxygen, making it unsuitable for most aquatic life (Ledec and Quintero, 2003).
- **Useful reservoir life** – This is the expected number of years before a reservoir's dead storage is completely filled and sediment commences to fill the live storage.
- **Extent of access roads through forests.**
- **Area of critical natural habitats affected.**
- **Fish species diversity and endemism** – Fish species diversity is the number of species known from the project area, including the dam and reservoir site, as well as the downstream zone of dam. Fish species endemism is the number of native species located only in the project area, or the river system where the project is located, and nowhere else on earth (Ledec and Quintero, 2003).

Box 6 provides an illustration of three large hydropower projects that have had contrasting environmental impacts. Box 7 provides an overview of the environmental impacts of hydropower schemes in the Himalayas.

Box 6 Contrasting environmental impacts of three large hydropower projects

The 500 MW Pehuenche hydropower scheme in Chile flooded only about 400 ha of land, with minimal damage to forest or wildlife resources, and has had no water quality problems. The Brokopondo Dam in Suriname inundated about 160,000 ha of biologically valuable tropical rainforest and has had serious water quality and aquatic weed problems, while providing relatively little electric generating capacity (i.e. around 30 MW) (Ledec and Quintero, 2003)

The Nathpa Jhakri Dam is a concrete gravity dam on the Satluj River in Himachal Pradesh, India. The primary purpose of the dam is to supply 1,500 MW of electricity. Construction commenced in 1993. In 2002 the World Bank carried out an Implementation Completion Report for the project from which Schneider (2005) reported that: "*No Environmental Assessment was carried out before appraisal of the project by the World Bank. The Environmental Assessment that was finalised later did not cover the entire project area, nor did it examine the majority of the substantial environmental impacts. The implementation of the Environmental Management Plan remained unsatisfactory up to 2002*" (Schneider, 2005).

Box 7 A summary of the environmental impacts of hydropower schemes in the Himalayas

A review of the environmental impacts of planned hydropower schemes in the Himalayas by Pandit and Grumbine (2012) reported that:

- Nearly 90% of Indian Himalayan valleys would be affected by dam building and 27% of these dams would affect dense forests.
- Around 54,000 ha of forests would be submerged and 114,400 ha would be damaged by dam-related activities.
- Most dams would be located in species-rich areas of the Himalaya. By 2025, deforestation as a result of dam building would likely result in extinction of 22 flowering plant (angiosperm) and seven vertebrate taxa.
- Disturbances as a result of dam building would likely reduce tree species richness by 35%, tree density by 42%, and tree basal cover by 30% in dense forests.

These results, combined with relatively weak national environmental impact assessment and implementation, point toward significant loss of species if all proposed dams in the Himalaya are constructed (Pandit and Grumbine, 2012).

4.1.6 Water use

A water footprint of a product or service is a comprehensive measure of freshwater consumption that connects consumptive water use to a certain place, time, and type of water resource (Dourte and Fraisse, 2012). A water footprint accounts separately for three types of freshwater consumption:

- Green water use, which is consumption from rainfall.
- Blue water use, which is consumption from groundwater or surface water.

- Grey water use, which is the water required to reduce pollutant concentrations to acceptable levels.

Mekonnen and Hoekstra, 2012; Dourte and Fraisse, 2012

The water footprint of hydropower schemes can relate to the blue water and grey water use to produce a given unit of electricity. Blue water is evaporated from the surface of storages behind dams and water can change its chemical composition and temperature significantly as a result of storage and different layers forming within the stored water. The latter can constitute pollution of the water when it is released from the storage and represents grey water use.

Mekonnen and Hoekstra (2012) carried out research to assess just the blue water footprint of hydropower schemes, for 35 selected sites worldwide. The aggregated blue water footprint of the selected hydropower plants was 90 Gm^3/year, which is equivalent to 10% of the blue water footprint of global crop production in the year 2000 (Mekonnen and Hoekstra, 2012). The total blue water footprint of hydropower generation in the world is considerably larger if one considers the fact that Mekonnen and Hoekstra's study covered only 8% of the global installed hydropower capacity (Mekonnen and Hoekstra, 2012). The water footprint for hydropower schemes in some low income countries is given in Table 3.

Scheme	Reservoir area (ha)	Installed capacity (MW)	Evaporation (mm/year)	Water footprint (m^3/MWh)	
				For theoretical max energy production	For actual energy production
Akosombo-Kpong, Ghana	850,200	1180	2,185	1,796	3,046
Cahora Bassa, Mozambique	266,000	2075	3,059	446	670
Itezhi Tezhi, Zambia	37,000	600	2,572	181	340
Kariba Zambia-Zimbabwe	510,000	1320	2,860	1,260	2,279
Kiambere, Kenya	2,500	150	2,356	45	65
Kulekhani, Nepal	2,000	60	1,574	60	169

Source: Adapted from Mekonnen and Hoekstra, 2012

Table 3 Blue water footprint for selected hydropower schemes in DFID priority countries

Mekonnen and Hoekstra (2012) note that their results were sensitive to both temperature and surface area of the reservoir, with almost a 1:1 relationship between change in these input variables and the water footprint. This highlights the difficulty in accurately estimating water footprints and how they could be affected by climate change and modes of operation of a hydropower or multi-purpose dam (resulting in different storage levels and therefore surface areas). Hurford and Harou (2014) investigate the trade-offs between different uses of water resulting from re-operation of a cascade of hydropower dams in Kenya, but choose not to include (blue) water footprint as a metric of performance. The meeting of irrigation, environmental and municipal demands was considered an effective surrogate which ensured no water was 'wasted' through evaporation. The water footprint of hydropower generation could be of less concern under circumstances where other demands are being met or trade-offs are being considered between significant demands on a basin (Hurford, pers. comm.).

This study recommends the following should be taken into account during the planning stage of hydropower schemes:

- Assessing the water footprint is an additional consideration when evaluating the environmental, social and economic sustainability of a proposed hydropower scheme (Demeke et al., 2013). It would allow hydropower schemes to be more easily compared with other power generation options, as well as other competing water uses.
- The water footprint of hydropower schemes should be studied in the context of the river catchment in which this water footprint occurs, because competition over water and possible alternative uses of water (e.g. irrigation, water supply) differ per catchment. For basin scale analysis, water footprinting may be less relevant if all major demands are considered simultaneously.

4.1.7 Greenhouse gas emissions

Hydropower is often cited as a green form of energy; however, some researchers believe that "*the clean, green image of dams may have been seriously overstated*" (Giles, 2006). In 1993 Rudd et al. were amongst the first researchers to postulate that hydropower schemes that utilise large reservoirs release significant amounts of greenhouse gases, especially in their early years of operation following the impoundment of the reservoir (Rudd et al., 1993). Lima et al. (2008) estimated reservoirs in the tropics could be contributing an additional 30% to existing estimates of global methane emissions. Greenhouse gases can be generated by decay of standing and inflowing biomass and stratification of the water body (St Louis et al., 2000; Giles, 2006; Fearnside, 2002 and 2004). They are emitted from the surface, by bubbling up from the sediments or through sudden pressure changes during turbine operations or other releases (St Louis et al., 2000; Giles, 2006; Fearnside, 2002 and 2004).

Although the researchers disagree on the amount of greenhouse gases emitted from large hydropower storage schemes in relation to other energy sources, they do agree that greenhouse gas emissions from tropical reservoirs can be significant. There also appears to be agreement that greenhouse emissions are correlated to reservoir age and latitude, with the highest emission rates from the tropical Amazon region (Barros et al., 2011). Thus future emissions will be highly dependent on the geographic location of new hydropower reservoirs (Barros et al., 2011).

As part of the Kyoto Protocol a Clean Development Mechanism (CDM) was initiated. This is a project-based mechanism that allows industrialised countries to generate emission reduction credits through projects in developing countries (Mäkinen and Khan, 2010). Hydropower is the most popular type of CDM project (Talberg and Nielson, 2009). An overarching requirement of the CDM is that project activities must help host countries to achieve sustainable development and contribute to the overall objective of the United Nations Framework Convention on Climate Change (UNFCCC) of reducing greenhouse gas concentrations in the atmosphere.

One of the main conditions of CDM funding is the principle of 'additionality', meaning it should not be available to projects which are profitable investments in their own right. CDM funding should only be used to support investment in low carbon technologies such as hydropower where this is not a profitable proposal. This is difficult to assess however, and leads to much of the CDM's reserves being consumed by large already profitable schemes (Pittock, 2010). Pittock (2010) also reports that CDM grant conditions conflict with the Convention on Biological Diversity and Ramsar Convention on Wetlands, allowing negative environmental impacts to be inadvertently promoted (Pittock, 2010).

In February 2006, the CDM Executive Board ruled that hydropower projects in the large-scale category must satisfy certain "power density" conditions in order to be eligible as CDM project activities (Mäkinen and Khan, 2010). The power density is defined as the installed generation capacity divided by surface area of the hydropower reservoir. Table 4 summarises the power density thresholds put in place as a precautionary measure whilst clarification of the magnitude of reservoir greenhouse emissions is established.

Power density of hydropower scheme (W/m^2)	**Eligibility to use approved methodologies under CDM rules**
<4	Excluded from using currently approved methodologies
4 to 10	Allowed to use approved methodologies but project emissions must be included at 90g CO_2 equivalent per kWh
>10	Allowed to use approved methodologies and project emissions can be neglected

Source: Mäkinen and Khan, 2010

Table 4 Restrictions on hydropower projects under the Kyoto Protocol Clean Development Mechanism (CDM)

There is limited scientific evidence underpinning these restrictions and associated guidance and further research is needed, including the consideration of multi-purpose reservoirs. Recent research has increased our knowledge of emissions from freshwater reservoirs (St Louis et al., 2000, Giles, 2006, Fearnside, 2004) but debate continues around net emissions, which must be calculated from an estimate of the emissions which would have occurred even if the water wasn't impounded – natural lakes and rivers emit GHGs also. Unfortunately, much of the research published on the topic has been produced by researchers connected to the hydropower industry, leading to questions about its objectivity (Mäkinen and Khan, 2010). Policy on reducing these emissions is largely held up by the scientific uncertainties.

Emissions from reservoirs are not currently reported as a mandatory requirement under the United Nations Framework Convention on Climate Change, which uses IPCC guidelines. They are however recognised as an area for future inclusion in the Good Practice Guidance. The issue is that standard methodologies have yet to be developed to allow these emissions to be reliably measured.

It is important to note that since 2011 global carbon markets have shrunk in value by 60%. This has affected the UN's "flexible mechanisms", including the Clean Development Mechanism (CDM) (Redd-Monitor, 2014). The UN flexible mechanisms now account for 1% of the value of the world's carbon markets and investment in new CDM projects has ground to a halt (Redd-Monitor, 2014).

4.2 What factors affect the performance of different types of hydropower schemes?

There are a number of factors that affect the performance of hydropower schemes including:

- Funding mechanisms and the role that public and private finance plays.
- Physical and environmental factors including: hydrology; sedimentation; climate variability.
- Climate change.
- Operation and maintenance.

- Type of scheme i.e. single purpose versus multi-purpose schemes.

