MALAWI CASE STUDY:

Harnessing Hydropower

A.P. Hurford, S.D. Wade and
J. Winpenny

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Report Summary

The Harnessing Hydropower study aims to provide an analysis of the historical performance of hydropower in selected countries and an assessment of the risks and opportunities related to future climate change in the context of water, energy and food security. The Malawi case study analyses the past performance of hydropower in the country and identifies priority interventions to help improve performance. It is intended to be useful to those with an interest in understanding the issues surrounding hydropower development in Malawi and/or developing programmes which promote the sustainability of existing or new hydropower schemes in this or similar political, socio-economic or geographical contexts.

Challenges in generating power

Demand for power in Malawi has increased in the last decade, although suppressed by lack of grid access. Only 9% of population nationally have access to the grid and this drops to 0.5% in rural areas (World Bank, 2010). Increasing access is one of Malawi's biggest challenges (Nchembe, 2013). According to Electricity Supply Corporation of Malawi's (ESCOM) estimates, since Kapichira II came online in December 2013 100% of current annual peak demand can be met with all Shire hydropower plants fully operational. However, demand growth means this figure will drop to around 83% by 2016 and 50% by 2022 with no further capacity increases.

Poor maintenance

Hydropower plants which have been in operation for decades have not been well maintained (Nchembe, 2013) due to structural issues within the power sector and shortfalls in funding from a failure to recover costs via tariffs (Consultees, 2013). This has led plants to fall out of production or underperform, reducing the already short supply of electricity. Firm energy from plants on the Shire river from 2010-2013 was around 190 MW with a peak daily generating capacity of 238 MW, 85% of the technical maximum of 279 MW (pre-commissioning of Kapichira-II).

Systemic feedbacks

This case study identified a 'vicious circle' of feedbacks primarily between lack of access to electricity, land degradation caused by removal and burning of forest biomass, and subsequent silt and sedimentation problems causing hydropower production to be reduced. Every 1% increase in silt load leads to a 1.3% increase in operating costs and 3.6% drop in hydropower production (LTS International et al., 2013).

Pressure on resources

A 300% population increase from 1966-2012 increased the burden on land for crop production and fuelwood, leading to clearing and cultivation of increasingly marginal land (Consultees, 2013). Water, energy and food (WEF) security are all negatively impacted as a result. Unsustainable management of crucial natural resources is costing the country 5.3% of its 6% annual GDP growth target (Yaron et al., 2013). In the short to medium term this is likely to be a bigger challenge to WEF security than climate change and will also compound longer-term climate related impacts.

Climate vulnerability

Malawi needs to increase its resilience to the changeable and erratic weather systems of the last two decades which have caused floods and droughts. These climatic features are unlikely to recede through climate change and associated temperature increases. Malawi's climate depends on the position of the inter-tropical convergence zone, which is difficult to predict from climate models. The country also lies on the boundary between two opposing responses to the El Nino Southern Oscillation (ENSO) making above or below average rainfall difficult to predict and project in climate models (McSweeney et al., 2010). In general, however, climate models suggest increased temperatures, wetter rainy seasons and drier dry seasons, with more rain falling in intense events. Intense events are more likely to lead to floods in the short term and droughts in the longer term, especially when falling on degraded land.

Climate change risks

Owing to the uncertainties surrounding likely climate change impacts, it is important that future investments are no/low regrets, and provide adaptability and resilience. The most vulnerable group in Malawi is the rural poor, and one way of improving both theirs and the nation's resilience is through soil and forest management practices which regulate the water cycle more effectively than at present. There is substantial local and international knowledge of how to achieve this and trials of conservation agriculture for example, have shown great promise for incentivising farmers in Malawi by demonstrating benefits 25 times greater than costs over a five-year period (Yaron et al., 2011). Without improvement, Malawi will be exposed to great risks from climate change; the 1992 drought is believed to have reduced annual maize production by around 60% with a related 10% reduction in GDP. The biggest opportunity presented by climate change is using it as a further incentive to act early to gain advantages of more sustainable practices sooner and to avoid compounding negative effects.

Conclusions

The capacity of hydropower schemes alone to improve water, energy and food security is limited. Grid electricity access is too low (1%) in rural areas to provide these households with a timely alternative to traditional biomass and kerosene energy sources, even if grid generation capacity were rapidly and substantially increased. Malawi is in the process of connecting to the Southern Africa Power Pool which will provide more resilient grid electricity and an opportunity to generate export revenues in time. Prohibitive costs of rural grid expansion and unavailability of reliable hydropower resources in many locations mean different types and sizes of hydropower development need to play their role in the country's energy system.

Existing hydropower schemes are run-of-river so while associated with fewer negative social and environmental impacts, they are unable to provide the multiple benefit potential of storage schemes. Storage schemes could provide multiple local benefits and more grid electricity, but the planning horizon for these types of project and the need to manage and mitigate environmental and social concerns make these medium to long-term solutions. Grid-connected hydropower schemes have potential to promote macro-economic growth by increasing the stability and quantity of electricity supply, encouraging investment in both industrial and service sectors. They could also reduce urban demand for woodfuel and charcoal. Considering the current activity in this sector, one option for supporting these kinds of schemes is ensuring environmental and social sustainability. Local micro- or off-grid solutions hold promise for providing more direct benefits to rural communities and increasing both their resilience to climate variability and change and water, energy and food security. The Mulanje Electricity Generting Agency off-grid hydro project is already underway in

Malawi which shows great potential for stimulating small business growth and could inform further investments.

This study suggests the interventions shown in Table 1 are priorities to help harness Malawi's hydropower potential.

1	Action	Expand small off-grid hydropower sector
	Rationale	Small off-grid hydropower has the potential to provide relatively low cost access to electricity to those in remote, off-grid areas of the country which have perennial rivers and elevation changes to exploit. Grid expansion can be costly and time consuming, and ultimately adds further demands to a grid system at the limits of its capacity. Similarly, expanding grid capacity to meet additional and growing demands from rural areas would take much higher investment funding and planning time. Thompson (1994) Collingridge (1980) describes four technical and indicators of inflexibility which can be related in relation to hydropower projects (in Nepal specifically, but applicable anywhere). The technical indicators of inflexibility where higher inflexibility leads to increased risk of failure are: 1. Large-scale 2. Long lead time 3. Capital intensive 4. Requiring major infrastructure early on This indicates that small off-grid hydropower schemes by contrast, are likely to be low risk and therefore relatively safe investments.
	Precedent	The Mulanje Electricity Generating Agency (MEGA) project at Mulanje (Box 7) provides a good example of what can be achieved in Malawi, albeit in areas with the perennial river flow to sustain a hydropower system and make it economically viable. There are further positive examples of small community run hydropower schemes in Nepal (Hurford et al., 2014a)
2	Action	Harmonise national EIA requirements with those of international funding agencies
	Rationale	The HE Power Ltd proposal for hydropower development on the Bua River (Box 5) has received all necessary approvals from the Malawi government, including for its Environmental Impact Assessment (EIA). However, in order for the developers to obtain funding through the African Development Bank (AfDB) they will need to fulfil the stricter EIA conditions of this lender. This prolongs the planning process and delays the expansion of grid capacity as well as creating inefficiencies in the system of development by duplicating studies. It would be much more efficient if Malawi harmonised its EIA requirements with those of international funding agencies, to ensure that one study is sufficient to gain all necessary approvals.
	Precedent	There is a large amount of information available from UNEP on training in environmental impact assessment, including legal, policy and institutional arrangements (UNEP, 2002)
3	Action	Develop national compensation standards for involuntary displacement
	Rationale	The Malawi government currently has no policy for compensating people who are displaced involuntarily by infrastructure developments such as hydropower dams. This has not been problematic thus far, but with plans afoot to develop new storage type hydropower schemes upstream of Lake Malawi, this is set to become an issue. Developers need to be able to factor in the costs of compensation to assess the financial viability of different schemes. Uncertainty can lead to delays or withdrawal of developers due to the objections of local people – these things cost money and time and deter investors. This has been a problem in numerous cases worldwide (International Rivers, 2014) but can be avoided.
	Precedent	The Harnessing Hydropower case study in Himachal Pradesh, India found examples of innovative compensation payment schemes being developed. These are being used to try and better balance the benefits of development between local people (often sacrificing land and livelihoods) and the wider population who benefit from grid electricity (Hurford et al., 2014b)

4	Action	Research and develop payments for ecosystem services approach
	Rationale	It may be possible to increase incentives for farmers to undertake soil and forest conservation measures for example, if payments for ecosystem services (PES) can be negotiated between them and those who stand to benefit downstream.
	Precedent	The Millennium Challenge Corporation (MCC) has included the concept of payments for ecosystem services in its compact with the Malawian Government to revitalize the power sector (MCC, 2013). This is intended to address sedimentation issues in the Shire river by having hydropower producers fund catchment conservation measures by farmers in the upper catchment. This can help incentivise making the investment in changing practices. There are positive examples from Cambodia (Arias et al., 2011) and the South West of the UK where a water company has for example, paid for adaptation measures on farms upstream of reservoirs to improve water quality arriving at the reservoir and thereby reduce their water treatment costs (South West Water, 2014). Measures have included fencing off rivers to prevent cattle incursion and providing covered sheds so that heavy rainfall does not lead to runoff highly polluted with dung. Overall it is cheaper for the water company to carry out these measures than pay for the increased water treatment costs.
5	Action	Analyse trade-offs associated with water resources developments to ensure sustainable resource use and equitable sharing of benefits
	Rationale	Owing to Malawi's water resources system being primarily focussed on a single basin – Lake Malawi, its tributaries and the downstream Shire River, there is significant potential for conflicts to emerge between different uses and users of this system. The interaction between farming practices and downstream water quality is an example of this already manifested. 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.
	Precedent	Different approaches to trade-off analysis are being developed in the research literature (e.g. Räsänen et al., 2013; Gómez et al., 2013; Hurford and Harou, 2014) and the World Conservation Union (IUCN) is leading an innovative project in Kenya's Tana Basin and Ghana's Volta Basin (IUCN, 2014) using many-objective trade-off analysis to identify portfolios of built and natural infrastructure which achieve the best possible (i.e. Pareto-optimal) trade-offs between a broad range of benefits including hydropower.
6	Action	Promote soil and water conservation practices
	Rationale	There are significant issues with the lack of soil and water conservation in Malawi which need to be addressed to increase resilience to climate change. Without this, floods and droughts could increase in frequency and or intensity. Upstream catchment conditions dictate to some extent the response of the catchment to intense rainfall and drought.
	Precedent	There is plenty of knowledge within Malawi and internationally (Consultees, 2013) which is available to be implemented. The payments for ecosystem services recommendation above may support this recommendation, but there are also other incentives which may be useful in persuading farmers to invest in more sustainable practices (LTS International et al., 2013). .

Table 1 **Prioritised interventions for harnessing hydropower in Himachal Pradesh**

SECTION 1

Introduction

1.1 Hydropower's role in world energy systems

Access to affordable, sustainable and reliable energy systems has been recognised as an important part of the post-2015 development agenda (UN, 2013). Hydropower currently provides around 16.5% of the world's electricity (REN21, 2013) and is the main energy source for more than 30 countries (IUCN, 2012). Hydropower could contribute towards climate mitigation through low carbon energy production and adaptation, i.e. where water storage reduces hydrological variability, but it will also likely be impacted by climate change in sometimes complex ways. At its simplest, the availability of water and its changing distribution in space and time are of primary importance.

The significant increase in hydropower generation capacity over the last 10 years is expected to continue over the next two decades with various environmental and social concerns representing the largest challenges to major hydropower developments (Kumar et al., 2011). Given the potential expansion of hydropower schemes to meet local, national or regional energy demands and reduce carbon emissions, it is important to understand how the performance of hydropower schemes can be maximised. This means making the best use of available water resources to meet different needs while protecting the environment and ensuring that hydropower developments are resilient to future climate change.

1.2 Objectives of the project

The overall objective of this project is to analyse the past performance of hydropower in selected countries and assess the risks and opportunities presented by future climate change in the context of water, energy and food security. Three countries, Malawi, India and Nepal, were selected as case studies, providing a wide range of political, socio-economic and geographic settings from which to draw evidence. The case studies aim to identify priority interventions for partner governments and donors to improve performance.