4.2.1 Funding mechanisms and ownership

This work found no studies offering a direct meaningful comparison between the performance of publicly and privately sponsored hydropower projects. There are a number of barriers to making a meaningful comparison which include:

- Private sponsors gravitate towards smaller, less risky, run of river projects, leaving larger projects involving storage predominantly under public ownership, management and financing.
- Each major dam project has unique features and factors which make comparisons difficult, and weakens the credibility of any lessons drawn. The larger the project, the more “unique” it is likely to be.
- Public regulators invariably take a close interest in private operators, and have a major influence on the performance of the project (e.g. through tariff controls, environmental restrictions, overriding operational protocols at times of drought or flooding). South Africa’s power problems in recent years is a result of government indecision and policy reverses, which have discouraged private entry into a sector still dominated by the parastatal ESKOM (World Bank, 2010).
- For major storage schemes the allocation of risks between the different parties can have a big influence on performance (Head, 2000).

The World Commission on Dams (WCD) analysed the performance of major dams, based on eight detailed case studies, wholly in the public sector, and literature searches of other cases. It should be noted that this report contains no acknowledgement of private finance or operation in major dam construction and operation. The WCD found that large dams demonstrated a tendency towards schedule delays and cost overruns (WCD, 2000). This has knock-on effects in terms of undermining the financial viability of dams or efforts to recover costs through tariffs. The average cost overrun of 81 large dam projects which the WCD scrutinised was 56%. Of the total sample, one quarter of the dams achieved less than planned capital cost targets whilst almost three quarters had cost overruns (WCD, 2000).

It may be significant that multi-purpose, rather than single purpose, dams showed particularly high variability in achieving their performance targets. The average cost overrun was 63% for the 45 multi-purpose projects, three times that of the single-purpose hydropower dams in the sample. The category of single purpose dams most prone to overrun was water supply dams, the average for which was twice that of single purpose irrigation or hydropower dams. WCD’s conclusion was that single purpose hydropower dams performed well in terms of cost overruns (WCD, 2000).

Within the power sector, hydropower has tended to have minority appeal to private generators, typically accounting for 5% or less of new private power projects, compared with 90% or more of privately financed projects that are fossil-fuelled (Head, 2004).

Private financial involvement in hydropower projects has always been on a smaller scale than publicly sponsored and financed schemes. For large hydropower projects in 2012, 15,509 MW of projects with private participation reached financial closure in developing countries, with total project costs of US$21.15 billion. For small hydropower projects, the corresponding figures were 1,113 MW to a value of US$1.25 billion. In both cases, Brazil accounted for most of the activity (PPIAF, 2013).

Within hydropower, public and private sponsors gravitate to different modes of supply. The bulk of private schemes are run of river projects, smaller and less risky in terms of investment than large projects involving stored water. Typical of this is one of the latest private hydropower projects in Pakistan, from the Hub Power Company, an 84 MW run of river, low head, project starting in March 2013 (PPIAF, 2013). Of the 10 hydropower projects with private participation analysed by Head (2000), six are run of river schemes, the remainder involving storage. Three of the projects are of the IPP variety. The largest project, a storage scheme, has 1,455 MW capacity.

4.2.2 Physical and environmental factors

The three main physical and environmental factors that affect the performance of hydropower schemes are the following:

- The hydrological regime.
- Sedimentation.
- Aquatic weeds

The performance of hydropower schemes is directly linked to the hydrological regime of the catchment in which they are located. Understanding the future hydrological characteristics of catchments is becoming ever more difficult because as a result of climate change it is no longer valid to assume that the future runoff will have the same statistical characteristics as past runoff (i.e. stationarity) cannot be assumed into the future (see Milly et al., 2008).

Between 0.3% and 1.0% of the storage volume of the world's reservoir is lost annually owing to sediment deposition (Mahmood, 1987; Morris and Fan, 1998; Basson, 2005). The annual construction costs to replace this loss in storage capacity have been estimated to be around US$13 billion per year and the associated environmental and social impacts would be significant (Palmieri, 2003). In 2000 the World Commission on Dams (WCD) reported that a survey of dams older than 25 years showed that 10% of the projects had lost 50% or more of their live storage volume owing to the deposition of sediment (WCD, 2000). The Tarbela Dam in Pakistan has experienced capacity reduction of 30% over the 40 years since it was commissioned (Roca, 2012) and plans are being made for upstream reservoirs simply to intercept sediment which will require substantial investment. In the case of the Kindaruma hydropower dam in Kenya, it is recognised that the associated storage has lost so much capacity to sediment that it would be cheaper to build a new dam than dredge the existing one. This is likely to be a common situation. A major issue associated with dredging the dam would be finding a site to deposit dredged sediment and the transportation to get it there (Hurford, pers. comm.).

Climate change will lead to changes in sediment loads owing to modifications to the hydrological regime and an increase in flood events when the majority of sediment is deposited (Kumar et al., 2011). An increase in sediment load will have an adverse effect on hydropower performance by:

- Increasing turbine abrasion and decreasing their efficiency.
- Reducing the live storage of reservoirs more quickly than originally envisaged.
- Reducing the degree of regulation and decreasing storage services.

Kumar et al., 2011

The proliferation of aquatic weeds, such as water hyacinth, in many countries has largely been attributed to water being enriched with phosphorous and nitrogen as a result of pollution (Chola, 2001). Aquatic weeds can have a significant impact on hydropower. Box 8 illustrates the issues faced in Malawi as a result of aquatic weeds blocking hydropower intakes.

Box 8 The impact of aquatic weeds on power generation in Malawi

From 2001, hydropower generation in the Malawi has been disrupted almost every year in the rainy season due to aquatic weeds (Kaunda and Mtalo, 2013). Repair of damaged parts such as screens and valves and removal of weeds increase the operating costs. The removal and management of weeds is costly for the Electricity Supply Corporation of Malawi Limited (ESCOM). For example, in 2009, the Malawian Government and ESCOM spent nearly US$ 1 million on silt and weed management at the Nkula, Tedzani and Kapichira hydropower plants on the Shire River and in the same year, the total revenue lost as a result of machine unavailability at all three stations was estimated to be close to US$ 1.2 million. The weeds cause reductions in hydropower generation by disrupting the flow of water to turbines and slowing water flows, leading to increased sediment deposition (Kaunda and Mtalo, 2013). There is evidence that aquatic weed infestation could be getting worse with climate change (Theuri, 2013).

4.3 What impact is climate change having on the hydropower sector?

Climate variability and climate change present significant challenges to existing hydropower and the development of future schemes. The recent Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report highlighted potential impacts on hydropower owing to a reduction in water availability in most dry sub-tropical regions, a decline in raw water quality and increased risk of flooding (IPCC, 2014). Seasonal, year-to-year and longer term natural variations in climate affect hydropower performance because of the amount of power generated being reliant on river flows. There are numerous factors to consider:

- The risks and opportunities posed by climate change to hydropower schemes.
- Whether hydropower is currently affecting the performance of existing hydropower schemes.
- Whether climate change is being taken account of in the planning and design of hydropower schemes.
- How climate change should be taken account of in the design and planning of new hydropower schemes.

Climate change is a particular threat to hydropower schemes with large dams. This is because many existing and planned hydropower schemes could still be in operation in 50 or even 100 years' time when the effects of climate change could be considerable (Giordano, 2012). Large hydropower schemes are generally not particularly adaptable to climate change because structures such as dams are often difficult to modify retrospectively (Pittock, 2010). For example, to adapt a hydropower dam to climate change may require it to be raised in height or to increase the size of its spillway, This is often not technically or economically feasible.

4.3.1 What are the risks and opportunities posed by climate change to hydropower schemes?

Future hydropower performance is likely to be affected by both climate change and socio-economic change. Numerous studies have indicated that hydropower economics are sensitive to changes in precipitation and runoff (Alavian et al. 2009; Gjermundsen and Jenssen 2001; Mimikou and Baltas 1997; Harrison and Whittington 2001, 2003). Climate change will affect two important climatic variables that affect hydropower performance, these are:

- Precipitation – affecting the water inputs to a basin with hydropower capacity
- Temperature – affecting the evapotranspiration rates removing water from a basin

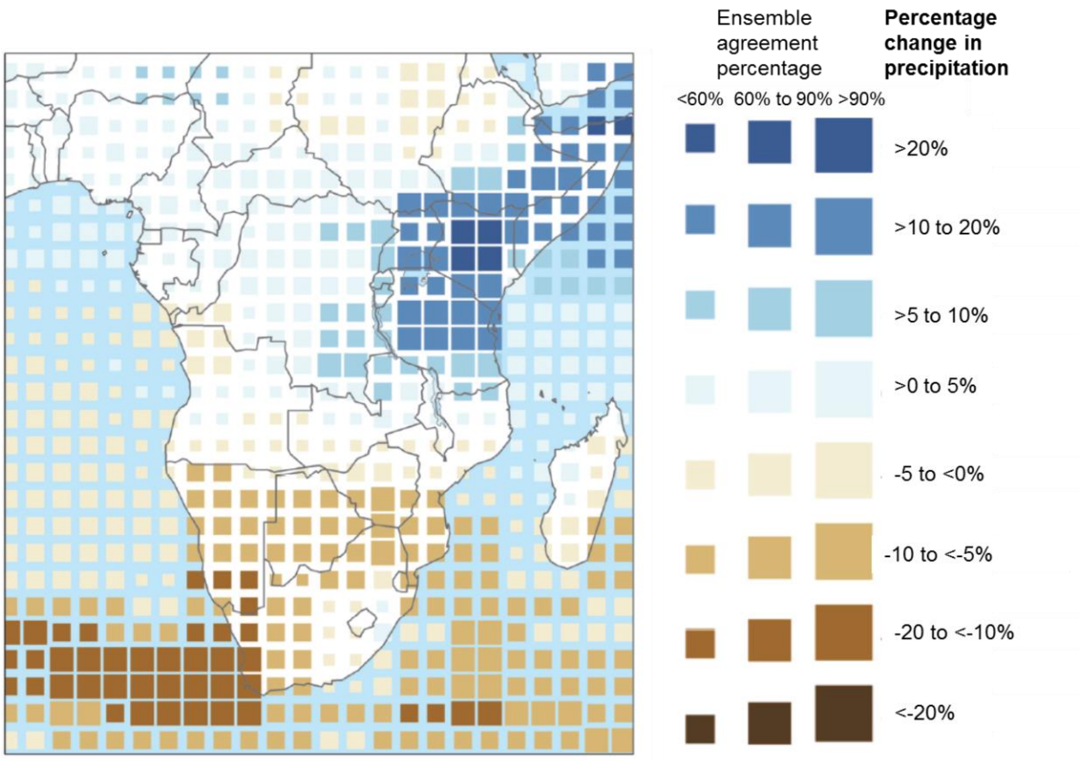
Figure 10 shows the percentage change in average annual precipitation by 2100 from 1960 to 1990 baseline climate, averaged over 21 ensembles from General Circulation Models (GCMs). The size of the grid square indicates the agreement of the different ensembles (i.e. the larger the grid square the greater the agreement). Figure 10 shows strong increases in annual precipitation over east Africa. In central and west Africa the predicted change in annual rainfall is small; however, in southern Africa precipitation is likely to decrease.

The future risks (and opportunities) that could be caused by climate change include:

- Changing quantities, as well as spatial and temporal patterns of rainfall and river flows could increase or decrease the period when turbines can operate and at what proportion of their full capacity
- Increased evapotranspiration rates in upstream catchments and evaporation rates from reservoir surfaces could reduce the water available for power generation.
- Increased sediment loads in rivers, as a result of more intense rainfall and land use change, could lead to greater silt loads and rates of sedimentation in reservoirs that can lead to loss of storage and damage to turbine blades.
- Increased flood magnitudes, as a result of climate change, could lead to an increased probability of dam failures, as a result of spillways not being able to pass the flood flow safely. This has the potential to increase the number of people at risk downstream.
- Increased flows in rivers fed by glacial melt water could increase in the short term, (i.e. at least up to the 2050s (Lutz et al., 2014; Immerzeel et al., 2013), thus increasing the potential to generate hydropower on rivers such as the Indus, Ganges, Brahmaputra, Salween and Mekong (Lutz et al., 2014).