1.3 Objectives of the report

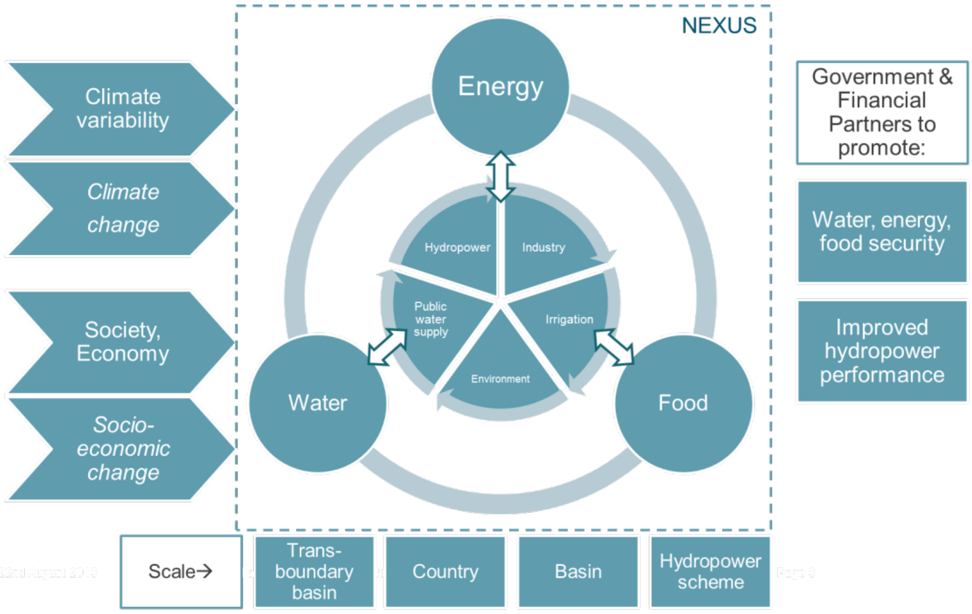
This report presents findings from the case study that focused on Malawi. It is intended to be useful to those with an interest in understanding the issues surrounding hydropower development in Malawi and/or developing programmes which promote the sustainability of existing or new hydropower schemes in this or similar political, socio-economic or geographical contexts.

1.4 A framework for analysis

For each country case study we have adopted a common framework to organise the collection of evidence, frame the analysis and to consider the issues related to hydropower in the context of the broader water-energy-food security debate.

Figure 1 provides a framework based on the research literature on the water-energy-food security nexus (e.g. Jägerskog, 2013). This considers the impacts of climate variability and climate change, future energy demands and the outcomes promoted by governments and financial partners that aim to promote water, energy and food security. It indicates that the performance of hydropower needs to be considered in the broader context of water, energy and food (WEF) security considering the trade-offs between the use of natural resources for different purposes and at different scales from large trans-boundary basins to local small-scale hydropower schemes.

Figure 1 A framework for assessing hydropower performance in the context of water, energy and food security



(adapted from IADB, 2011)

Collecting and interpreting evidence on hydropower performance at national, basin and scheme scales is a challenging task. Many previous studies have involved detailed river basin modelling using various water resources, energy systems and land allocation models to simulate the performance of river basins and in some cases optimise the use of water and land resources to meet specific targets (e.g. McCartney 2007; Tilmant et al., 2010; Mulatu et al., 2013).

We have adopted a different approach focused on understanding the historical performance of hydropower schemes, describing the linkages between water-energy-food issues for selected case studies and then considering options for development interventions to promote sustainable hydropower development.

1.5 Structure of the report

Evidence was drawn from available literature and information gathered by consulting a wide range of stakeholders during case study country visits (Appendix A) and analysis was carried out to illustrate the key issues. This information is presented in five sections outlined below:

- Case study context: A summary of national water, energy and food security literature to provide background information on each case study (Section 2).

- Systematic mapping: Highlighting the interactions between water-energy-food issues supported by some qualitative assessment of potential impacts of climate and socio-economic change (Section 3).
- Hydropower performance and its influencing factors: A review of information and data relating to past hydropower performance provided by documents and through consultations during the country visit (Section 4).
- Ongoing Interventions: Identification of the types of interventions already being undertaken which will influence the performance of hydropower. (Section 5)
- Conclusions: Based on the key issues identified by the case study, six priority interventions are identified and described. (Section 6)

SECTION 2

Case study context

This section describes the political, socio-economic and geographic characteristics of the country which relate to its hydropower potential and water, energy and food security.

2.1 Development status

Malawi is a low income country with a population of over 13.5 million and Gross National Income (GNI) per capita of US$290 (World Bank, 2012). Up to three-quarters of the population live on below $1.25 a day and 40% live on below $1.00 a day (DFID, 2012). In recent years, Malawi has made progress on many Millennium Development Goals (MDGs) with strong economic growth averaging over 7% between 2006 and 2010, driven by strong harvests and improved economic management. The situation deteriorated with Gross Domestic Product (GDP) per capita declining in 2011/2012 to 1.9% (DFID, 2012; World Bank, 2013a) although it has since recovered once more to over 4% growth, which it is expected to maintain (World Bank, 2014). Malawi has one of the world's lowest rates of access to grid electricity, averaging 9% nationally but only 0.5% in rural areas (World bank, 2010). In addition generating capacity is low at 351 MW, with 98% of this coming from three hydropower plants on a single river, the Shire (Figure 2), which is fed by Lake Malawi. Malawi underwent political upheaval in 2012 owing to the death of then President Bingu wa Matharika (Box 1).

As detailed in Section 5 of this report, a broad range of international actors have recognised the importance of Malawi's energy sector and hydropower's role in it and are supporting the government to improve the situation. China and India are key emerging partners. China is currently providing US$190 million in grants and concessional loans for infrastructure development with India providing US$180 million in lines of credit mostly for irrigation (African Development Bank (AfDB), 2011).

2.2 Wider context

Malawi is in a similar position to Ethiopia in terms of water availability per head, high reliance on hydropower and low access to grid electricity for the population. Zambia and Mozambique are in a similar position among African countries for which all data were available, but with higher water availability per head (Figure 3), suggesting that trade-offs between different water uses are likely to be less pronounced.

2.3 Development planning

Since the political upheaval of 2012 (Box 1) two main documents have been used for national planning. The first, Malawi's Growth and Development Strategy II, was developed prior to 2012 and the second in 2012 by the new president, the Economic Recovery Plan, described in Box 1.

2.3.1 Malawi Growth and Development Strategy II (MGDS II)

Malawi's situation has improved significantly since the first Growth and Development Strategy (2006-2011) (Government of Malawi (GoM), 2007) was formulated. Economic growth has exceeded the target of 6% and food security increased for Malawi to become self-sufficient in food production, except in extreme climatic conditions. Malawi faced four years of persistent droughts to 2012 which cause the number of food insecure grow from 2% to 11% (approximately 1.6 million people) between 2011 to 2012 (USAID, 2012).

Figure 2 The position of the Shire River and its existing hydropower plants downstream of Lake Malawi

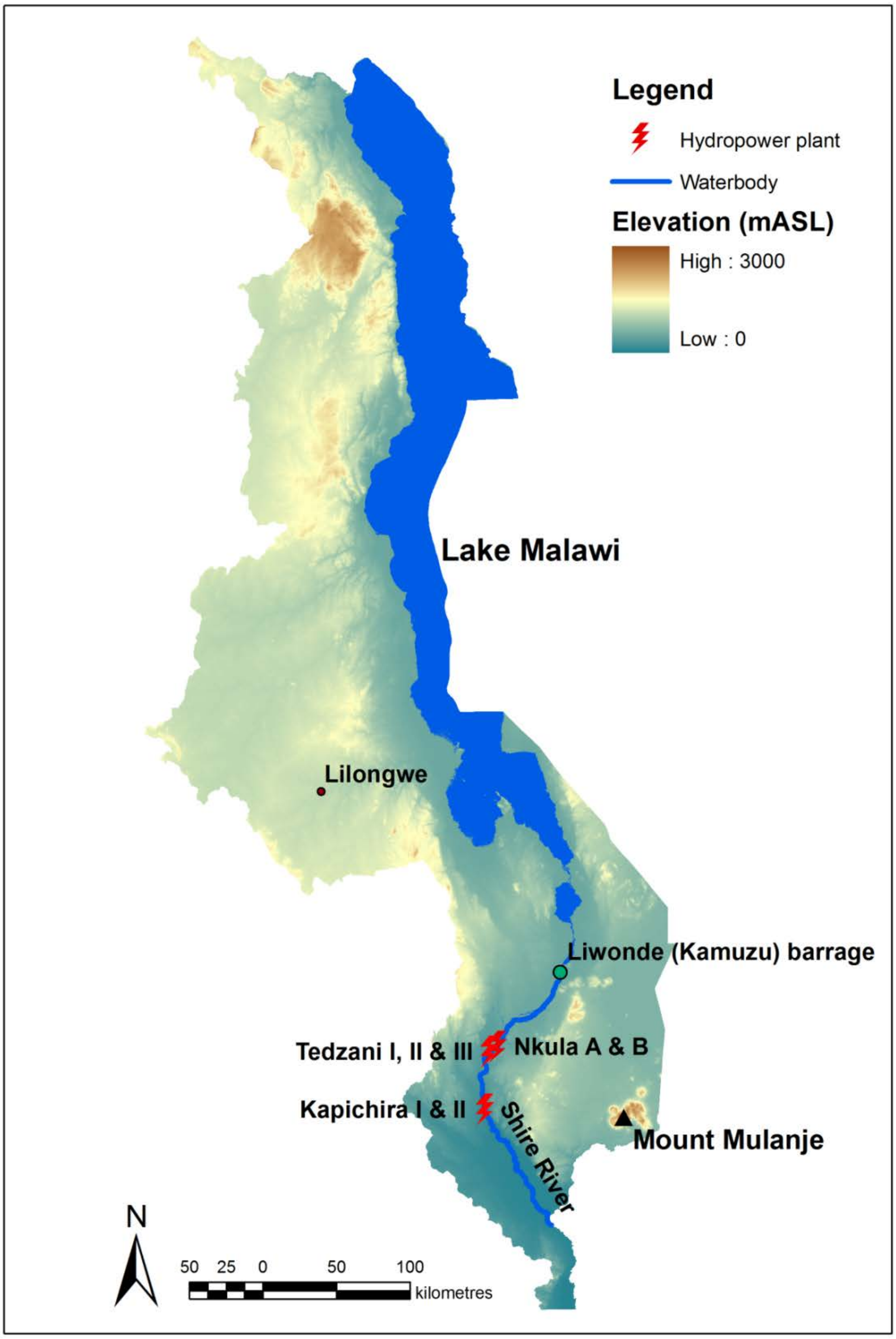
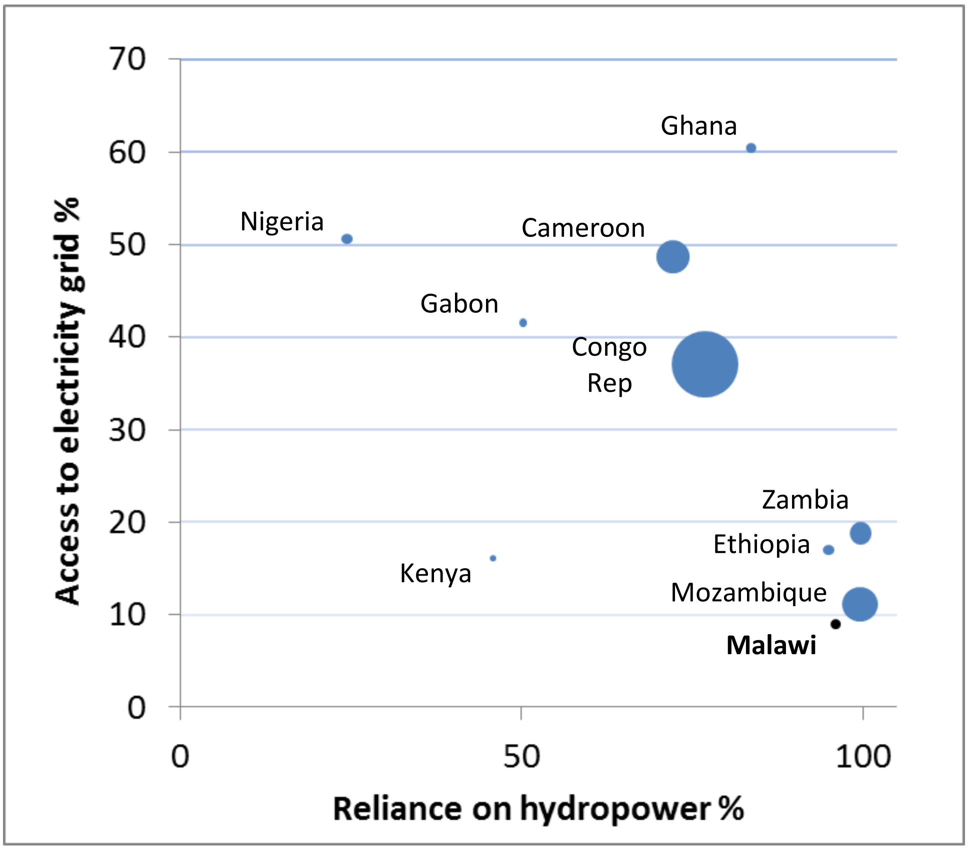


Figure 3 Reliance on hydropower and access to electricity with water availability per head represented by the size of the circles



(Data source: World Bank, 2013b)

MGDS II (2011-2016) (GoM, 2012a) builds on this success, with the objectives of wealth creation and reduction of poverty through sustainable economic growth and infrastructure development. Relevant to the Harnessing Hydropower study, Key Priority Areas include:

- Agriculture and Food Security
- Energy
- Green Belt Irrigation and Water Development
- Climate Change, Natural Resources and Environmental Management

Box 1 Political upheaval in 2012 and impacts relevant to this research

Malawi underwent political upheaval in 2012 owing to the death of then President Bingu wa Matharika. The new President (Joyce Banda) implemented a national 'economic recovery plan' (ERP) (GoM, 2012b) identifying immediate, short, and medium-term interventions to get the country 'back on track'. One of the main aims is improvement of the macro-economic environment to increase private sector participation in the development of the country, including in the hydropower sector. Another is the reduction of energy constraints on economic growth, and specifically:

- Continue financing works at Kapichira II (hydropower) rehabilitation project;
- Establish new hydropower stations;
- Continue pursuing the Millennium Challenge Compact with a view to widen its scope (Revitalising the Power Sector);
- Manage electricity demand by encouraging economic usage of electricity, including usage of energy saver bulbs;
- Encourage regional interconnectivity;
- Explore establishment of coal generated electricity;
- Enhance research in other sources of energy including wind and solar; and
- Promote Public Private Partnerships (PPP) in energy generation and distribution.