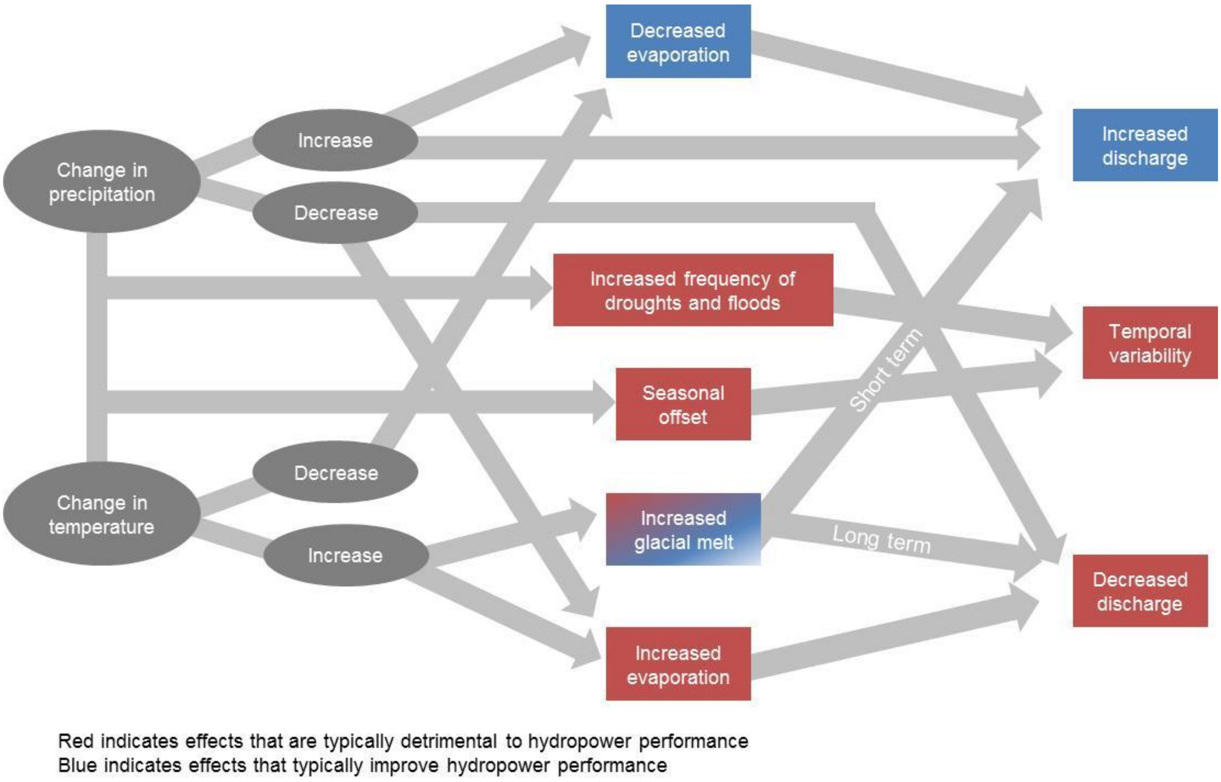
Figure 11 shows the ways in which changes in precipitation and temperature, will affect hydropower performance.

Figure 10 Percentage change in average annual precipitation by 2100 from 1960-1990 baseline climate, averaged over 21 Coupled Model Intercomparison Project (CMIP3) models



Source: Adapted from Met Office, 2012

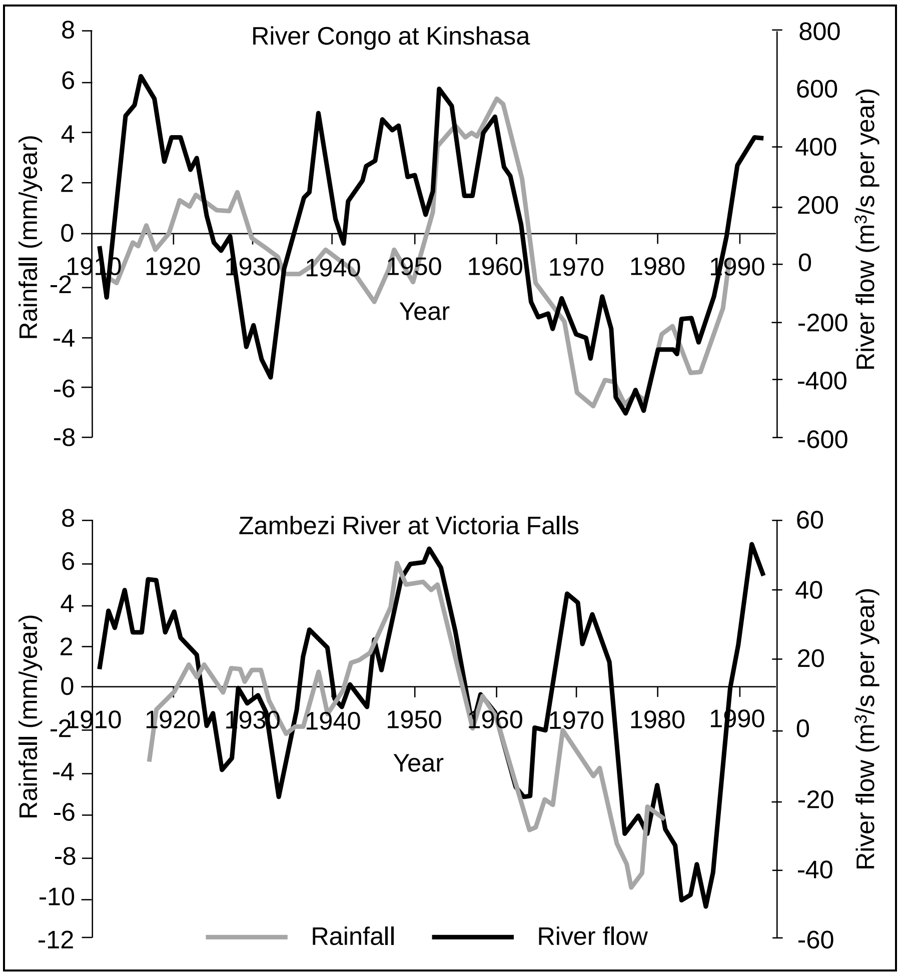
Figure 11 Flow chart of climate change effects on hydropower performance



4.3.2 Is climate change affecting the performance of existing hydropower schemes?

In many countries in sub-Saharan Africa rainfall and river flows in have high levels of variability across a range of spatial and temporal scales (Conway et al., 2008). Figure 12 illustrates the variability of 20 year moving average flows in the River Congo and Zambezi River over the last century. Figure 12 shows that future trends in river flows and rainfall related to climate change will need to be large and prolonged over time, in order to enable "formal attribution", and to create conditions beyond those which have already been experienced during modern times (Conway et al., 2008). As a consequence it is challenging to state categorically that climate change is currently having an effect on the performance of hydropower schemes in sub-Saharan Africa.

Figure 12 20 year running trends in rainfall and flows for the Zambezi River and River Congo



Source: Adapted from Conway et al., 2008

In South Asia the hydrological regime of many rivers on which hydropower schemes are located is driven by glacial melt water from the Himalayan mountain range region. There is some evidence that temperatures are rising faster at higher elevations (Thompson et al., 2000), suggesting that high mountains may be more vulnerable to climate change and this will have a significant impact on hydrological regime of major rivers in the region such as the Indus, the Brahmaputra and the Ganges (IRIN, 2012).

A recent study assessed the importance of glacial melt water for the Indus, Ganges, Brahmaputra, Salween and Mekong Rivers and investigated how climate change will change river flows in the coming decades. The study indicated that despite the glaciers in the

Himalayas retreating river flows will increase until at least the 2050s (Lutz et al., 2014). However, from the data currently available it is challenging to say whether climate change is currently having a statistically significant effect on rivers flows in South Asia. Nevertheless, consultees for the Himachal Pradesh, India case study reported that climate change was the cause of the Nathpa Jhakri dam (India's largest) generating more power than expected since its commissioning in 2004 (Hurford et al., 2014a)

4.3.3 Is climate change being accounted for in the planning and design of hydropower schemes?

Both Pottinger (2009) and Limi (2007) claim that climate change impacts are rarely explicitly considered when planning hydropower projects. Cole et al (2013) states that it "*would appear that the siting of hydropower dams is often a process dominated by political and fiscal considerations, lobbying, corruption and compromise*" (Coles, 2013). A recent scoping study conducted for the World Bank noted that: "*Most hydropower/reservoir operators do not see climate change as a particularly serious threat. The existing hydrological variability is more of a concern, and the financially relevant planning horizons are short enough that with variability being much larger than predicted changes, the latter do not seem decisive for planning*" (Rydgren et al. 2007).

Owing to the variability of the flow regime in many low income countries where hydropower schemes are located it is only after the 2050s at which climate-driven changes in rainfall and river flows are expected to emerge from natural variability (EEA, 2007). Hence if the planning horizon of water resources projects is of the order of 25 years this means that that when planning a hydropower scheme the natural variability of the existing hydrological regime is often within the variability of the climate change projections.

This has important consequences for the management of hydropower and irrigation schemes under future climate change scenarios. The planning horizon for many hydropower and schemes rarely stretch beyond 2050 (IRENA, 2012). As an example in South Africa the planning horizon for Integrated Water Resources Management is 25 years (Department of Water Affairs, 2010).

Rydgren et al. also stated that the thinking that pervaded the stakeholders that they had engaged with was that when General Circulation Models (GCMs) were applied to sub-Saharan African rainfall, the predicted changes over the next 100 years were smaller than natural variability, making interpretation difficult (Rydgren et al., 2007).

It is also important to note that a calculation of the internal rate of return is often used by internal funding agencies such as the World Bank to assess the viability of investments in long-lived infrastructure. When calculating the internal rate of return of a project, the mathematical function used is such that a small value is put on income and/or costs incurred beyond 25 to 30 years into the future. Rydgren et al. postulate that one of the reasons that climate change is not taken into account when planning hydropower is that within such a relatively short planning horizon an increase in the variability of river flows as a result of climate change are often not expected to be noticeable on top of historical variability (Rydgren et al. 2007). Box 9 provides details of the consideration of climate change in the planning of the Grand Renaissance Dam hydropower scheme in Ethiopia.

Box 9 Consideration of climate change in the planning and design of the Grand Renaissance Dam, Ethiopia

In April 2011, the Ethiopian Government commenced construction of a hydropower dam on the Blue Nile, 45 km east of its border with Sudan, which has been named the Grand Ethiopian Renaissance Dam. The hydropower scheme will generate approximately 6,000 MW of electricity and will cost nearly US$5 billion (Hammond, 2013). To date, the World Bank and other international donors have refused to support the project, and the Ethiopian Government is attempting to finance the project through a national bond (Hammond, 2013). The hydropower scheme is scheduled to open in July 2017.

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

It has been reported that the lack of transparency with regards to planning of the project is "*unnerving*" some Non-Governmental Organisations and neighbouring countries (Power-Technology.com, 2013). There are also concerns that Ethiopia will be over-dependent on hydropower. Ethiopian Electric Power Corporation's Mulugeta Asaye said recently that: "*The rainfall in Ethiopia varies considerably from year to year, therefore an overdependence on hydropower makes the energy supply very unstable*" (Power-Technology.com, 2013).