In Annex II the ERP specifically identifies the Kholombidzo Hydro-Electric project (run-of-river on the Shire River) as one of three prioritised projects in the energy sector alongside Thermal Power (coal generation) and Regional Power Interconnection (joining the Southern African Power Pool (SAPP)) (GoM, 2012b).

Additionally, impacting on food security (positively or negatively) are policies on the diversification of crops to focus on those with commercial and export market potential such as groundnuts, rice, coffee, sunflower, soya, pigeon peas, cotton, cassava and sugar. There is also a pledge to continue the Greenbelt Initiative (started under the previous President) focussing on irrigation farming of high value crops, aquaculture and animal farming around Lake Malawi.

MGDS II recognises that to achieve an efficient energy supply, strong inter-sectoral linkages especially with the water, natural resources and agriculture sectors will have to be established. An efficient supply of hydropower requires a constant supply of water through proper conservation of catchment areas, connections to neighbouring countries and exploring other sources of energy. The sub-sector will also require strong public-private partnerships especially in generation, distribution and transmission. Main strategies include:

- Improving efficiency in generation, transmission and distribution;
- Ensuring provision of reliable electrification for mining, irrigation, business, tourism, and other economic activities.
- Improving management of Electricity Supply Commission of Malawi (ESCOM) and other service providers
- Accelerating implementation of Malawi-Mozambique (SAPP) inter-connection;
- Constructing mini hydro power stations along the Shire and other major rivers to supplement electricity supply in the three regions.

- Expanding the Rural Electrification Programme (increase resources, promote development of micro hydropower stations and use of solar energy for off grid power supply) and use of both grid and off-grid options;
- Ensuring that energy provision takes into account and puts in place measures to deal with negative environmental impacts that may set in.

(Source: GoM, 2012)

Key strategies for addressing the other areas are shown in Appendix B.

2.3.2 National Adaptation Plan of Action (NAPA)

Malawi developed a NAPA in 2006 (Republic of Malawi (RoM), 2006) which features a number of urgent actions for adaptation and project activities relevant to this study (Box 2). There are however barriers to implementation of these actions and activities which may provide stakeholders with some guidance on possible areas of intervention (Box 3).

Box 2 Five urgent actions for adaptation and project activities relevant to this study (NAPA, 2006)

1) Improving community resilience to climate change through the development of sustainable rural livelihoods:
   a. Improving access to water, including water treatment works,
   b. Improving water management to withstand erratic rains through water harvesting, water conservation, and small-scale irrigation,
   c. Promoting sustainable utilization of *dambos* (river head valleys), wetlands and river valleys under sustainable *dimba* (family garden) cultivation
2) Restoring forests in the Upper, Middle and Lower Shire Valleys catchments to reduce siltation and the associated water flow problems:
   a. Creating buffers of vegetation along the Shire River, and other rivers, such as the Ruo, to physically trap silt, chemicals and other pollutants before they reach water ways
3) Improving agricultural production under erratic rains and changing climatic conditions:
   a. Improving early warning and climate observational systems to improve agricultural extension delivery systems to the farming communities
4) Improving Malawi's preparedness to cope with droughts and floods:
   a. Conducting rapid assessment of drought and flood risk by producing zoning maps,
   b. Designing and testing appropriate strategies, policies and laws to facilitate urgent efforts in dealing with climate disasters,
   c. Preparing drought and flood preparedness plans,
   d. Integrating climate change plans into land use planning,
   e. Constructing and rehabilitating dams and other flood mitigation measures in key areas, including climate proof critical bridges, and
   f. Building multi-purpose dams.
5) Improving climate monitoring to enhance Malawi's early warning capability and decision making and sustainable utilization of Lake Malawi and lakeshore areas resources:
   a. Enhancing the capacity of monitoring stations in terms of data collecting, retrieval and distribution,
   b. Building capacity,
   c. Developing fish breeding facilities in Lake Malawi, rivers and fish ponds to help restock fish in the lake and rivers,
   d. Developing a fish farming enterprise.
   e.

(Source: RoM, 2006)

Box 3 Possible barriers to implementation of National Adaptation Plan of Action (NAPA, 2006)

(i) Extreme poverty of the most vulnerable groups, who are also illiterate, making it difficult to transfer new technologies and conduct meaningful long-term planning,
(ii) Poor infrastructure, especially poor roads and bridges, making it difficult to access rural areas, hence difficulties in delivering farm inputs (e.g., fertilizers and seeds), and accessing markets,
(iii) Limited credit opportunities for rural communities, to allow family households to easily access farm inputs,
(iv) Food insecurity in the Southern Africa Development Community (SADC) that would make it difficult for Malawi to acquire food from neighbouring countries, further aggravating the costs of coping with current droughts and floods,
(v) Existence of a large number of HIV/AIDS orphans, creating a major drain on family energy, cash and food, a situation that is more critical in rural areas among the poor, with limited capacity to produce enough food and are easily attacked by diseases,
(vi) Poor health conditions of resource poor rural communities, leading to high rates of malnutrition, especially in children and the elderly, limiting the ability of the people to effectively respond to opportunities for work, and
(vii) Limited analytical capability of local personnel to effectively analyse the threats and potential impacts of climate change, so as to develop viable adaptation solutions.

(Source: RoM, 2006)

2.4 Water, energy and food security status

This section describes the current status of Malawi in terms of water, energy and food security.

2.4.1 Water security

Malawi has significant freshwater resources and a surplus of water available in the Shire River downstream of Lake Malawi (Figure 2) in average and moderately dry years. Water availability per head is approximately 1,049 m^3 per annum, which is average for sub-Saharan Africa (World Bank, 2013b). Urban and rural communities have reasonably good access to water for household water use. However, a lack of water resources infrastructure means that resources are not fully utilised for irrigation, industry or public water supply. Only 6% of available water resources are abstracted[1] (World Bank, 2011) and as such Malawi can be characterised as low to moderately water stressed (Falkenmark, 2013).

The recent national water resources management plan identified and prioritised investment needs for irrigation and public water supplies, improving water quality and dealing with sedimentation and aquatic weed growth problems in some river basins (Atkins, 2011b). Future water availability is likely to be affected by climate and land use change, including land and water management in the trans-boundary Lake Malawi basin . Future water resources development in Malawi therefore requires an integrated approach at basin scale,

[1] Most water abstracted is used for agriculture (84%), followed by domestic use (12%) and industry (4%); over 80% of the rural and 95% of the urban population have access to improved water sources (World Bank, 2011).

considering, water quantity and quality and the trade-offs between using water for hydropower and irrigated agriculture (Atkins, 2011b).

2.4.2 Energy security

Malawi's energy mix is based on the use of heavy fuel oil, diesel and existing hydropower facilities as well as fuel wood, which is hugely important for household energy, comprising 95% of rural and 55% of urban energy supply. Charcoal provides around a third of urban household energy supply (Yaron et al., 2011).

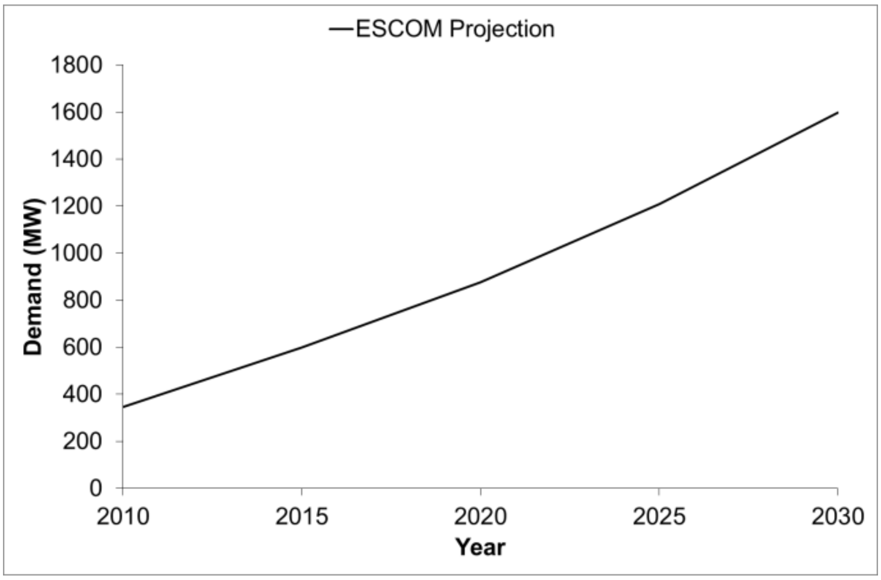
The total national installed capacity for electricity generation as of January 2014 is 351 MW, 98% of which comes from hydropower plants on the Shire River. Electricity Supply Corporation of Malawi Limited (ESCOM) is the country's parastatal electricity generation and transmission company, responsible for all aspects of the grid and generation. ESCOM is regulated by Malawi Electricity Regulatory Authority (MERA). Projections suggest that demands will increase more than four-fold by 2030 (Figure 4) from a 2010 baseline. National coal reserves are proven and being mined and plans are in place to increase the diversity of electricity sources by developing a coal fired power station (GoM, 2012b; MNREE, 2010). The country is nevertheless very likely to depend on electricity imports as well as new hydropower schemes.

Access to electricity is a significant problem and Malawi is one of the least electrified countries in the world. Transmission lines extend the entire length of the country and most villages are situated quite near the grid but access to electricity is only 9% of the population (30% in urban areas and 0.5% in rural areas (World Bank, 2010)). Access in rural areas has made little progress over the last two decades. Box 4 describes the relationship between access to energy and the Millennium Development Goals in Malawi.

2.4.3 Food security

Agriculture is Malawi's most important economic sector, employing about 80% of the population. Maize accounts for over 80% of cultivated land; the country produces an average of 3 million tonnes of maize annually, above the 2.3 million tonne level needed for self-sufficiency. However, widespread food shortages are commonly experienced in rural areas. This is attributed by the 2006 NAPA to floods and droughts causing acute crop failure despite attempts at seasonal forecasting. Chronic food insecurity and malnutrition lead to health related problems in these communities. The Lower Shire has seen some of the worst floods (2000/01) and droughts (1991/92) in living memory in recent times.

Figure 4 ESCOM demand projections 2010-2030



Over-use of marginally productive lands, soil erosion and nutrient depletion, poor access to financial services and markets, unfavourable weather events, and small landholdings all combine to exacerbate food insecurity. Post-harvest losses are estimated to be around 40% of production. According to the Malawi Vulnerability Assessment Committee report released in June 2012, more than 1.6 million people in rural areas would be at risk of hunger in 2012 and 2013 (IFPRI, 2012).

2.5 The role of hydropower

Hydropower provides the main source of electricity generation and continues to figure strongly in the Malawi Electricity Investment Plan of 2010 (Ministry of Natural Resources, Energy and Environment (MNREE), 2010), in the short-, medium- and long-term:

- The short-term plan is to increase capacity by 234MW by completing Kapichira II (Commissioned December 2013), upgrading Nkula A and installing ‘hydromatrix’ retrofit turbine-generators. Expected total costs are US$193 million.
- In the medium-term, eight hydropower plants could contribute, alongside a coal-fired plant, biomass and wind installations, to a further 1240MW increase at a cost of US$1.25 billion.
- In the long-term, the proposed Kholombidzo barrage on the Shire River is expected to be accompanied by hydropower plants on the North Rumphi and Luweya rivers and a modular nuclear power plant to generate an additional 770MW at a cost of US$754 million.

(Source: MNREE, 2010)

In the medium to long term, climate change projections suggest that Malawi may rapidly move from a country of surplus water resources to one of water scarcity as dry season flows decline and agricultural demands increase (Gamula et al., 2013; Atkins, 2011a). Therefore, increased competition between different water users may affect the performance of existing and new hydropower schemes.

Box 4 Relationship between energy and the Millennium Development Goals in Malawi

1. Eradicate extreme poverty and hunger

In most rural and urban areas of Malawi, the poor are getting poorer. This mainly affects women, due to the scarcity of household energy for cooking, i.e. need to collect firewood.

2. Achieve universal primary education

Scarcity of biomass fuels is contributing to poor feeding of school children both at home and at school. Children from poor families spend many hours fetching firewood, which affects their health and studies. While the current school feeding programme meets the nutritional needs children attending school, in most cases the cooking does not use energy efficient sources and thus exacerbates the already poor natural resource base.