In the state of Himachal Pradesh in northern India climate change was not of great concern to stakeholders that the study engaged with (Hurford et al., 2014). Immediate needs for development funded by hydropower revenue seemed to be more pressing and first hand evidence suggests an opportunity to harness increased river flows for greater revenue generation (Hurford et al., 2014).

4.3.4 How should climate change be accounted for in the planning of hydropower schemes?

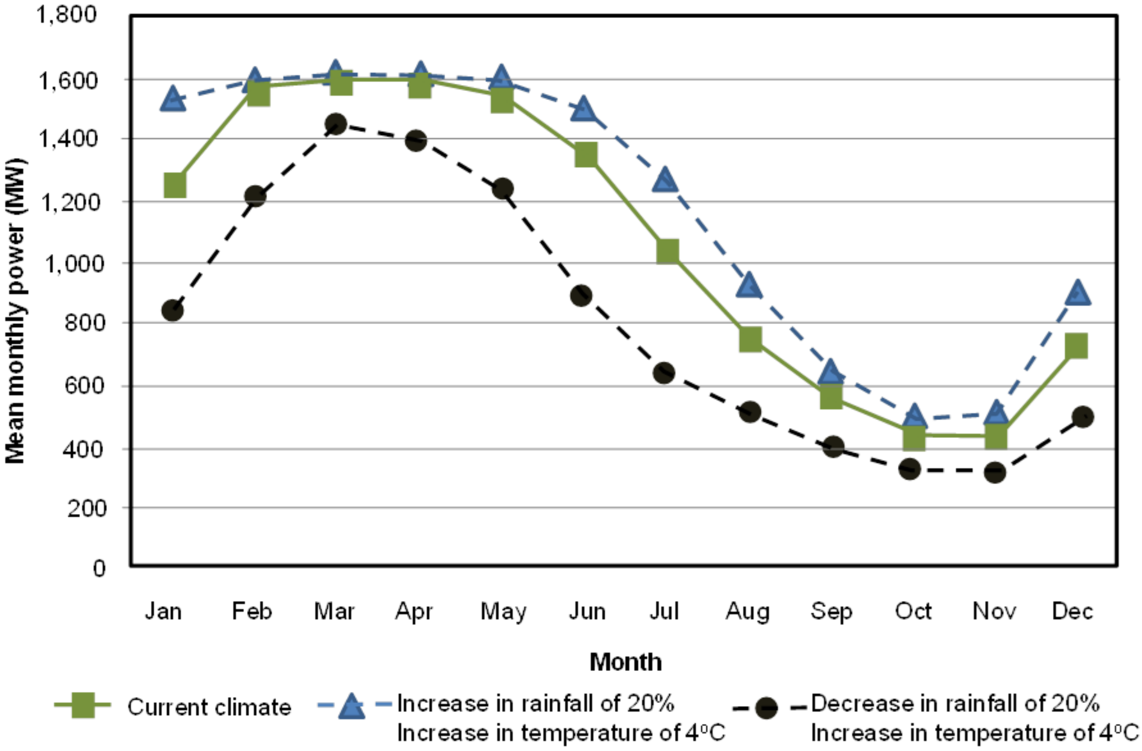
Climate change can be accounted for in the planning of hydropower schemes via the use of hydrological models that rely on rainfall-runoff models to translate changes in precipitation and temperature into altered river flows. The changes can be based on results from General Circulation Models (GCMs) and Regional Climate Models (RCMs) which provide information on how climatic variables may change in the future. Unfortunately, different GCMs tend to predict a different change in temperature and precipitation, which results in significant and often, contradictory, differences between the resulting river flow impacts. An alternative to this method is to examine the river basin's sensitivity to changing climate, through the application of uniform changes in precipitation and temperature.

For example, Harrison et al. carried out research to investigate the effect of future climate change on the net present value (NPV) of the proposed Batoka Gorge hydropower project on the Zambezi river in southern Africa in context with other key project parameters

(Harrison et al., 2003). The project will comprise a 181 m tall concrete, arch dam and two hydropower plants, each with an installed capacity of 800 MW; one on the Zambian side and another on the Zimbabwean side of the river.

The first stage of Harrison et al.'s work was to investigate how changes in future flow directly affect the potential amount of power that can be generated by the Batoka Gorge hydropower project. The study found that although volumetrically greater changes in output occurred during the high flow period, changing climate has a proportionately greater impact on low flows (Harrison et al., 2003). Under the wet climate change scenario (an increase in precipitation of 20%), power production was found to be raised by 7% and 18% for high and low flow periods, respectively, while under the dry scenario (a decrease in rainfall of 20%), monthly power output decreased by 23% and 30% on the same basis (Harrison et al., 2003). These changes are shown in Figure 13.

Figure 13 The impacts of two future change scenario on predicted mean monthly power generation at the proposed Batoka Gorge hydropower site on the Zambezi



Source: Adapted from Harrison et al., 2003

SECTION 5

Development of hydropower schemes

5.1 What measures are needed to incentivise investment in sustainable hydropower schemes?

The sustainability of hydropower developments should be considered in the light of the original broad definition of sustainable development: “development that meets the needs of the present without compromising the ability of future generations to meet their own needs” (World Commission on Environment and Development, 1987). In the context of this study, needs are focussed primarily on water, energy and food security.

There are a range of economic incentives to encourage investments in sustainable hydropower schemes these include:

- Fiscal incentives (e.g. tax incentives that include income tax, value-added tax, and customs duty incentives).
- Non-fiscal incentives (e.g. risk cost sharing, support of land acquisition and resettlement).
- Capital-smart subsidies (i.e. philanthropic investment and training, see Desjardins, 2013)

In many countries the regulatory environment has changed several times in the past 30 years. This often makes private investors cautious, especially where the initial fiscal and licensing regime turns out to have been too generous to the licensees and results in changes in policies and regulations that disadvantage the original investors. The latter point is evidenced by the Himachal Pradesh case study which showed existing power producers are fighting attempts to increase the environmental levies they are required to pay. Consistency and stability in the investment environment could therefore improve and incentivise investment in sustainable hydropower schemes.

In the Lower Mekong region there a number of mechanisms, currently being applied that aim to improve the sustainability of private sector investment impacts. These include:

- Investors use of sustainability frameworks and corporate social responsibility frameworks.
- Benefit sharing, including development projects aimed at poverty alleviation
- The related concept of payments for ecological services, in catchments where hydropower development takes place.

Foran et al., 2011

5.2 How could the planning processes for new hydropower schemes be improved?

Planning for hydropower development has traditionally been oriented toward individual projects. However, this approach does not always allow hydropower to address multiple needs and requirements. Addressed early in the planning process, hydropower infrastructure offers multiple opportunities for local development such as investments in roads, social infrastructure, communications, and skill building in large projects can be leveraged to support local or regional economic development or to anchor growth poles across economic zones (World Bank, 2009).

There is evidence that adopting a "holistic" approach to hydropower planning at the basin level can yield important benefits. A recent study of two river catchments in the states of Himachal Pradesh and Uttarakhand in northern India came to the following conclusion: "*Planning for hydropower development needs to evolve from a project-based engineering approach to a more holistic one, an approach incorporating river basin planning and integrating potential social and environmental issues across multiple projects and the entire river basin. Such a framework would help to optimise the benefits and minimise the costs*" (Haney and Plummer, 2008).

These two catchments in India have ambitious plans for developing a number of hydropower sites, including some earmarked for private developers. However, many of these are likely to be new and untested for the challenges facing them (Haney and Plummer, 2008). A project-by-project approach will not take sufficient account of the system-wide aspects of multiple hydropower projects along the same river. The performance of the projects is likely to be enhanced by the use of catchment-wide modelling, coordinated operational protocols, and catchment and environmental protection. Likewise for the anticipation of risks from fluctuations in flow and cumulative flooding.

The design of hydropower projects has been found to be more sustainable when the power system planning itself is conducted according to integrated demand-side and supply-side principles, in a participatory manner, leading to a rigorous justification of the need for new hydropower (Foran et al., 2011).

Planning can be strengthened by supporting governments in understanding the strategic value of hydropower through integrated cross-sectoral planning, identification of strategic storage sites, improvement of hydrological data and analysis, and mainstreaming hydropower into climate-change programmes. An understanding of strategic value and the avoided costs and delays and win-wins which may become available through more integrated planning could help to incentivise such approaches. A significant increase in funds and technical assistance for prefeasibility studies is recommended to develop "*pipelines of quality projects*" (Haney and Plummer, 2008). Box 10 gives recommendations for improving the planning process in Himachal Pradesh, India.

Box 10 Recommendations for improving the planning process in Himachal Pradesh, India

The World Bank recently carried out a study specific to Himachal Pradesh which identified the following major issues that could improve the current planning and development of hydropower schemes:

- Planning is focused on individual developments and a lack of coordination means benefits are not maximised.
- Lack of data and sharing of information is largely responsible means that substantial hydrological and geological risks are associated with hydropower developments.
- Design flood methodologies are not consistent and could lead to incorrect spillway sizing in cascades of dams. No provision is made for failure of an upstream dam.
- More effective measures for managing silt are required to ensure the viability of hydropower investments.
- Simple modelling has shown that the optimisation of cascade of hydropower projects as a system can provide greater energy output with less physical footprint than individual design and operation, this is not being taken into account in planning.
- Upstream storage would bring benefits to existing and planned projects via regulation of flows, flood control and sediment trapping.
- A diversity of developers has created confusion and lack of coordination in relation to regulations. Many are new to hydropower and lack appreciation of issues such as environmental flows.
- Success is variable in social, environmental and Catchment Area treatment (CAT) plans. CAT funds are often reallocated to other catchments. CAT plans aims to improve the quality of environmental and especially watershed services from the catchment (Thadani, 2006)
- Strategic Environmental Impact Assessments at a basin level are recommended to address environmental and social issues.

Source: Haney and Plummer, 2008

5.3 What types of policies are required to develop sustainable hydropower schemes?

In order to develop sustainable hydropower schemes the following policies need to be in place:

- **Accounting for climate change uncertainties in new hydropower developments** - Planning needs to take account of future climate change uncertainties to ensure that the designs of hydropower schemes are adaptable to avoid future adverse effects. This can be done via a number of mean as detailed in Section 4.3.4.
- **Appropriate national compensation standards for involuntary displacement** – Many countries have no policy for compensating people who are displaced involuntarily by infrastructure developments such as hydropower dams. Plans for hydropower schemes need to be able to factor in the costs of compensation to assess the financial viability of different options. Uncertainty can lead to problems such as delays or withdrawal of funders owing to the objections of local people. This has been a problem in numerous cases worldwide (International Rivers, 2014) and is

best avoided. The case study in Himachal Pradesh, India found examples of innovative compensation payment schemes being developed. It also uncovered aspirations for a more partnership-based approach between local people and developers whereby displacement could become more voluntary and the benefits would be shared more equitably.

- **Sustainable methods to facilitate payments for ecosystem services –** The benefits of ecosystem services, especially those downstream of hydropower schemes should be recognised. For example, in some cases it may be possible to increase incentives for farmers to undertake soil and forest conservation measures if payments for ecosystem services can be negotiated between them and those who stand to benefit downstream. This could help to minimise sedimentation of reservoirs.
- **Harmonisation of national Environmental Impact Assessment (EIAs) requirements with those of international funding agencies –** To obtain funding for hydropower schemes from international funding agencies it is often necessary that the EIAs developed for the scheme fulfil the lenders' requirements. Failure to do this can prolong the planning process and delay the expansion of grid capacity, as well as creating inefficiencies via the development by duplicating studies. In most countries it would be more efficient if their EIA procedures with the requirements of international funding agencies, to ensure that one study is sufficient to gain all necessary approvals.
- **The assessment of Cumulative Impacts Assessment (CIAs) from cascades of dams –** This is required when a series of hydropower schemes are planned on the same river or within the same basin with cumulative impacts in common on flora and fauna, on downstream water availability or quality, on basin sediment dynamics, on navigation, on local communities' livelihoods, or on adjacent land uses because of increased access from associated roads. Policies should be put in place to allow CIAs to be carried out in accordance with the requirements of international funding agencies.
- **Promotion of soil and water conservation practices** - There are significant issues with lack of soil and water conservation in many low income countries. These need to be addressed to increase resilience of hydropower schemes to climate change. Without this, floods and droughts could increase in frequency and or intensity leading to reductions in power generation as a result of loss of storage, damage to turbine blades from sediment.
- **Analysis of trade-offs associated with water resources developments to ensure sustainable resource use and equitable sharing of benefits at a river basin scale –** It is important to understand the trade-offs between different water uses in order to ensure the sustainability of water resources, as well as environmental and social systems at a basin scale. Consideration of the broader impacts of any hydropower scheme may improve sustainability and could foster increased cooperation locally, regionally and internationally. Win-wins may be identified where all parties benefit from greater cooperation, thereby incentivising this activity and increasing sustainability.

5.4 Should new hydropower schemes be refurbished before new ones are developed?

Generally, existing hydropower schemes should be rehabilitated, refurbished or upgraded before new facilities are constructed. Adding additional and/or more efficient turbines generally has a much lower social and environmental impact than building new schemes. It is important to note that hydropower is a mature technology hence even very old hydropower equipment is only likely to be 5% to 15% less efficient than the most modern plant (when able to run at full capacity and not suffering from lack of maintenance or turbine damage) (Lier and Goldberg, 2011). Hence the largest increase in hydropower power generation performance will be in cases where the equipment has deteriorated (e.g. to such a degree that there are significant efficiency gains simply by replacing it with traditional designs and solutions). Box 11 provides brief details of the impacts of rehabilitation on power generation for the Trushuli-Devighat hydropower scheme in Nepal.

Box 11 The impacts of rehabilitation on power generation for the Trushuli-Devighat hydropower scheme in Nepal

In Nepal, modifications to the intake, provision of an extra de-sander, dredging the forebay and refurbishing the generators/turbines and power house control systems at the Trushuli-Devighat hydropower station in 1995 improved average annual power generation by 46% from 194 to 284 GWh a year.

World Commission on Dams, 2000

In 2011 Lier and Goldberg completed a study looking at the rehabilitation of existing hydropower infrastructure for the World Bank. Lier and Golberg looked at two investment scenarios with respect to the rehabilitation of hydropower schemes:

- “Life extension” to the existing facilities to restore their initial performances. This usually includes the replacement of equipment on a “like for like” basis where there is minimum effort to enhance the overall output of the scheme.
- “Upgrade” of the scheme (e.g. efficiency, output) which yields greater output but at increased costs which is justified by the additional revenue over the service life of the equipment (Lier and Goldberg, 2011).

The impact of these two investment scenarios on energy production are shown in Figure 14.

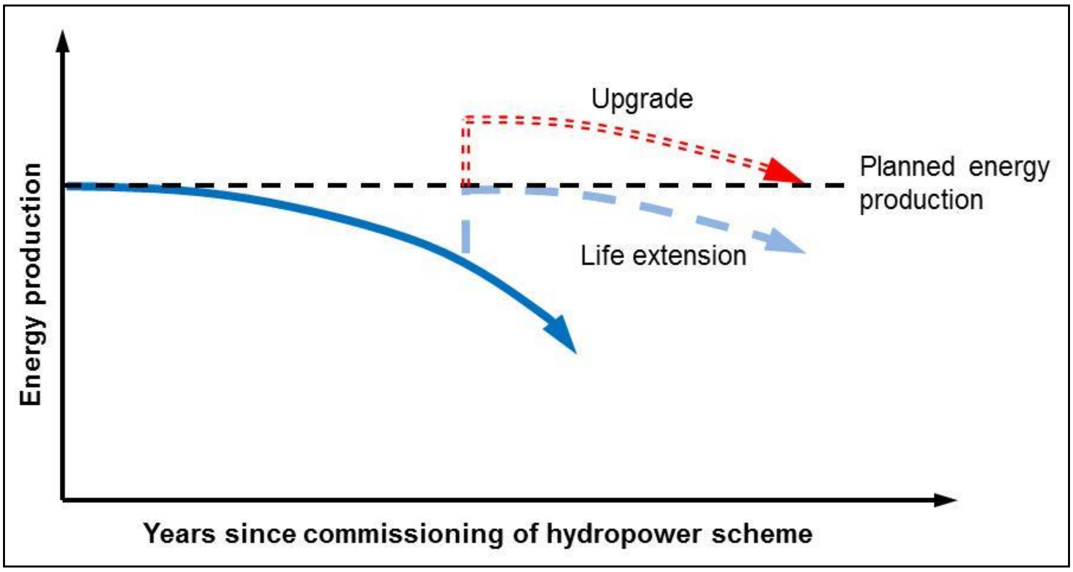
By 2016, 57% of the installed hydropower capacity in Africa will be greater than 35 years of age. Rehabilitation of schemes could provide an additional 1,650 MW of power by 2020. Life extensions estimated to have an internal rate of return of 15.7% upgrades 17% (Lier, 2011).

There are two possible approaches to improve the performance of hydropower schemes when they are rehabilitated as follows:

(i) Installing turbines that are more efficient than the old ones. This means that more power can be generated by the same scheme thanks to an increase in efficiency. This has the potential to increase the efficiency of the scheme by 5%, depending on the year in which the turbine was installed (Czerwinski and Robert, 2011).

(ii) Improving the peak capacity of the hydropower scheme owing to an increase in the maximum power output. For example, this can be achieved by rehabilitating the generator. This can improve the performance of the scheme by up to 30% (Czerwinski and Robert, 2011).

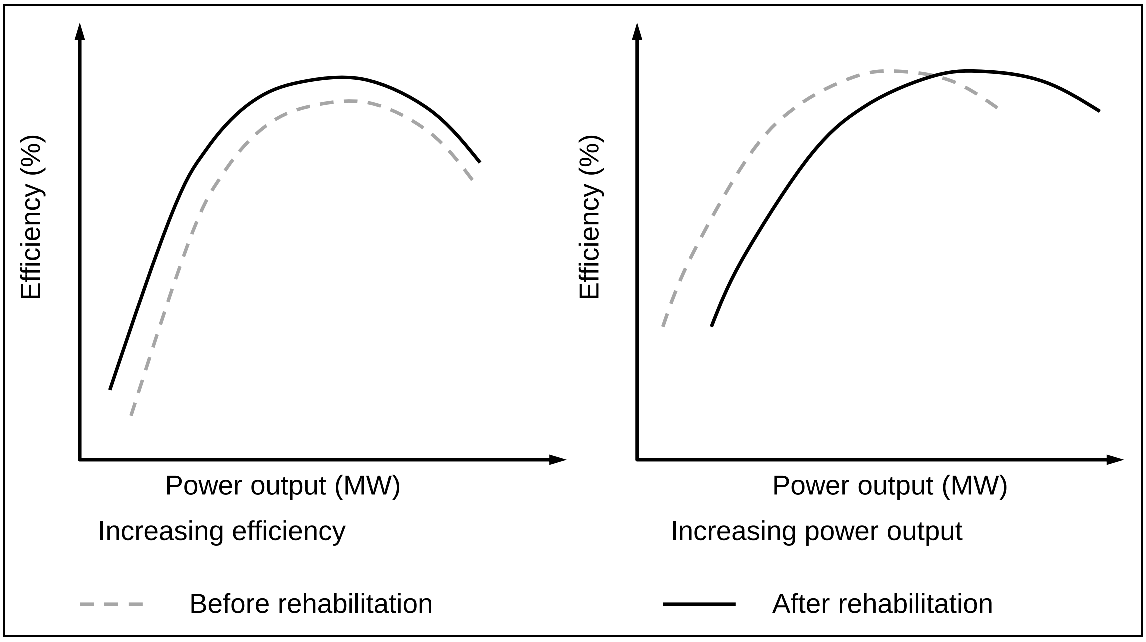
Figure 14 Illustration of the conceptual impacts of an upgrade versus a life extension on energy production of a hydropower scheme



Source: Adapted from Lier and Goldberg, 2011

These two approaches to performance improvement are shown in Figure 15 Each hydropower scheme would need a specific study to assess the gains in performance improvement that these approaches can provide. Box 12 provides details of the rehabilitation of the Kiambere hydropower scheme in Kenya, where the replacement of the turbines has increased both the efficiency *and* the peak capacity of the scheme.

Figure 15 Illustration of the two main ways in which the performance of a rehabilitated hydropower scheme can be improved



Box 12 The rehabilitation of the Kiambere hydropower scheme in Kenya

The Kiambere hydropower scheme in Kenya was commissioned in 1988 and includes two vertical Francis turbines with a design capacity of 72 MW and a head of 150.5 m. Numerous problems were encountered with the turbines after the plant was commissioned including cavitation. The scheme was rehabilitated in 2010 and new turbines installed that have increased the installed capacity from 144 MW to 168 MW. The new type of Francis turbines installed have shown no trace of cavitation after 5,000 hours of operation and have helped to reduced maintenance costs and increase efficiency of the scheme.

Norplan, 2010

5.5 What could the private sector role be in the development of new hydropower schemes?

Private financial involvement in hydropower projects has always been on a smaller scale than publicly sponsored and financed schemes. For large hydropower projects in 2012, approximately 15,500 MW of projects with private participation reached financial closure in low income countries, with total project costs of US$21.15 billion. For small hydropower projects, the corresponding figures were 1,113 MW to a value of US$1.25 billion. In both cases, Brazil accounted for most of the activity (PPIAF, 2013). For sub-Saharan Africa the scale of investment needed to achieve universal energy access is about US$15 to US$20 billion per year, every year, through to 2030. In order to achieve this objective it will be necessary to use public funds to leverage private sector investment (USAID, 2014).

In the future the private sector could play a critical role in hydropower schemes. The financing requirements of many large projects exceed funds available from governments and public sources. However, in many low income countries the lack of strong regulatory and enabling environments set against intense scrutiny of larger projects raises considerable risk for private capital. The inherent complexities of large hydropower schemes further compromise private sector investment.

Within the hydropower sector, public and private sponsors gravitate to different modes of supply. The bulk of private schemes are run of river projects, which are smaller and less risky in terms of investment than large projects involving stored water. Typical of this is one of the latest private hydropower projects in Pakistan, from the Hub Power Company, an 84 MW run of river, low head, project that commenced in March 2013 (PPIAF, 2013). Of the 10 hydropower projects with private participation analysed by Head (2000), six were run of river schemes, the remainder involved storage. Three of the projects were of the IPP variety. The largest project, a storage scheme, has 1,455 MW capacity. Box 13 provides details of the Bujagali public-private hydropower scheme in Uganda.

Box 13 Bujagali hydropower scheme in Uganda: An example of a public-private partnership project

The 250 MW Bujagali hydropower project was completed in 2012 and was the largest private sector investment in Uganda's history. The project represents one of the largest foreign private power sector investments ever made in sub-Saharan Africa.