3. Promote gender equality & women empowerment

Collection of biomass (firewood) is one of the most difficult tasks being performed by women in Malawi, in both the rural and urban areas. It takes most of their energy and time, and affects their health and welfare. Provision of reliable and affordable energy services for household cooking will contribute to gender equality and empowerment of women. Access to light will allow school girls to study after they finish attending to household tasks.

4. Reduce child mortality

Scarcity of biomass fuel to boil drinking water for children, boil water for bathing, exposure to smoke and poor lactation by mothers who spend considerable time in collecting firewood are factors contributing to high child mortality. Energy is required for storage of vaccines which require refrigeration. Modern energy services make this possible at the rural level.

5. Improve maternal health

Pregnant women and lactating mothers spend many hours fetching and carrying heavy loads of firewood. Due to scarcity, plastics are used to supplement the wood, charcoal and other wastes that smoke heavily, causing air pollution which is a health hazard to women and children. Women are avoiding cooking nutritious foods like beans that require high energy inputs due to the scarcity of biomass fuels. These factors are hindering efforts to improve maternal health. Poor lighting in delivery rooms as a result of no electricity is another hindering factor in improving maternal health which could be addressed through the introduction of renewable energy technologies.

6. Combat HIV/AIDS, malaria and other diseases

Collection of biomass fuels over large distances, away from home and in the wilderness, exposes women to the risk of harassment and unsafe sex, spreading HIV/AIDS.

7. Ensure environmental sustainability

Malawi is a net emitter of greenhouse gases resulting mainly from burning wood for cooking and from the limited use of coal in industries. The unsustainable use of biomass fuels and clearing of forests to obtain firewood or open up land for agriculture are the main contributors to climate change. The supply potential of biomass fuels has declined in almost all regions, causing deforestation that is now also contributing to soil erosion, floods, destruction of catchment areas for water, drought and reduction of agricultural productivity, hence accelerating poverty.

8. Develop a global partnership for development

Innovations in modern energy supply provide an opportunity for partnerships. The capacity of developing countries to come up with new technological innovations is limited but can be enhanced through partnership with developed and other developing countries.

(Source: UNDP, 2013)

2.5.1 Hydropower and economic growth

The major challenge for Malawi is to diversify its land-locked agro-based economy and spur private sector growth, which until now remains sluggish (AfDB, 2011). Improvement of poor infrastructure in general and hydropower in particular are linked strongly to economic growth. The energy supply-demand deficit is recognised as a major constraint on economic growth (Gamula et al., 2013) and has, according to AfDB, discouraged would-be investors in both the industrial and mining sectors from seriously considering investing in the country (AfDB, 2013).

"The capacity of the aged Nkula and Tedzani hydro power generation plants is failing to keep pace with increasing demand. As a result power outages have become frequent. The Electricity Supply Corporation of Malawi (ESCOM), GoM's sole electricity company, has a total installed capacity of 302MW[2] (95% hydro). Only 265MW is available against a demand of 295MW. Demand is growing rapidly and is projected to reach 478MW by 2015. A World Bank Enterprise Surveys conducted in 2009 showed that lost sales due to power outages in Malawi were 17%, the third highest among 118 countries included. Energy constraints are already affecting investments and economic growth. The Kayerekera uranium mine is operating using diesel power generators as ESCOM could not guarantee power supply". (AfDB, 2011).

In this context infrastructure development (including hydropower) and agricultural growth are both important national objectives but these need to consider (i) the interactions between water-energy-food objectives and (ii) the potential impacts of climate change on water security.

2.6 National Water Resources Assessment

A comprehensive water resources study for Malawi was completed in 2011 that identifies water availability on a catchment basis and the major constraints on water use under a range of design flow conditions and under future conditions, considering climate and socio-economic change (Atkins, 2011a & 2011b). While the baseline supply-demand balance is healthy across most of the country for 'average dry' conditions, the lack of infrastructure means that not all the resources can be exploited. A scenario for 2020 of the dry season water balance with medium economic growth showed that resources are still expected to be available in the Shire basin but there are supply-demand deficits in most other basins.

The Atkins study was a coarse national assessment and some of its findings may be misleading at the sub-catchment and local scales. For example it used 1991 as the design "drought year" as this affected the entire country but flows were not low in 1991 in the River Shire, which is Malawi's major water resource.

2.6.1 Recommendations of the assessment

The main pressures on the water supply-demand balance are increased agricultural demands, combined with a reduction of dry season flows due to climate change. Together these indicate that there may be shortages of water under 'average dry' and drought conditions and important trade-offs between water for hydropower generation and irrigated agriculture (Box 5). The recommendations of the national water resources assessment were strongly in favour of (i) prioritising public water supplies as these had the greatest economic benefit; (ii) protecting and prioritising flows for existing and new hydropower and (iii) only

[2] Quoted figures are direct from the cited document so discrepancies in installed capacity cannot be accounted for by the authors of this study. They may be a function of reporting in 2011.

promoting irrigated agriculture upstream of hydropower schemes (including the entire Lake Malawi basin) that demonstrated very high benefits per unit of water use. The report favoured limiting the areas of irrigation in basins with water scarcity and favoured construction of storage to improve the reliability of irrigation schemes.

As with any long term water resources planning the study involved making a number of assumptions, for example on the future performance of hydropower, efficiency of irrigation and economic benefits related to different investment strategies. In addition, other more recent studies of the Shire River have presented a very different water resources picture, with greater scarcity and favouring increased irrigation at the expense of hydropower performance (NORPLAN, 2013).

Box 5 Findings from the 2011 Water Resources Assessment

- In an average year, there is estimated to be a national surface water resource availability of approximately 42,500 Ml/day.
- The River Shire catchment downstream of Lake Malawi is the country's major water resource providing approximately 80% of dry season flow. This is where the major hydropower plants are located as well as important existing sugar cane production and proposed new irrigation schemes. There is currently little conflict as irrigation schemes are downstream of hydropower schemes which are run-of-river so store little water.
- There is currently little surface water resource available under extreme drought conditions, although some Water Resource Areas (WRAs) do retain some limited resource availability.
- By 2035, due to the effects of climate change, wet season yields rise by approximately 4%, whilst average dry season resources are projected to reduce by 10% by 2035. This will increase the demand for water for irrigation of crops.
- Over the same time period, drought condition dry season resources are predicted to reduce by nearly 50% to just over 4,000 Ml/day. The climate is highly variable so moderate droughts may occur as frequently as 1 in 5 or 10 years but the real concern of the River Shire would be a long period of years or decades with lower rainfall, which would reduce Lake Malawi levels substantially.
- Sustainable groundwater resources are estimated to make up only 2% (1,300 Ml/day) of the nationally available total water resource.
- Water use is constrained by a lack of infrastructure
- There are significant risks related to weed infestation from invasive species and erosion and sedimentation in some basins, including the Shire Basin where the majority of hydropower is generated.
- Poor water quality is also an issue that may limit water use, particularly under future conditions. Soil erosion and nutrient pollution are the main drivers and under future scenarios there will be less water in the dry season to dilute pollution. The impact is most likely to be felt downstream of Lake Malawi where sediments are not settled out by retention

(Source: Atkins, 2011a)

The national assessment raises a number of issues that are directly relevant for this project, for example:

- How sensitive are the findings to the performance of hydropower and to what extent is the recommended national strategy valid if hydropower under-performs due to lower flows, sedimentation or other outage events?
- Can the major agricultural investments, such as the major "Green Belt Initiative", deliver economic growth if water availability is constrained?
- Will smaller scale farmers have access to water for growing crops in areas of water scarcity and where there are potential conflicts with hydropower needs?
- While there are specific issues in the Shire River, are there opportunities for delivering small-scale hydropower, off-grid solutions and agricultural growth in the larger Lake Malawi basin, without detrimental impacts downstream?
- In the context of considerable uncertainty due to climate change and the rate of economic growth can interventions be identified that are 'low regrets', adaptable as the directions of change become apparent and can be made resilient in the longer term?

Box 6 shows the strategic priorities identified by the Water Resources Investment Strategy

Box 6 Strategic priorities identified in the Water Resources Investment Strategy

- Public water supply should take priority where water is scarce.
- Maintaining inflows to the Lake Malawi-Shire system should be a top priority. This will involve limiting consumptive water use upstream of and from Lake Malawi to essential, water efficient and high benefit uses. It will also require cooperation with Tanzania and Mozambique, both important sources of inflow to the system.
- Significant inter-seasonal storage, backed up by conjunctive use of groundwater where appropriate, is likely to be required to meet non-irrigation (principally public water supply) demand in many basins. The need for storage is likely to increase with climate change.
- Irrigation upstream of/from Lake Malawi should be restricted to schemes which provide high benefits (e.g. crop yield or value) relative to their water use.
- Preference should be given to arrangements where irrigation abstraction takes place downstream of hydropower production. Hydropower should take priority where there is conflict between these uses, unless the irrigation is expected to produce high economic benefits.
- Construction of inter-seasonal storage should be considered for non-Shire hydropower schemes due to the highly seasonal flows and cost of alternative power supplies.

(Source: Atkins, 2011b)

2.7 Climate change impacts and adaptation

This section first describes the climate projections for Malawi before contemplating the possible impacts on hydropower and other sectors. Urgent actions for adaptation and project activities relevant to this study under the National Adaptation plan of Action (NAPA) are then highlighted.

2.7.1 Baseline climate

Malawi's wet season rainfall depends on the position of the Inter-tropical Convergence Zone (ITCZ) which can vary in its timing and intensity from year to year. Topographical influences also cause local increases in rainfall with altitude. Inter-annual variability of rainfall is strongly influenced by the El Nino Southern Oscillation (ENSO), but the particular way ENSO influences Malawi's climate is difficult to predict as the country lies on the boundary of two opposing responses. These can cause either above or below average rainfall

2.7.2 Climate projections

Models show wide disagreements about the changes in ENSO events and this uncertainty is translated into considerable uncertainty related to Malawi's future climate, particularly seasonal rainfall and projected river flows (McSweeney et al., 2010a & b). Recent multi-model assessments show that individual climate models disagree on changes in annual discharge for Malawi's rivers (Schewe et al., 2014).

Temperature is projected to increase as a result of climate change, with more 'hot' and less 'cold' days and nights. Mean annual temperature is projected to increase by 1.1 to 3.0°C by the 2060s, and 1.5 to 5.0°C by the 2090s (McSweeney et al., 2010a & b).

Mean annual rainfall is not projected to change substantially although different models project a large range from -13% to +32% change. Within the year, dry season rainfall is projected to decrease (-5 to -20% ensemble median) while wet season rainfall increases (+1 to +11% ensemble median) (McSweeney et al., 2010a & b).

Models consistently project increases in the proportion of rainfall that falls in heavy events, these events increasing in the wet season and decreasing in the dry season. This could suggest increased likelihood of flood events (McSweeney et al., 2010a & b).

2.7.3 Impacts on hydropower schemes

Future hydropower performance is likely to be affected by both climate change and socio-economic change. For example, potential challenges include:

- Flows in the Shire River and therefore hydropower generation from plants on it are highly dependent on Lake Malawi water levels, meaning they are extremely vulnerable to drought. Higher temperatures could increase evaporation rates, which may not be sufficiently balanced by rainfall and river flows to maintain water levels. There is a history of droughts affecting the lake's outflows. This presents a major risk to electricity generation on the river (Kaunda and Mtalo, 2013).
- Increased incidence of floods cause damage to hydropower and other infrastructure as occurred at the Tedzani power stations in 2001 (Kaunda and Mtalo, 2013). Loss of power generating capacity has serious national economic consequences. Sediment levels in the Shire River could increase as a result of changing rainfall patterns and especially more intense rainfall events. Sedimentation is already a serious problem, causing damage to hydropower turbines and loss of storage capacity for providing peak demand power generation. Without action to address upstream catchment

degradation (the primary source of the sediment) generation reductions or outages such as those at Nkula in 1996 and Kapichira in 2003 (Kaunda and Mtalo, 2013) could become more common.

- There is evidence that aquatic weed infestation could be getting worse with climate change (Theuri, 2013). Aquatic weeds already cause disruption of hydropower generation on an annual basis, and cost hundreds of thousands of US dollars to manage (Kaunda and Mtalo, 2013) to prevent more frequent problems. Weeds interact with sedimentation problems by slowing the flow, allowing more deposition of sediment which reduces storage capacity.

2.7.4 Other impacts

In terms of climate change's possible impacts on agriculture, it is estimated that the 1992 drought reduced the country's annual maize production by around 60% leading to a 10% reduction in GDP (RoM, 2006). More regular droughts could severely hinder Malawi's attempts at economic expansion. Floods can lead to compromised water quality and associated diseases such as diarrhoea, cholera and malaria.