In 2005 Bujagali Energy Limited (BEL) was selected as the preferred bidder and entered into a power purchase agreement and an implementation agreement with the Ugandan government. BEL has signed a 30 year power purchase agreement (PPA) with the Ugandan government, who will also lease the land to the company for the period of the PPA.

The hydropower plant will be operated by BEL, which was established by the project sponsors and the government of Uganda for the sole purpose of developing and subsequently operating the plant for the 30 year period, following which it will be transferred to the government of Uganda for a nominal price of US$1.

Bujagali is the first power project built in the country to secure private financing. Until now, like many projects in sub-Saharan Africa, projects in the country were built with financing support coming solely from multi- lateral organisations such as the World Bank.

As a result of the implementation of the Bujagali scheme, Uganda's supply exceeded its demand for the first time ever. Daily power outages are rare and the industrial operations can run freely, no longer compromising the country's progress.

Hydroworld.com, 2013: Water Power Magazine, 2013

Ethiopian hydropower generation is entirely in the public domain but the Ethiopian Electric Power Corporation had been encouraging the private sector to invest in the energy sector, prior to its division into two separate utilities for generation and transmission (Kribu, 2013).

With respect to small scale hydropower in India, subsidies for their development through the private sector are in place; however, they vary from state to state. Some states also provide concessions such as leasing of land, exemption from electricity duty and entry tax on power generation equipment (Liu, 2013). In many counties in South Asia there is a lack of/low interest from the private sector to develop small hydropower plants because there is no proper tariff structure and/or electricity market system. In Bangladesh, India and Nepal Administrative complexity and long waiting times delay small hydropower development (Liu, 2013)

In Kenya, there is a high private sector interest in small hydropower mainly via small hydropower use on tea plantations (i.e. United Nations Environment Programme project). The Kenyan Government is motivated to remove legal and regulatory barriers (Liu, 2013). In Zambia development of small hydropower is usually conducted by the private sector (Liu, 2013). In Mozambique, the Energy Fund Fundo de Energia (FUNAE), with its focus on rural electrification using renewable energy technologies, will provide good support for possible private investors, as some of the resources needed for the rehabilitation and/or construction of new hydropower schemes can be mobilized locally. However, it is important that the Government actively encourages private sector investment in renewable energy projects in Mozambique and creates clear incentives for investors, manufacturers and developers to utilize renewable energies when making investments in the country.

SECTION 6

Hydropower and the water – energy – food security nexus

6.1 How does hydropower compare to other power generation technologies?

It is currently challenging to compare the performance of hydropower with other options for power generation because of the limited information available on technical issues such as:

- kWh of power generated per US$ of investment.
- Greenhouse gas emissions over the cycle of the scheme.
- Water use per kWh of power generated.
- Capital, as well operation and maintenance costs.
- Number of beneficiaries.
- Social and environmental impacts.

The above should be relatively “simple” to measure; however, this is often not the case and there is often a lack of consensus on the figures for the above subjects. This is without the further complication that in many countries the regulatory environment has changed several times in the past 30 years, complicating direct comparisons.

However, Figure 16 shows the global levelised costs of power generation for the first quarter of 2013. The general levelised cost of power generation is the average cost of power from a new generating plant over its entire lifetime of service (Eschenbach, 2014). The use of levelised costs allows a comparison of various sources of power production to be compared on an even basis (Eschenbach, 2014). Figure 16 indicates that the global levelised costs of hydropower generation compare well with other forms of energy, apart from new gas and coal fired power stations.

With regard to greenhouse gas emissions, electricity production is a challenging issue when it comes to mitigating emissions without jeopardising development goals (Mendonça et al., 2012). Figure 17 shows the life cycle greenhouse gas emissions from hydropower schemes compared with other forms of electricity generation systems. However, many of the hydropower schemes that Raadal et al (2011) researched are in temperate regions such as North America and Europe. Researchers tend to agree that hydropower schemes located in tropical regions emitted more greenhouse gases than those found in cooler parts of the world (Mendoça et al., 2012).

In terms of water use Table 5 compares the average blue water footprint of hydropower with that of other methods of electricity generation. The blue water footprint[5] of hydropower schemes will vary significantly depending on a variety of factors (e.g. reservoir volume to surface area ratio, climate, modes of operation). The blue water footprint of hydropower schemes rarely appears to be assessed at the

5 This is the volume of surface and groundwater consumed as a result of the production of a good or service.

planning stage of schemes. An estimation of a hydropower's water scheme's footprint would allow straightforward comparisons to be made with the green water footprint[6] of an irrigation scheme or **the water footprint of industries.**

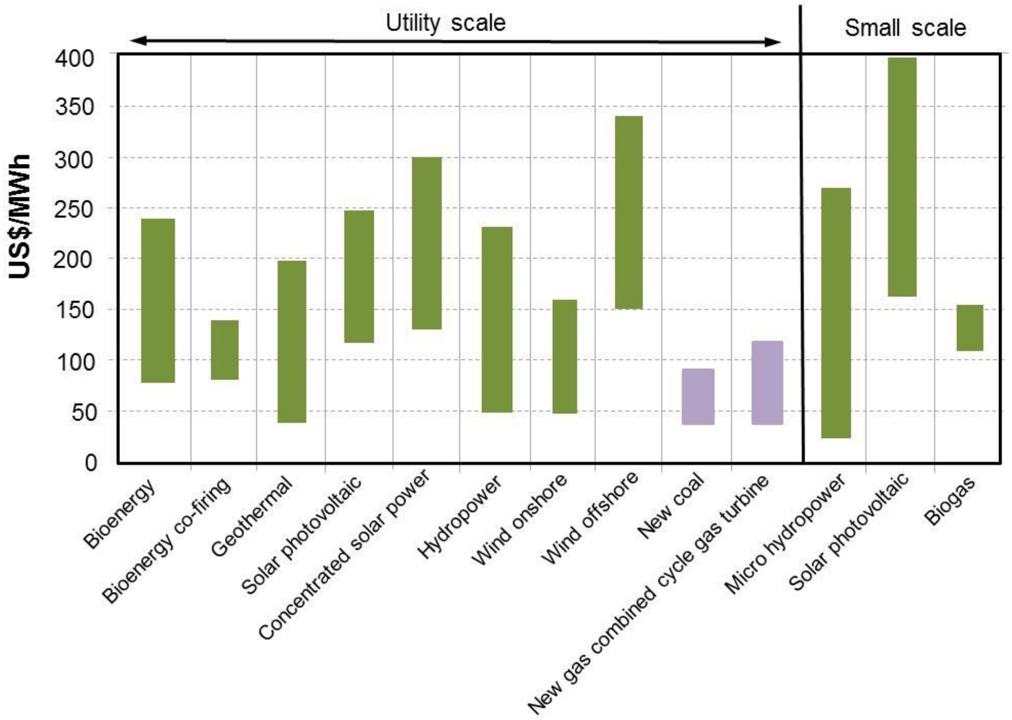
	Solar	Wind	Bio-electricity	Hydropower	Gas	Coal	Nuclear
Blue water footprint (m^3/MWh)	~0	~0	0 to 150	245	~4	~4	~4

Note: The water footprint of the hydropower schemes studied by Mekonnen and Hoekstra varied from 1 m^3/MWh for San Carlos in Colombia to approximately 3,000 m^3/MWh for Akosombo-Kpong in Ghana.
The value for hydropower of 245 m^3/MWh represents an average for 35 studied sites worldwide.
The blue water footprint of bio-electricity is dependent on the crop.

Source: Adapted from Gerbens-Leenes et al., 2008; Mekonnen and Hoekstra, 2012; Raadal et al., 2011; Rodriguez et al., 2013

Table 5 Blue water footprint for the production of electricity from various sources of energy

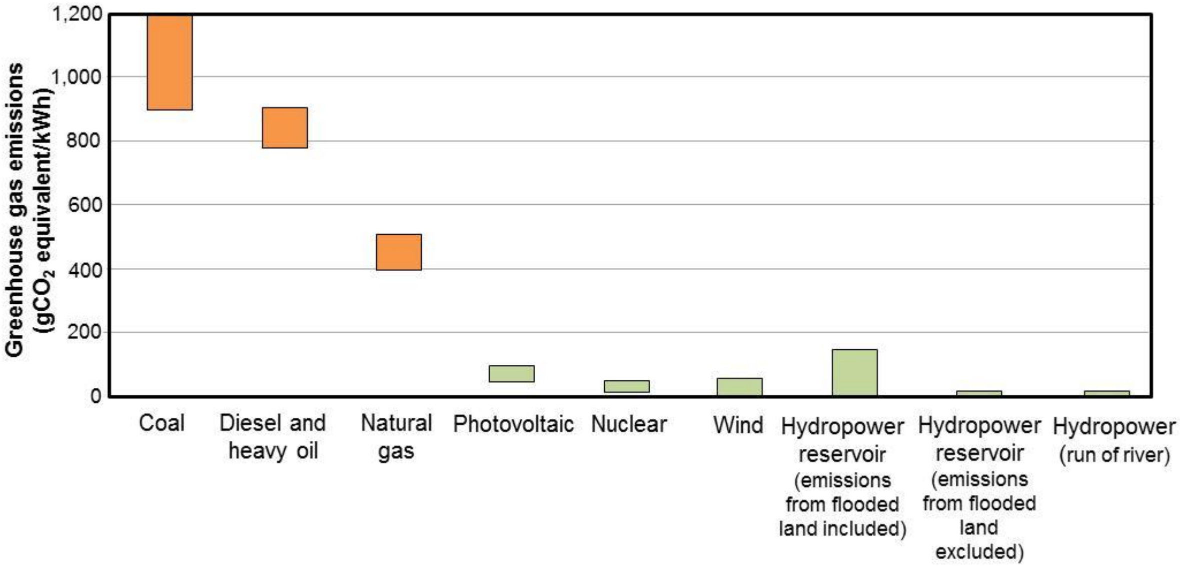
Figure 16 Global levelised costs of power generation for the first quarter of 2013 for a range of power generation techniques



Source: IEA, 2013

6 This the precipitation on land that does not run off or recharge the groundwater but is stored in the soil or temporarily stays on top of the soil or vegetation

Figure 17 Life cycle greenhouse gas emissions from hydropower schemes compared with other forms of electricity generation systems



Source: Raadal et al., 2011

6.2 How does the water, energy and food security nexus impact on hydropower schemes?

Water, energy and food supply systems are inter-connected and benefits from hydropower schemes can trade-off against benefits from other sectors (e.g. domestic water supply, industrial water supply, irrigation, different parts of the environment, e.g. aquatic and terrestrial) depending on the relative locations (i.e. upstream/downstream) of various demands or their abstraction points within a basin. Interactions between the built and natural systems supporting water, energy and food security have recently come under increasing scrutiny owing to the recognition of their ability to impact on each other and especially in a world with increasing competition for resources.

There are different approaches available to explore hydropower performance in the broader context of water – energy – food security. A large number of research studies make use of detailed quantitative hydrological, water resource, crop production and economic modelling at the catchment scale. However, the timescales of this study and the data available means that this study has been based on literature and previous modelling studies, where possible using these to illustrate the sensitivity of hydropower production to future climate change scenarios or the potential economic implications.

A framework for assessing hydropower performance within the water – food – energy nexus is shown in Figure 18. Figure 19 shows an example of some of the key linkages between hydropower performance, water resources, energy and food systems.

Figure 18 A framework for assessing hydropower performance in the context of the water – energy – food security nexus

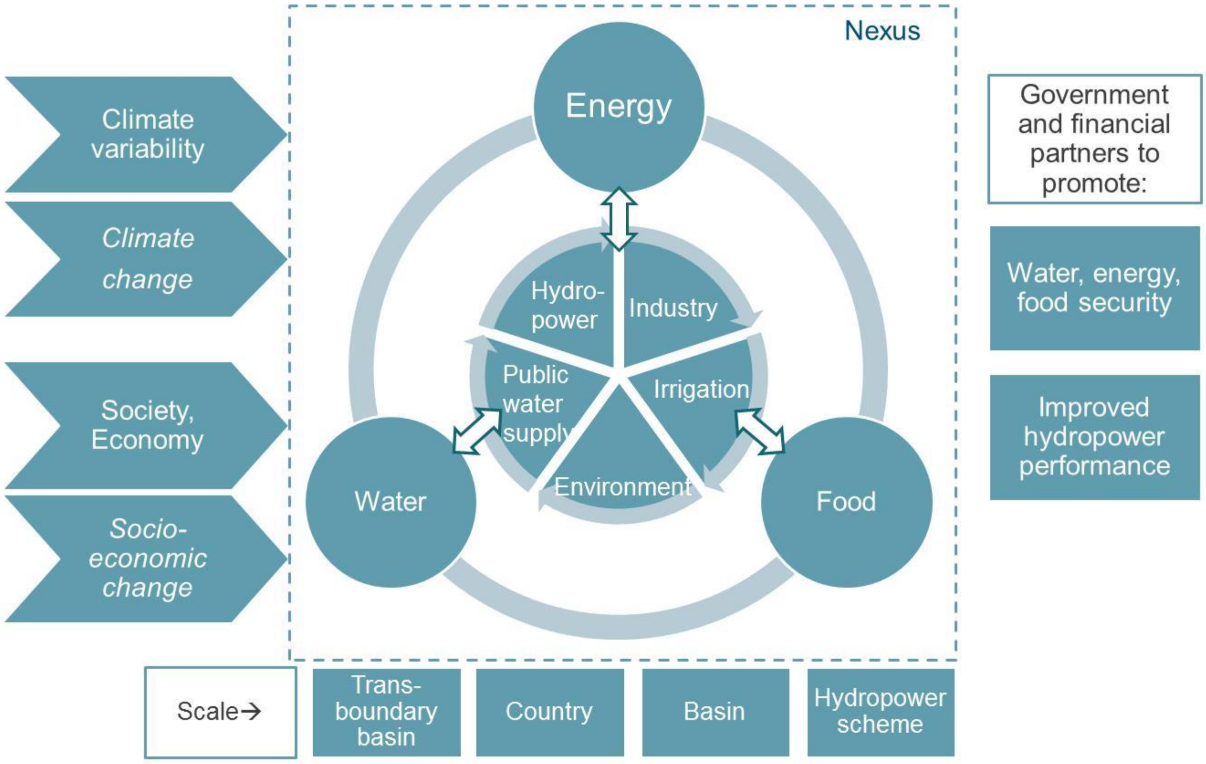
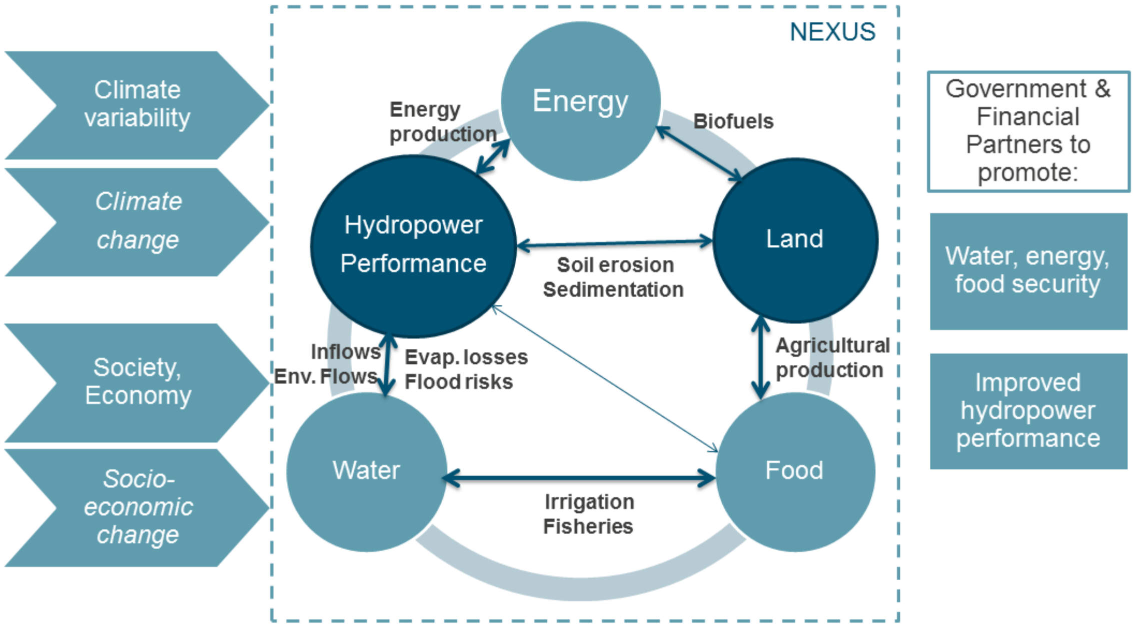


Figure 19 An example of some of the key linkages between hydropower performance, water resources, energy and food systems



6.3 How can trade-off analysis techniques be used to assess the role of hydropower within the water - energy - food security nexus?

The role of hydropower within the water – energy - food security nexus can be assessed using a range of methods from qualitative approaches to more data driven and quantitative modelling approaches. A range of factors can determine which approach is chosen, including:

- The goal of the analysis
- The level of capacity and trust between competing stakeholders at different scales
- Sectoral integration
- Access to data
- Capacity for analysis

Jägerskog et al., 2013

There are some tools under development which aim to identify win-win opportunities where all parties can gain from explicitly sharing the available resources. In the case of transboundary catchments water resources are rarely sustainably, efficiently or equitably utilised, even though water is critical to economic growth and particularly in developing countries (Phillips et al., 2008). This often results from the perception that one party's gain must be another party's loss. By analysing a broader range of benefits from water resources and highlighting the potential for win-wins, it may be possible to move the perception away from a simple gain-loss situation (Phillips et al., 2008).

Phillips et al. (2008) have produced a methodology for analysing the opportunities for increasing benefits in transboundary water resources management, noting it would also be applicable in non-transboundary contexts. The focus is on developing 'win-win solutions', where each party benefits more by cooperating than by acting in isolation. The conceptual framework of the Transboundary Waters Opportunity (TWO) analysis consists of a matrix of four key development opportunities and two main categories of water source for realising the opportunities (Phillips et al., 2008). The framework facilitates context-specific analysis and can be adapted where necessary by adding opportunities and water sources. Example opportunities are wastewater re-use and optimal siting of multipurpose dams.

The methodology is intended to be applied in a range of contexts, including:

- Formal negotiations or training in relation to identifying 'win-win' development opportunities
- Identifying promising opportunities for detailed investigation through either political negotiation or strategic analysis of options and trade-offs
- As a scenario tool to illustrate future options
- Identifying investment opportunities for public and private financiers

Phillips et al., 2008

Phillips et al. postulate the following wide range of uses for the TWO analysis framework:

- Strategic-level planning taking into account various riparian perspectives
- Supporting decision-making by the donor community on increasing benefits from water use
- Determining major infrastructural requirements based on the preferred allocation of resources

- Providing chronological investment sequence information to all sources of finance

Phillips et al., 2008

Such a framework could be used to analyse the use of hydropower within the water – energy – food nexus.

In recent years a number of modelling techniques have been developed to carry out multi-objective trade-off analysis, which is being applied in the Volta Basin of Ghana and the Tana Basin of Kenya under the WISE-UP to Climate project (IUCN, 2014). Examples of some of the variables, which are generally benefits, that can be traded off in such models are shown in Table 6. Such models allow both quantitative and qualitative benefits to be traded off against one another.

Trade-off variable	Objective
Hydropower revenue in US$	Hydropower revenue is maximised dependent on hydraulic head levels in the associated reservoir or pondage, flow rate through the turbines and timing of releases as bulk energy prices vary though the year.
Irrigated agriculture revenue in US$	Agricultural revenue is maximised dependent on minimising crop water deficits during growing seasons. This is dependent on the crop type.
Deficit in municipal water supply in m^3 of water	The deficit in the volume of water supplied to the urban areas was minimised.
Firm energy from hydropower in GWh	A firm energy objective is to maximise the electrical output in GWh at 90% reliability.
Difference between the regulated and natural flow duration curve in % difference	Deviation from the natural flow duration curve. This variable is used as a proxy for ecosystem services. The objective is to minimise this variable.
Difference in the natural and regulated hydrograph flood flows in m^3/s	Deviation from the natural flood hydrograph. This variable is used as a proxy for ecosystem services. The objective is to minimise this variable.

Source: Adapted from Hurford and Harou, 2014

Table 6 Examples of variables used to assess the trade-offs between hydropower, irrigated agriculture, municipal water supply and the environment

SECTION 7

Conclusions and recommendations

7.1 Conclusions

The conclusions below can be drawn from the case studies and literature review. It is important to note that the order of the conclusions is not intended to signify their importance and that the particular context of an existing or planned hydropower scheme (in terms of politics, topography, climate, etc.) will dictate to a large extent which of the conclusions are most relevant.

Hydropower will play an increasingly important part in supplying electricity in low income countries in Africa and Asia over the next 30 years

Hydropower offers a range of advantages over alternative methods of generation. It is a renewable source of energy and well selected sites can generate low cost power. Storage hydropower schemes can usually be operated flexibly, providing a rapid response to changes in demand. In an integrated power system, reservoir and pumped storage hydropower could be used to reduce the frequency of start-ups and shutdowns of thermal plants, better balancing supply and demand under changing patterns thereof. Hydropower offers a “hedge” against volatile energy prices and risks associated with the imported supply of electricity or fossil fuels (World Bank, 2009). Under the right circumstances, schemes can be designed to provide additional water-related benefits, such as irrigation and municipal supplies

Existing hydropower schemes should be “re-operated”, improved and rehabilitated before investing in new infrastructure

Generally, existing hydropower schemes should be rehabilitated, refurbished or upgraded before new facilities are constructed. Adding new or more efficient turbines generally has a much lower social and environmental impact than building new schemes. It is important to note that hydropower is a mature technology hence even very old hydropower equipment is only likely to be 5% to 15% less efficient than the most modern plant (when able to run at full capacity and not suffering from lack of maintenance or turbine damage) (Lier and Goldberg, 2011). Hence the largest increase in hydropower performance will be in cases where the equipment has deteriorated (e.g. to such a degree that there are significant efficiency gains simply by replacing it with traditional designs and solutions.

New hydropower schemes need to be assessed within the context of comprehensive catchment-wide and national planning

New hydropower schemes should be considered in the context of the whole catchment taking into account how climate change will influence flows, and how future river flows will meet competing and perhaps increasing demands for power generation, the environment, and water supply for domestic, agriculture and industrial uses. Community- and ecosystem-based adaptation approaches that integrate the use of biodiversity and ecosystem services into an overall strategy aimed at empowering people to adapt to climate change must be central to any comprehensive planning efforts with respect to new hydropower dam developments (Beilfuss, 2012).