2.8 Selected case study basin: The Shire Basin

The Shire River basin is the country's major water resource providing hydropower and resources for agriculture. The Shire River begins at the outlet of Lake Malawi and its catchment is considered to be the area which flows in to the river below this point. However, the volume of water in the lake and the behaviour of its catchment also impact on flows in the Shire River. This includes most of the surface of Malawi and parts of Tanzania and Mozambique. The main components of the system are shown in Figure 5 with Lake Malawi providing storage and balancing of flows from upstream basins. The geographical locations are better illustrated in Figure 2. Outflows from Lake Malawi are controlled by lake levels and regulated by the Kamuzu Barrage. There are currently three hydropower dam sites in a cascade that now provide a cumulative capacity of 343 MW[3] (including Kapichira II) (Figure 2). There are a number of tributaries that provide additional flows in the wet season (November to April), an off-take for public water supply and several existing significant irrigation schemes both upstream of Nkula dam and Kapichira dam. An additional turbine is being installed at Kapichira and at the same time a major irrigation project is under consideration, the Shire Valley Irrigation Project (SVIP).

Outflows from the lake have been affected by geomorphological changes, specifically the formation and evolution of sand bars at the outlet, and possibly tectonic movement of the Great Rift (Nicholson, 1998). During the early 20th century there was a long period of low lake levels and low or no flow from Lake Malawi (Figure 6); this historical variability from effectively 'no flow' 1900-1920 to periods of flooding in the 1980s is of much greater magnitude and significance than projected climate change. The large number of studies on the River Shire and the water resources available for different uses and their conclusions are strongly influenced by the choice of hydrological series used to assess reliability and risk (Atkins, 2011a; NORPLAN, 2013); if the early 20th century low flow period is included many investments may appear to be high risk and unsustainable but if a shorter record is used that reflects the current system there appears to be sufficient resources for sustainable growth of hydropower and some agriculture.

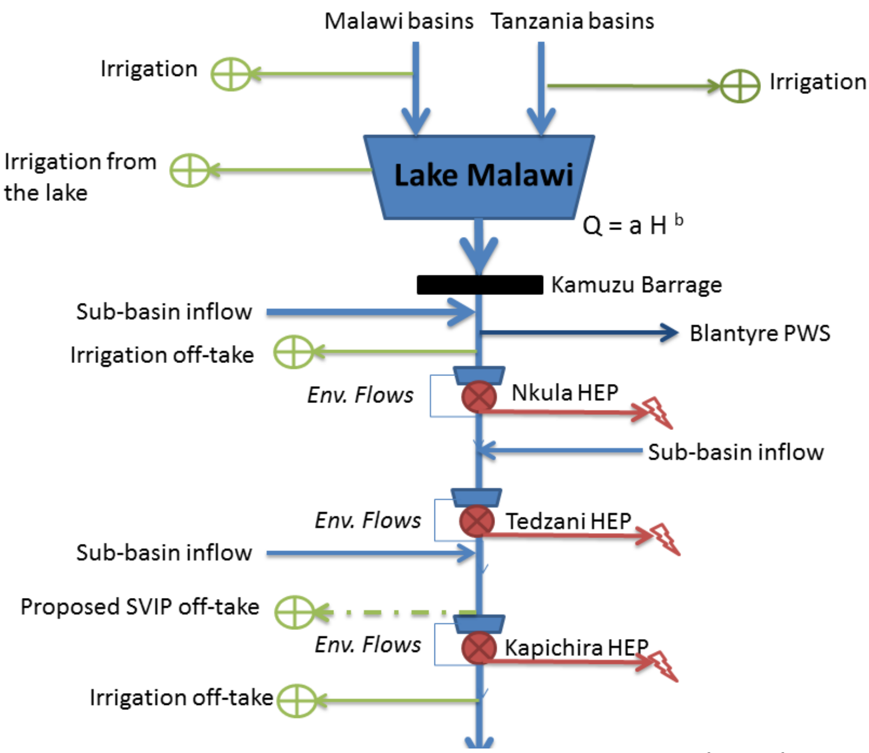
[3] This is the total generation capacity on the Shire River alone. There is a small 4MW hydropower scheme on the Wovwe River and a small amount of diesel generation capacity. There is also some inconsistency in numbers quoted by different sources.

The National Water Resources Assessment (a component of Atkins, 2011a & b) suggests that there are sufficient resources in the Shire basin to meet demand even during periods of very moderate drought (based on 1991 as a drought year and a demand of approximately 1000 Ml/d or 11.5 m^3/s). However, in Section 3 (Figure 13), we show that the development of new irrigation schemes and new hydropower requirements mean that there could be a shortage of water in moderate to severe drought years.

The national assessment highlights the existence of an 'infrastructure deficit', i.e. that more investment is needed to make use of the available water resources (Atkins, 2011a). The two main metrics for this assessment are the water resource balance and the infrastructure balance. The water resource balance is defined as the forecast total demand for water compared with the forecast total surface water and groundwater yield (i.e. how much water is available from the available sources). It therefore identifies the lack of availability of water resources within a given water resources area. The infrastructure balance is defined as the forecast total demand for water over the capacity of the existing water infrastructure (i.e. how much water can actually reach consumers using existing engineering schemes). It therefore identifies the presence or absence of infrastructure capacity issues and the overall size of the investment problem to be resolved, irrespective of the source of that water where one exists. These metrics are considered during average wet season conditions, average dry season conditions and an extreme drought (using the 1991 event as a benchmark), both now, in 2020 and in 2035, under a range of economic growth scenarios.

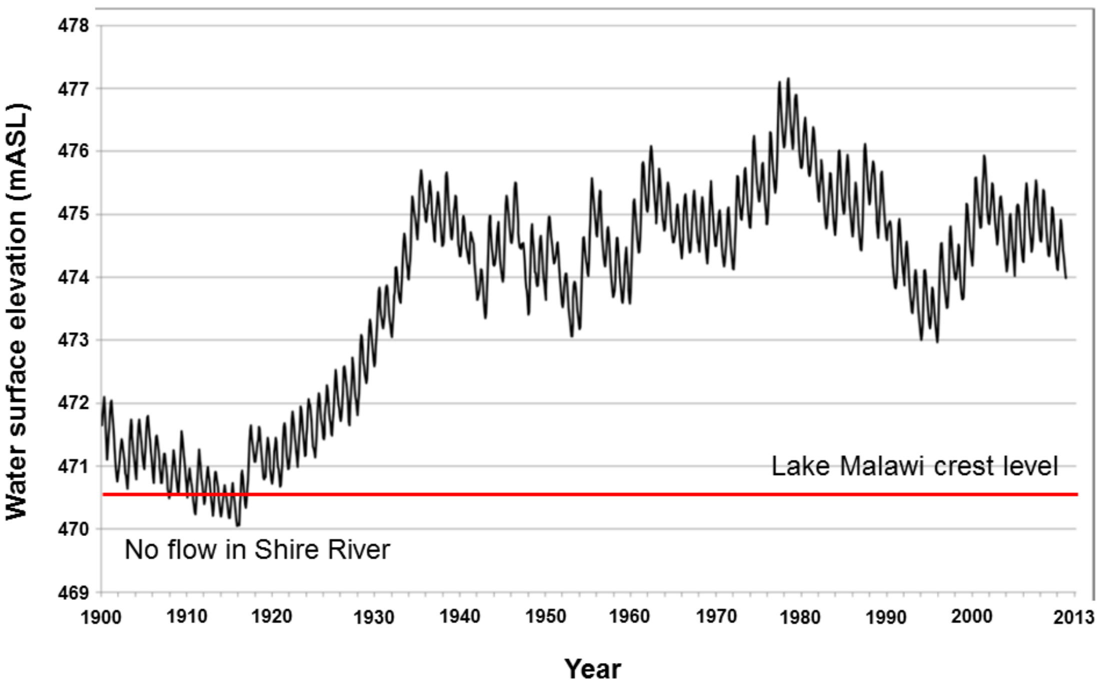
Resources are still available under future climate change scenarios but the infrastructure deficit increases and the demand for water for irrigation is anticipated to rise significantly under a medium economic growth scenario (leading to an infrastructure deficit of approximately 5,000 Ml/d). The report also indicates that there is a high risk of sediment issues (in 10% of the Shire basin) and a high risk of weed infestation by invasive aquatic reeds (Atkins, 2011b).

Figure 5 A simplified schematic of the River Shire system



(Based on NORPLAN, 2013)

Figure 6 Average monthly water levels at Lake Malawi in the period 1900-2011 showing the periods for Scenarios used in the modelling from the NORPLAN, 2013 study of the Shire Basin



(Source: NORPLAN, 2013)

2.9 Section summary

This section has shown the following main points:

- Malawi faces significant development challenges, despite good performance against Millennium Development Goals.
- Water security is high in terms of water availability, but low in terms of the risks of floods and droughts.
- Energy security is low, owing to the lack of access to electricity for the majority of the population who live in rural areas. Their use of traditional biomass energy sources is unsustainable.
- Food security is low owing to degraded land and risks from floods and droughts.
- Electricity supply is a major constraint on growth.
- Hydropower development is intertwined with issues of natural resource management upstream.
- Trade-offs are emerging between the use of water upstream for irrigation and hydropower downstream.
- Malawi is highly vulnerable to climate change, especially because of the land degradation which has taken place over recent decades.
- Climate change is on the agenda and has been considered in the National Water Resources Assessment and Investment Strategy.

SECTION 3

Systematic mapping

This section takes a look at where hydropower sits within the system of interactions between water, energy and food security in Malawi. It begins by providing a schematic map of current system interactions, before considering how climate change and socio-economic change might perturb the system.

3.1 The ‘vicious circle’

Figure 7 illustrates the current interactions in the system in which hydropower is embedded. This is necessarily a simplification but gives a basic understanding of the issues which are evidenced by the material gathered under this study. It shows how certain features of the system directly affect water, energy and food security, while others have a contributing role. Feedbacks in the system are undermining attempts to increase hydropower production and availability of electricity to the country. The system can be seen from various perspectives however. For instance, the lack of access to modern forms of electricity can be linked through a chain of consequences to reduced crop yields and increased costs of providing public water supply, due to increasing deforestation, land degradation and siltation. These feedbacks must be broken to allow the system to develop sustainably.

Figure 7 Hydropower system interactions in Malawi impacting on water, energy and food security both within the state and downstream

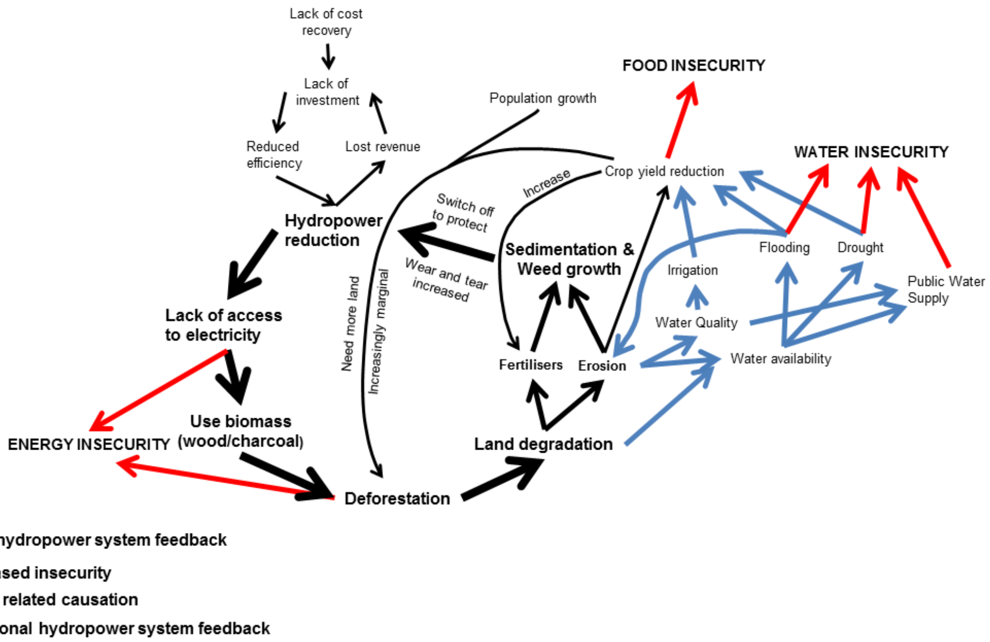


Figure 7 is explained below by focussing on the main features of the cycle marked by thick black arrows.

3.1.1 Hydropower reduction

Hydropower generation is currently reduced by three main factors: 1) the need to turn off turbines to protect them from high sediment loads or aquatic weed infestation, 2) Lack of maintenance leading to inefficiency/mechanical breakdown, 3) Lack of water during severe drought periods[4].

Lack of maintenance itself results from two main factors: 1) reduced revenue resulting from shutdowns, and 2) Lack of cost recovery through the electricity tariff system.

3.1.2 Lack of access to electricity

Hydropower is currently insufficient to meet peak demand: the maximum recorded demand was 279.72 MW as registered at 07:30Hrs on 6 August, 2013; with load shedding[5] of 19.33 MW (net availability 260.39 MW), against a total installed capacity of 287MW (Nchembe, 2013). Note that demand is suppressed by the lack of access to grid electricity.

Lack of access to electricity also results from poor grid penetration across the country and the capacity of the transmission system. This leaves access unbalanced between rural areas where 80% of the population live and urban areas. In 2010 grid access stood at 30% of urban households but only 0.5% of rural households, averaging 9% nationally (World Bank, 2010).

Increasing access to electricity would itself generate more demand. Without additional capacity expansion, performance of hydropower in meeting demand could actually decline overall (although more people would be benefitting).

3.1.3 Use biomass (wood/charcoal)

Lack of access to electricity forces people to use other forms of energy. There is not a strong market for Liquid Petroleum Gas (LPG) in Malawi, owing to lack of foreign currency to import it. The primary energy sources for cooking in rural areas are fuelwood and charcoal. For lighting, kerosene is often used. In urban areas with access to electricity, electric lights and cookers are available but charcoal is stocked for cooking in case of power cuts.

Production of charcoal is a lucrative business for rural populations exporting to urban areas. Production requires additional quantities of wood to be burnt, in excess of that which actually becomes charcoal, exacerbating pressure on forestry resources.

3.1.4 Deforestation

Deforestation results from two main processes; the cutting of wood for fuel and charcoal and the clearing of land for conversion to agriculture. Clearing of land is required due to increasing population pressure in a largely rural economy. As crop yields decline due to land degradation this can be balanced by increasing productive area. Deforested land tends to be more marginal (i.e. steeper slopes and lower quality soils) as the better land has usually been brought into production first.

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4 Note that drought in the context of Lake Malawi is a long duration drought over many years, when the lake received less inflows and levels are reduced.

5 Load shedding involves purposefully shutting off sectors of the grid to prevent demand exceeding supply. This can be done on a rotating basis, often known as “rolling blackouts” or where a common occurrence may be publicly scheduled for particular areas at particular times of day so people can plan around it.

3.1.5 Land degradation

Deforested land, especially on steep slopes loses stability. This leads to increased erosion or landslides. Experimental results from the UK show rainwater runoff generation processes can also be different on deforested than on forested land. Less water penetrates the soil through conduits formed by tree roots, so runoff is increased. Soil water storage potential can also be higher under tree cover (Marshall et al., 2009, Archer et al., 2013). Land degradation therefore tends to increase flooding by increasing runoff rates and increase droughts by decreasing water storage in the ground. This has implications for water availability.

Increased runoff is a greater erosive force. As land is eroded, it loses nutrients and therefore fertility. Where fertiliser is applied, rainwater runoff can lead to these being washed away. These effects are exacerbated where fields are tilled to provide planting ridges which channel water downslope (Consultees, 2013). Loss of nutrients and availability of irrigation impact on crop yields. Erosion has implications for water quality downstream, through both physical sediment and nutrient pollution. Declining water quality can increase costs of treatment required for irrigation and public water supply (Table 2).

Water resources board	% change in treatment cost increase for 10% increase in sediment yield
Lilongwe	1.6
Southern region – Chiradzulu	1.4
Southern region – Mwanza	1.3
Northern region – Mzimba & Rumphi	2.9
Northern region – Karonga	0.6
Northern region – Nkhata bay	No correlation found

(Source: LTS International et al., 2013)

Table 2 **Increases in water treatment costs associated with increasing silt loads**

3.1.6 Sedimentation and weed growth

In the Shire River in recent years sediment loads and aquatic weed infestations have become an increasing problem. Although the subject of on-going studies, it is likely that weed growth is promoted by nutrients washed off agricultural lands. The removal and management of weeds costs ESCOM hundreds of thousands of US dollars per year. The weeds still 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). Certainly the sediment loads are attributable to land erosion upstream. There is some debate about how much is sourced in riparian land such as marshes frequented by elephants, and how much is carried off agricultural land. The main water management problem faced by the irrigation interests in Lower Shire is at present the heavy silt content of the water. Continuous mechanical removal of silt from the intake channel is needed to maintain irrigation operations on the Sucoma Sugar Estates (Consultees, 2013).

3.2 Future forcing of the circle

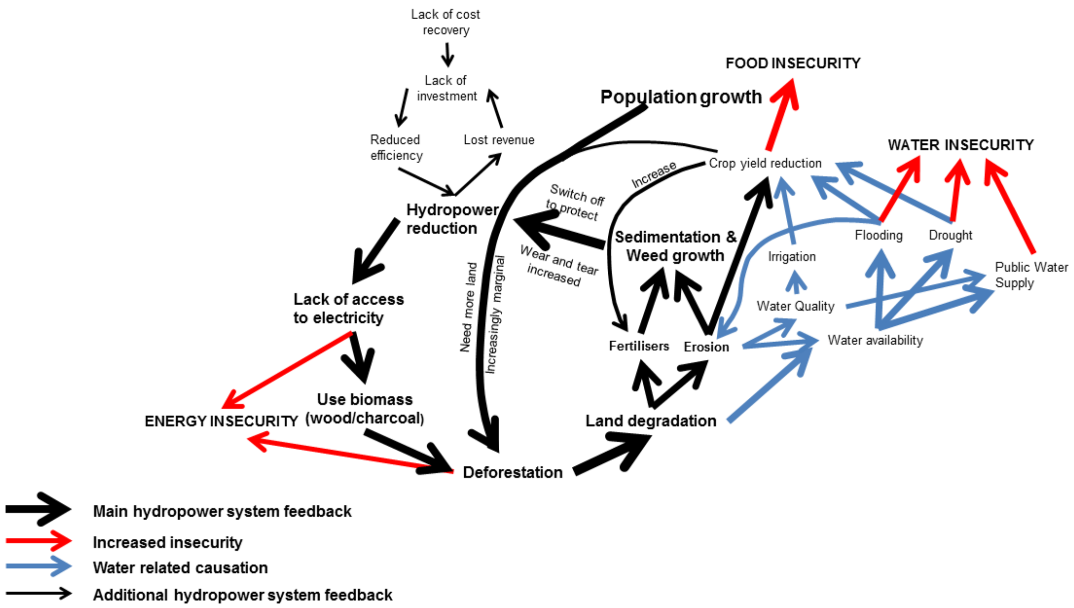
The system described above is dynamic and subject to many influences both inside Malawi and beyond its borders. Below we describe how socio-economic changes and climatic changes might impact on the system. A direct visual comparison of the three schematic diagrams relating to current and changed interactions can be found in Appendix C.

3.2.1 Socio-economic change

At present there is a clear pressure on the system from population growth. Malawi's population grew from 4.0 million in 1966 to 13.1 million in 2008. It is predicted to reach 26.1 million by 2030 (National Statistical Office of Malawi, 2009). As long as the country has an economy based primarily on agricultural production and a majority rural population, then population growth is likely to be coupled to requirements for more land and associated deforestation with accompanying knock on effects (Figure 8). This could be mitigated by intensification of agriculture through irrigation and improved soil conservation measures as well as application of fertilisers. This would help make better use of currently farmed land rather than requiring development of increasingly marginal land. It may also increase production enough to generate additional income and provide more food security. Implementing a second growing season could be fundamental to this.

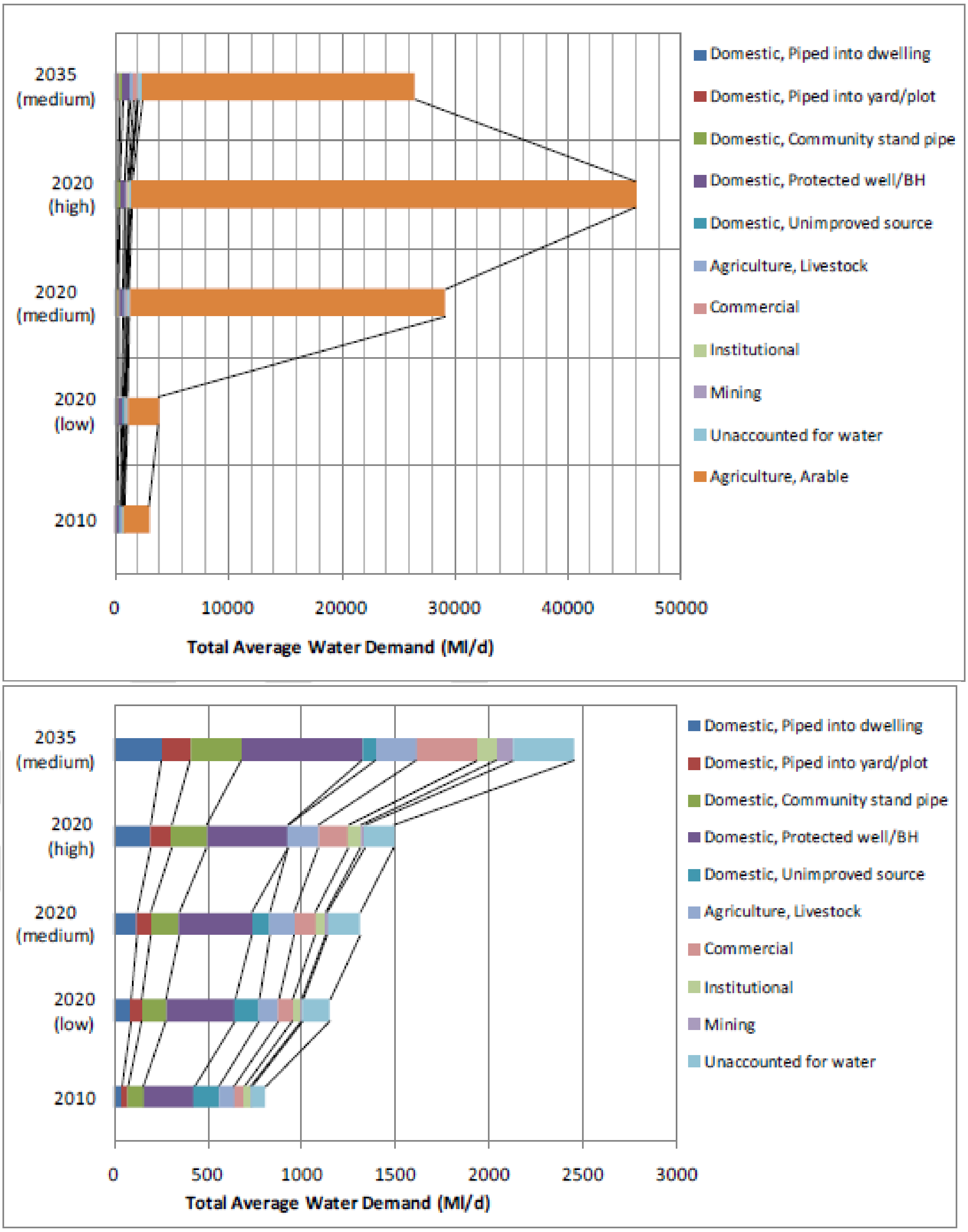
Atkins' (2011a) water resources assessment for Malawi projected that by 2020 total average water demand (Ml/day) could have increased by between 30-1400% (low to high growth scenarios) as a result of GDP growth and give a single medium growth projection of 760% increase by 2035. The vast majority of the increases, and uncertainty in estimates, are attributed to irrigated agriculture. For example the 2020 high growth scenario results in only around 100% growth in demand distributed evenly across all other sectors, and the 2035 (medium) projection is around 200% increase (Figure 9). It will be very important for hydropower generation on the Shire River whether these irrigation demands materialise and whether they are upstream or downstream of plants.

Figure 8 Possible changes to the current system shown in Figure 7 resulting from socio-economic changes



Note: Arrow thickness increase/ decrease compared to Figure 7 indicates increased/ decreased influence.

Figure 9 Projected increases in total average water demand (Ml/day) from 2010 baseline.



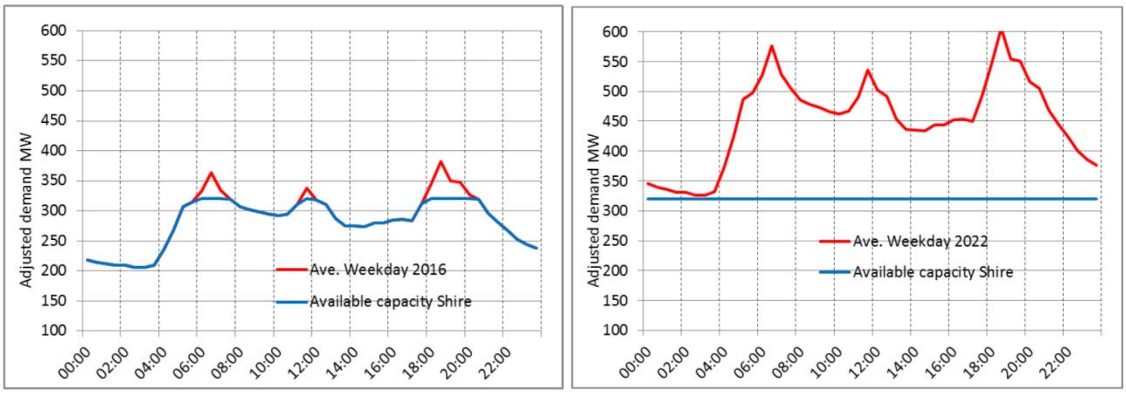
Note: Top figure includes agriculture, bottom figure excludes agriculture (source, Atkins, 2011a)

As the economy grows and becomes more industrialised in line with the Malawi Growth and Development Strategy II (see Section 2) the link between population increase and pressure on land may begin to be broken. Similarly, increases in agricultural production through intensification and addition of a second growing season could provide a more secure subsistence supply and generate additional income through commodity sales. Intensification could prevent increasing extent (i.e. conversion of more land to agricultural production).