Comprehensive analysis needs to be undertaken at national level to define the best way of addressing the specific water – energy – food security challenges faced by particular countries. For example, should international funding agencies invest US$80 billion in the proposed Grand Inga hydropower project on the River Congo in the Democratic Republic of the Congo (DRC) that will generate 40,000 MW and potentially foreign exchange from export sales of electricity, or would it be more sustainable and advantageous to use these funds to put in place small-scale, off-grid, power generation (e.g. wind, solar, small-scale hydropower) that are more likely to directly benefit the 94% of the DRC's population that do not have access to electricity? Such questions remain difficult to answer and involve highly political issues with potentially different sections of the population benefitting, depending on the investments selected.

There is a paucity of suitable hydrological data with which to plan new hydropower schemes in many low income counties, so monitoring should be improved with some urgency
Hydropower schemes based on limited and unreliable hydrological data have the potential to underperform and not to attain the benefits the infrastructure is designed to generate. Generally, in the past two decades hydro-meteorological networks in low income countries have deteriorated.

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

Climate change scenarios should be incorporated into the planning and design of new hydropower schemes to ensure their performance is resilient to changes
Hydropower is so fundamentally reliant on river flows that it is wise to consider the risk of future variations or changes in flows being sufficient to impact on the performance of existing or planned schemes.

Iimi (2007), Rydgren (2007) and Pottinger (2009) all claim that climate change impacts are rarely explicitly considered when planning hydropower projects. There is evidence in the research literature and from the case studies undertaken by this study to suggest that the possible effects of climate change are not being taken into account when new hydropower schemes are being planned (see Iimi, 2007; Pottinger, 2009; and Beilfuss, 2012). Climatic uncertainty as the result of climate change should be incorporated into planning and design of hydropower schemes as a matter of course to help to avoid over- or under-designed infrastructure and financial risk, and to improve the resilience of such schemes.

There is some limited work that suggests that planned investment for hydropower in Africa is in regions that are unlikely to experience the worst effects of climate change and hence are fairly low risk in terms of being non-performing or not meeting targets for returns on investment. However, there are also other studies that contradict these findings. Some published research indicates that flows in major Asian rivers fed by melt water from the Himalayas may increase at least up to the year 2050 (see Lutz et al., 2014; Immerzeel, 2013), thus increasing the potential for hydropower generation.

Evaluations of proposed new hydropower schemes should include an assessment of their water footprint and greenhouse gas emissions
It would appear that the water footprint and greenhouse gas emissions have in many cases in the past not been estimated at all when hydropower schemes have been evaluated. There is a growing body of evidence to suggest that in "hot" countries that these are larger than

previously anticipated. Hence there is a need to evaluate these additional factors when new hydropower schemes are planned and the performance of existing ones are assessed to reduce unintended consequences.

Technological innovations can improve environmental performance and reduce operational costs of hydropower schemes
Although hydropower technologies are mature, recent research into the following areas will help to improve the economic efficiency and lessen the negative impacts of future hydropower schemes: variable-speed turbines; fish-friendly turbines; new sediment management techniques; more efficient tunnelling methods; use of models to assess and optimise the trade-offs between energy, irrigation and water supply needs as part of integrated river basin management.

Environmental and social issues will continue to play a significant part in the development of new hydropower opportunities
Potential negative social and environmental impacts of hydropower projects vary depending on the project's type, size and local conditions. Experience gained over the past 80 years, together with recently developed sustainability guidelines and criteria, and innovative planning approaches based on stakeholder engagement and technical innovations should be used to help to improve the sustainability performance of future projects. Such approaches are only just beginning to be demonstrated by projects such as WISE-UP to Climate (IUCN, 2014).

The benefits of large hydropower schemes often do not reach the poorest communities
Although hydropower has contributed to economic development worldwide, in many low income countries the electricity produced has failed to reach the rural poor for a variety of reasons including a lack of distribution infrastructure (see Collier, 2006; Hankins, 2009; Imhof and Lanza, 2010). The benefits of supplying a small amount of electricity are generally greatest for the people currently without access to electricity, usually the rural poor (Collier, 2006).

Improvements are required in the understanding of the water – energy – food nexus and the place of hydropower within it
There is no harmonised 'nexus database' or analytical framework that can be used for monitoring or trade-off analyses (SEI, 2011). Hence the effects of increasing energy or water scarcity on food and water or energy security, as well as potential synergies between land, water and energy management, are not well understood (SEI, 2011). One question that needs to be addressed is the extent to which the higher availability of one resource in the nexus (i.e. water, energy or food) can sustainably reduce scarcity of another, and how might this work at different spatial scales (e.g. local, regional and national).

Investments in new hydropower schemes should ensure that they increase the climate resilience of poor and vulnerable communities
Investments in new hydropower schemes should aim to enhance climate resilience by helping poor and vulnerable communities prepare for, withstand, and recover from the negative effects of climate change. However, there have been some cases where large hydropower dams can decrease, rather than enhance, climate resilience, especially for the rural poor, by increasing evaporative water loss, prioritising power generation over other demands for water and changing the hydrological regime which supports food production. For example, in 1992 Gammelsrod estimated that the modified seasonal flows caused by hydropower schemes on the Zambezi River in southern Africa reduced the value of shrimp fisheries in the estuary by US$10 million dollars per year (Gammelsrod, 1992).

Regional pools of sustainable power should be diversified to reduce the dependency on energy sources that can be affected by climate change
Diverse methods of power generation are critical for climate change adaptation in water stressed regions(Beilfuss, 2012). Regional power supply grids such as the one developed by the Southern African Power Pool (SAPP) provide a means for diversifying power production and reducing dependency on energy sources that can be affected by climate change, which in some cases will include hydropower. SAPP could play a key leadership role in adapting the regional power grid to the realities of climate variability and water scarcity through promotion of decentralised energy technologies, energy efficiency standards, demand-side management, and feed-in tariffs to support renewable technologies(Beilfuss, 2012). In practice to date however, SAPP has emphasised large-scale coal and hydropower development to feed the regional grid, without serious consideration of climate change impacts and risks(Cole et al., 2013; Beilfuss, 2012).

7.2 Knowledge gaps

There are a number of knowledge gaps related to the performance of hydropower and its role within the water – energy – food security nexus under climate change. These are briefly detailed below.

Assessment of the performance of hydropower under future climate change
More work is required to assess the impacts of climate change uncertainty on proposed hydropower schemes in low income countries relative to other variables (e.g. capital costs, operation and maintenance costs, internal rates of return). This could help to:

- Develop guidance for rehabilitation, upgrading or uprating existing hydropower plants to increase efficiency, output, capacity and value.
- Identify opportunities to redevelop very old hydropower plants, having obsolete equipment and less than optimum use of the water resource.
- Identify dams originally developed for flood control, irrigation, navigation or drinking water and assess the feasibility of adding hydropower generation.

Estimation of greenhouse gases from hydropower scheme reservoirs
Hydropower is often cited as a green form of energy with “low” greenhouse gas emissions; however, recent research indicates that for hydropower schemes with large reservoirs located in tropical and semi-tropical regions, the greenhouse gas emissions in grammes equivalent of CO_2/kWh may similar to other “dirty” energy sources such as coal fired power stations. There is disagreement amongst researchers concerning the quantities of greenhouse gases emitted by reservoirs. The Kyoto Clean Development Mechanism now limits funding for hydropower projects with less than 10W of installed capacity per m2 of reservoir surface area, in recognition of potential for greenhouse gas emissions. Further research is required in tropical and sub-tropical low income countries to enable a more accurate methodology for defining lifecycle emissions from hydropower schemes to be put in place.

Minimisation and utilisation of greenhouse gases generated by hydropower scheme reservoirs to generate power
Methane could be extracted from the water in reservoirs and burnt as a renewable source of energy. There is some limited research describing the potential for extracting methane from reservoirs to be used as a renewable energy source (Ramos et al., 2009), based on earlier work by Kling et al. (2005). However, further work is needed to investigate methods to minimise the emissions from hydropower schemes including understanding the processes via which these gases are generated.

Water consumption and footprinting tools for different power generation technologies
There are limited data on consumptive water use in the energy sector for different power generation techniques (e.g. hydropower, thermal, nuclear), compared to the data for the actual water withdrawn from the aquatic environment (e.g. surface or ground waters). Existing data on the consumptive use of different power generation techniques are often not consistently traced throughout the full lifecycle. In order to compare the water use of different power generation techniques a widely accepted water footprinting tool is required.

Uniformly applicable water footprinting frameworks do not yet exist that allow the comparison of water use efficiency for different forms of energy or food production (SEI, 2011). Such water footprinting frameworks would have to consistently integrate water productivity with water scarcity and opportunity costs in any particular location (SEI, 2011). This is not a simple task. Water footprinting of hydropower schemes in relation to the amount of hydropower they generate could serve as a useful differentiator in selecting from a range of options for development

Impacts of hydropower on ecosystem services including their cumulative effects
There is still insufficient knowledge on the impacts of hydropower schemes on ecosystem services including the relationships between river flows, the state of aquatic ecosystems and terrestrial flora and fauna. There is also a need to improve the assessment of environmental risks associated with cumulative impacts, resulting from development of cascades of dams for hydropower schemes in the same basin.

There are suggestions that there is a need for a publicly available clearinghouse to store existing data on environmental impacts and environmental mitigation measures for hydropower schemes covering areas such as: the passage of fish; environmental flow releases; and water quality. This would require clear criteria for inclusion of data and information (e.g. recent, peer-reviewed journal papers and credible web sites). These data could help to reduce the cost of mitigation decisions and support comprehensive reviews of environmental issues.

For hydropower schemes that store water behind a dam there is a need to carry out more research in order to separate the environmental impacts of the dam from the impacts of hydropower operation itself.

Role and impacts of small-scale hydropower schemes in low income countries
It is widely reported that small scale hydropower is "environmentally friendly". However, more work is needed to accurately assess the environmental impacts caused by small hydropower so that such schemes can be compared with other forms of electricity generation (e.g. large scale hydropower, thermal, wind, solar) on the scale of the impacts per kW of power generated (Abbasi, 2011). It is possible that the impacts of the widespread use of small scale hydropower may be no less numerous or less serious, per kW generated, than those from hydropower produced from large storage dams (Abbasi, 2011).

No accurate statistics on the potential for small scale hydropower are available for Africa. Their rates of development are commonly thought to be lower than for large-scale hydropower (Klunne, 2013). Currently, grid connected small hydropower is mostly constructed and operated by either national utilities or Independent Power Producers (Klunne, 2013). To increase the deployment of small hydropower, as well as, isolated mini-grids and off-grid electrification different implementation models will be required. This is an area that requires further research, although positive examples are available from the Malawi and Nepal case studies in particular.

Financing of small-scale hydropower schemes in low income countries
Small hydropower projects (<10 MW) are often less profitable and thus more difficult to finance than larger schemes. Part of the reason for this may be that they cannot serve large industrial demands which commonly provide contracts for power purchase which a developer can then use to support loan requests to banks. Several of the cost components involved in developing hydropower do not change proportionally with the project's size. However, small scale-hydropower can have a number of environmental and social advantages and particularly where they are not part of a national grid they are likely to provide greater local benefits. There is a need to carry out more research into sustainable financing and business models that are required to facilitate the development of off-grid small hydropower in the low income countries, although positive examples are available from the Malawi and Nepal case studies in particular.

Private sector participation in the development and operation of new hydropower schemes
There is need to carry out more research into how the private sector can effectively participate in hydropower scheme development and operation. Research is needed into how to devise an appropriate "enabling environment" (i.e. providing enough inducements without creating excessive rewards), how to compensate private partners for the provision of public goods and price in the degradation or loss of existing public goods resulting from a development. Methods must also be developed to allocate the "correct" proportion of the risks to private sector partners.

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