Development of irrigation schemes upstream of Lake Malawi could reduce the volume of water reaching the lake and thereby the flows in the Shire River. Further analysis of the trade-offs will be necessary to make decisions about how best to manage the available resources to equitably share benefits from them. Developments in Tanzania and Mozambique could also impact on flows into the lake, so political relationships will need to be managed to ensure Malawi has some influence over any such development. Despite a historically cooperative relationship (Nyasa Times, 2012a), there have recently been tensions between Malawi and Tanzania over territorial rights to Lake Malawi, relating to exploration for oil and gas (Nyasa Times, 2012b) but these are likely to remain peaceful. A Joint Permanent Commission for Cooperation (JPCC) exists between Malawi and Mozambique helping avoid similar tensions over the resources of Lake Malawi. In 2008 an agreement was signed to make cooperative use of the Cahora Bassa hydropower dam in Mozambique. This has yet to benefit Malawi owing to the continuing lack of grid connection. By analysing the trade-offs between water use for different purposes in different basins or countries, it may be possible to identify synergies which allow win-wins rather than necessitating one party to sacrifice for another's gains.

Figure 10 shows some projections for peak electricity demands above the available capacity from the existing hydropower plants, for 2016 and 2022.

Figure 10 Peak demands above available supply capacity for 2016 (left) and 2022 (right)



(Source: NORPLAN, 2013)

3.2.2 Climate change

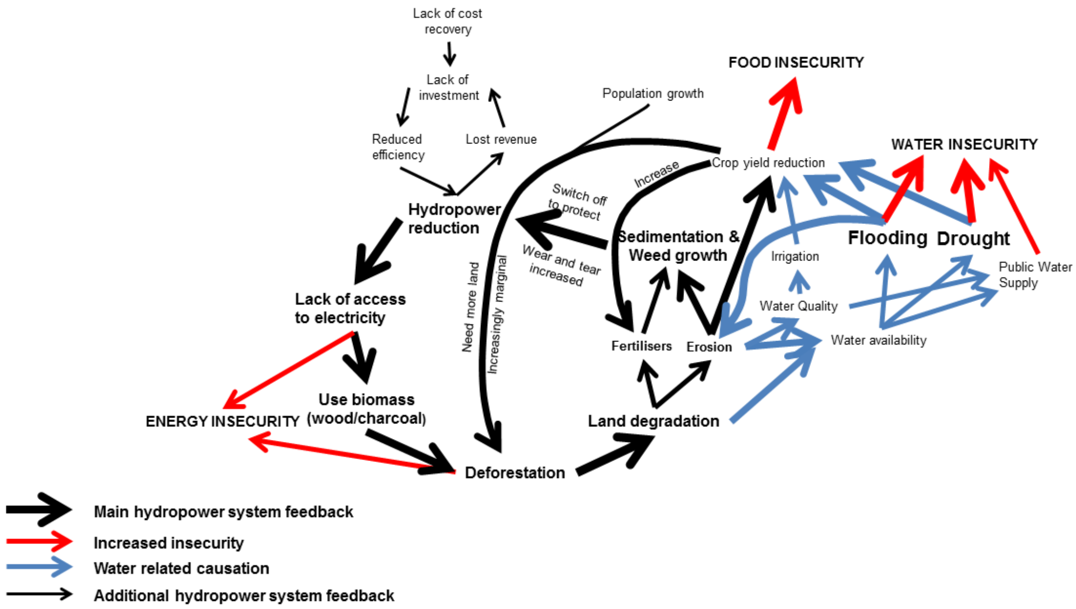
Increasing temperature is likely to increase evapotranspiration from vegetation and evaporation from Lake Malawi. This will affect water storage in the lake and thereby flow rates in the Shire River. It could also increase the water demand from irrigated crops along the Shire River.

Changing intensities of rainfall events could affect water availability by increasing runoff. Soil is less able to absorb all the water landing on it as rainfall intensity increases. This may increase peak runoff, decreasing soil and groundwater water availability upstream, but increasing river flows downstream. This can have positive and negative impacts downstream; more water for irrigation and hydropower is good, but flooding is not. Figure 11 illustrates the possible impacts.

Changing intensities of rainfall can have implications for erosion. More runoff has greater erosive potential, so could increase sediment loads downstream and the quantity of nutrient washed off the land. This will exacerbate the land degradation issue in Figure 8**.** and associated reductions in crop yields. Similarly, problems with sedimentation of hydropower pondages and siltation damage to turbines are also likely to increase as well as costs of treating water (removing silt and other pollutants) for domestic or irrigation use (LTS International et al., 2013).

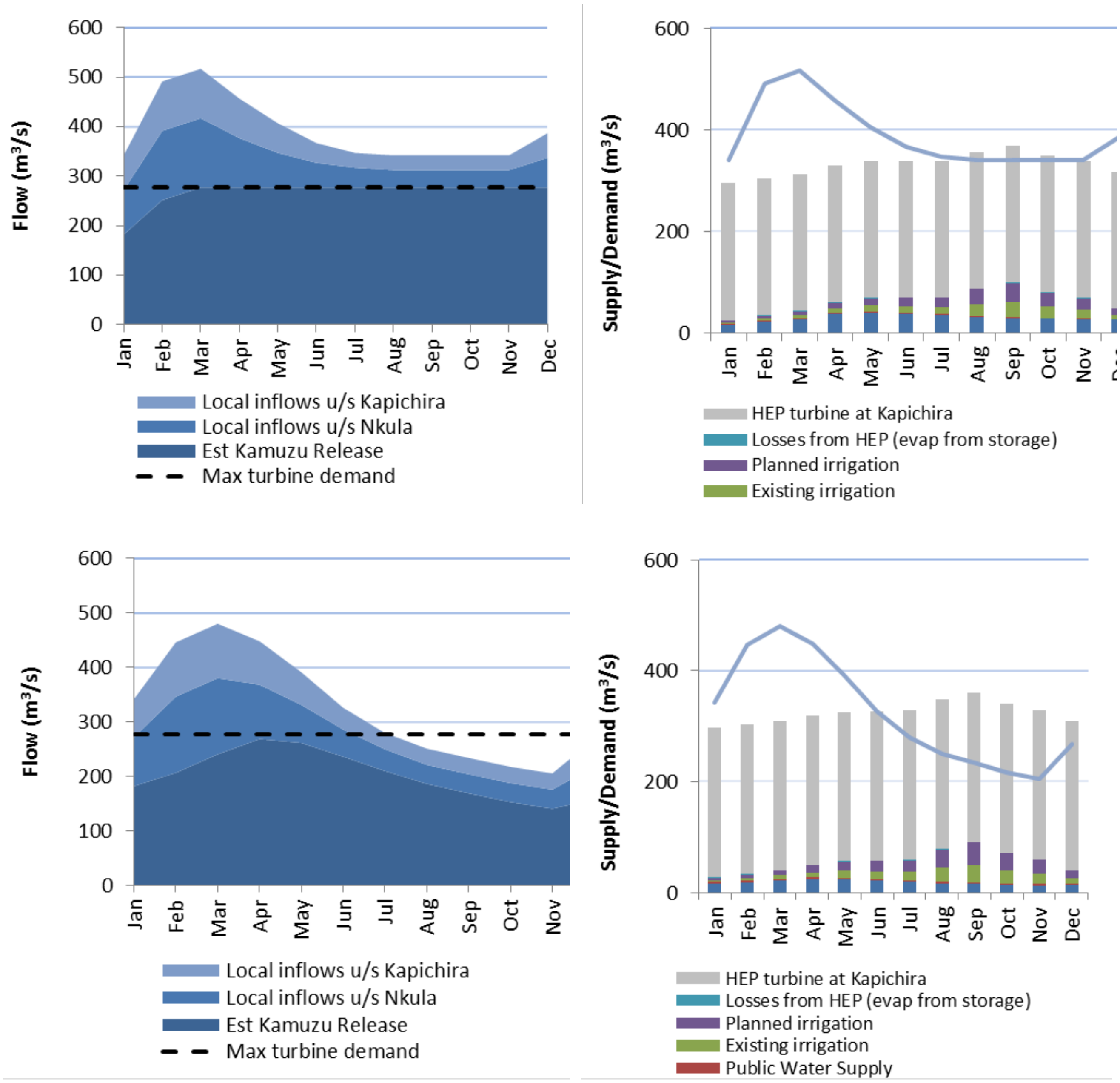
Increased incidence of drought could decrease water availability and crop production outside in excess of the current level. For example, it is estimated that the 1992 drought reduced the country's annual maize production by around 60% leading to a 10% reduction in GDP (RoM, 2006). Figure 12 illustrates the possible impacts.

Figure 11 Possible changes to the current system shown in Figure 7 resulting from climate changes – arrow thickness increase/ decrease compared to Figure 7indicates increased/ decreased influence



The water resources situation in the Shire is general perceived as good with low or moderate water stress. However, based on data from the national water resources assessment, Figure 12 illustrates a water resources balance with moderate drought and more severe drought with new planned irrigation and Kapichira II in place. The total demand is shown as bars and the supply as a line graph. It shows that demands can be met during moderate droughts but that there could be supply-demand issues in more severe droughts even without climate change. The calculation is very sensitive to assumptions regarding the design flows and operation of barrages but it illustrates that there is a risk of serious hydropower performance degradation in drought years.

Figure 12 Illustrative examples of River Shire system performance for moderate water resources drought 1 in 5 years (top) and severe drought of 1 in 40 years (bottom) with Shire Valley Irrigation Project and Kapichira II in place



SECTION 4

Hydropower performance and its influencing factors

This section looks at the performance of hydropower in Malawi in relation to the measures of performance identified in Section 2 of the Harnessing Hydropower Literature Review (Lumbroso et al., 2014).

4.1 Power generation

The hydropower turbine capacities in the Shire basin are summarised in Table 3. A theoretical maximum capacity is shown in column 4. If all turbines were running at full capacity 100% of the time the energy generated would be 343.3MW[6]. It is not possible for hydropower plants to run at full capacity for 100% of the time due to the need for maintenance outages as well as meeting varying demand. The periods of greatest demand are early morning, lunchtime and later in the evening and between 10 pm and 6 am demand is significantly lower.

Year	Site	Turbine Capacity (MW)	Cumulative capacity (MW)	Cumulative theoretical output GWh/day	Comments
1966	Nkula A	24	24	0.6	Capacities based on Gamula et al., 2013
1973	Tedzani I	20	44	1.1	
1977	Tedzani II	20	64	1.5	
1980	Nkula B	60	124	3.0	
1986	Nkula B	20	144	3.5	
1992	Nkula B	20	164	3.9	
1996	Tedzani III	51.3	215.3	5.2	
2000	Kapichira I	64	279.3	6.7	
2013	Kapichira II	64	343.3	8.2	Recently commissioned but excluded from the time series shown in Figure 13

Table 3 Hydropower turbine capacities in the Shire basin

The following output measures were considered for the Shire hydropower cascade using data provided by ESCOM for a period of just under 11 years:

- Energy generated (MW)
- Reliability of energy supply (energy duration curves)

[6] With development up to Kapichira I and a capacity of 284 MW

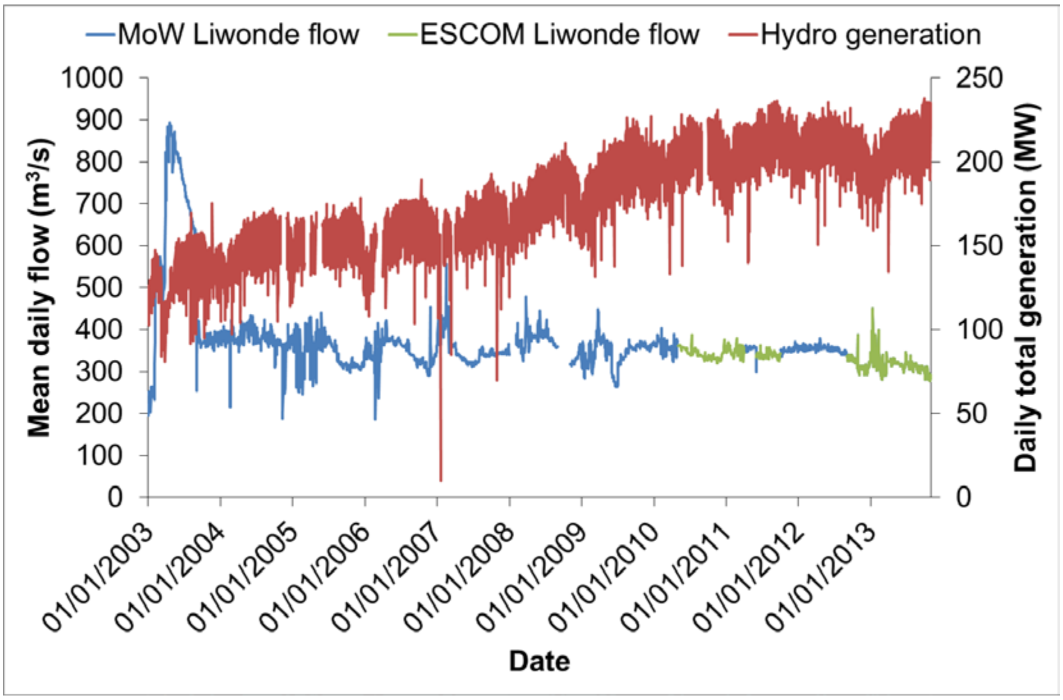
- Energy generated (% of target demand)[7]
- Days with unplanned outage (%)
- Days with flow below the volume required for hydropower production (%)

4.1.1 Energy generated by hydropower in the Shire basin

A time series of river flow and the energy generated from turbines in the Shire basin is shown in Figure 13. Analysis of the associated data and other sources shows:

- Average daily generation has increased steadily over the period 2003-2013 and now reaches little over 200 MW. The increase in generation is attributed to meeting an increasing demand (Consultees, 2013). Although no new stations were commissioned over this period, the Tedzani I and II stations were closed for refurbishment for a period pre-2003 to mid-2008.
- After approximately mid-2010 the trend for increasing electricity generation ceased as supply was maximised and exceeded at the operational capacity. 'Load shedding' where certain areas of the transmission grid are shut off prevents demand exceeding supply.
- Regular fluctuations are attributed to variations in demand, particularly the reduced demand at weekends (Figure 14). Figure 15 shows that the demand profile represented by daily generation data in Figure 13 does not capture the finer resolution peaks in demand however. Real system peaks in Figure 15are around 50% higher than those shown by the daily time series in Figure 13.
- Days with lower production or no production may be due to low demand, planned outage for maintenance or unplanned outage due to low flows, heavy silt loads, aquatic weed blockages or mechanical problems.

Figure 13 Time series of mean daily flow and energy generated based on data from the Ministry of Water (MoW) and ESCOM



[7] Demand has changed over this period and data are limited so this is only addressed qualitatively

Figure 14 Mean daily total electricity generated for each day of the week and calendar year

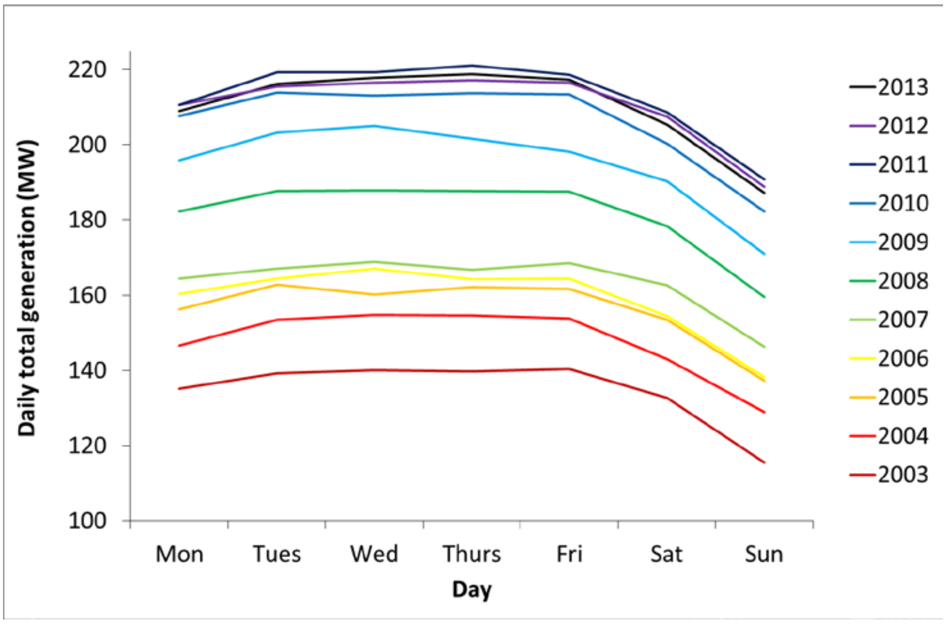
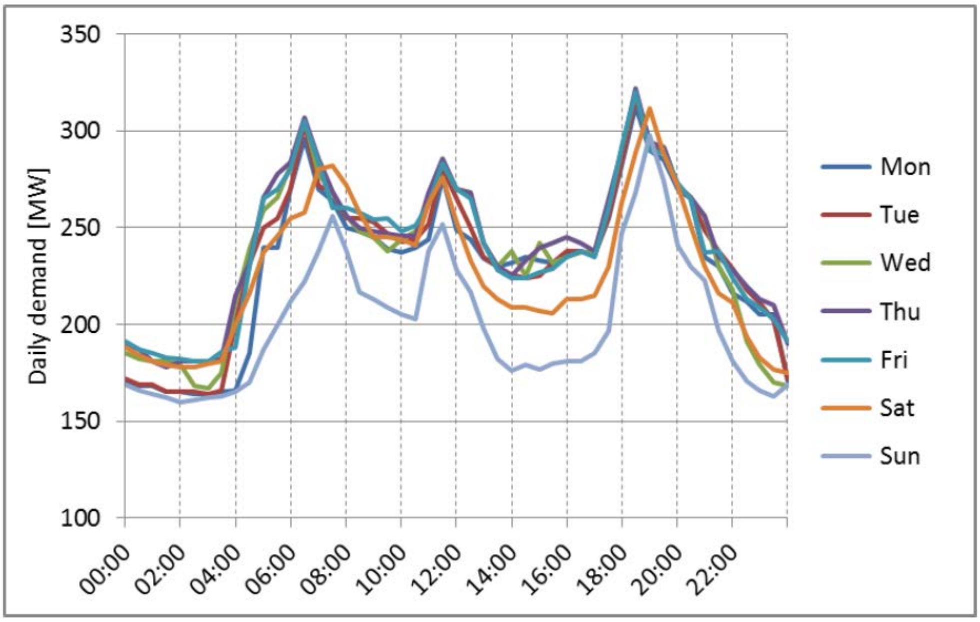


Figure 15 Demand variation throughout a typical July day in 2012



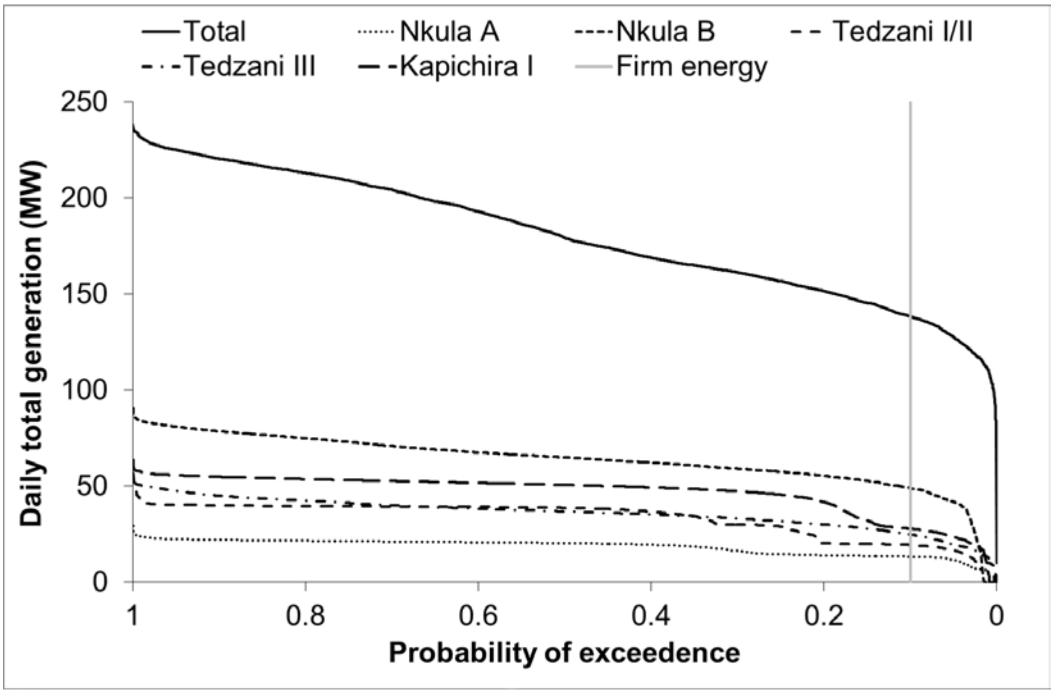
(Source: NORPLAN, 2013)

4.1.2 Reliability of energy supply (energy duration curves)

The reliability of the energy supply is one of the most important factors for energy users. The concept of 'firm capacity' is used to describe the amount of energy which can be produced with a certain level of reliability, usually 90 or 95%. This is similar to the concept of 'low flow' levels in river management, where Q90 would be the flow exceeded 90% of the time. 'Firm energy' here refers to the actual energy generated with 90% reliability, i.e. exceeded 90% of the time. Based on the full time series (2003-2013) the firm energy appears to be around 115 MW (Figure 16) but looking at the most recent 3 years of the available record, this rises to 190 MW (Figure 17). The greater consistency in generation over the period 2010-2013 is evidenced by the flatness of the curves compared to the 2003-2013 plot. It is worth noting that the flow at Liwonde did not drop below the 278 m^3/s level required for full utilisation of the installed hydropower capacity during this time. Only other factors (including demand variation) can therefore account for the lower level of generation.

Where curves meet the y-axis of the plot before the point of zero probability of exceedence, this indicates outages (i.e. no power generated). The probability at the point where the curve meets is the probability of outage (information is not available to suggest whether planned or unplanned).

Figure 16 Reliability of energy generation for Shire hydropower plants 2003-2013



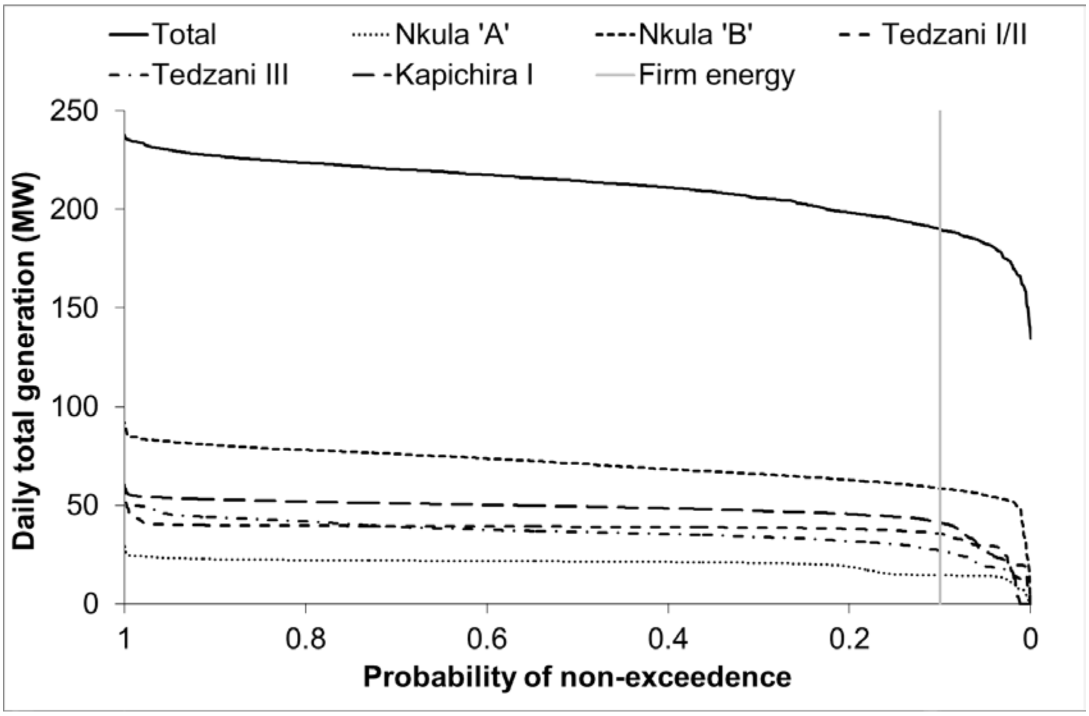
4.1.3 Energy generated (% of target demand)

The analysis of generation time series and reliability suggests that the Shire hydropower schemes generally met target demand up to 2010 with some periods of missing data that may indicate outage events.

There is anecdotal evidence of serious shortages of energy since then but this is difficult to quantify with the available data (Consultees, 2013). Design estimates of energy supply and demand from Shire hydropower for 2016 suggest a potential shortfall of 1-5 hours every weekday or approximately 3% to 14% of the time (NORPLAN, 2013).

Energy plan projections indicate an exponential increase in demand compared to a lagging linear increase in supply, for example with Kapichira II in operation turbine capacity reaches 350 MW but the projected capacity requirements are around 410 MW in 2016 (NORPLAN, 2013). This suggests an immediate capacity deficit of 15% and the urgent requirement to install new supply, increase efficiency and reduce demand.

Figure 17 Reliability of energy generation for Shire hydropower plants 2010-2013



4.1.4 Days with unplanned outage (%)

Occasional maintenance at hydropower plants will require shut down of plants but unplanned outage may also occur due to low flows in the river, problems related to weed growth or high silt loads. There were no official statistics available on unplanned outage but recent studies have assumed a maximum capacity of 320 MW (91%) (NORPLAN, 2013)[8], rather than 350MW due to hydraulic constraints, planned maintenance and unplanned outage. It is clear that significant operational expenditure is required to remove aquatic weeds and that silt loads and sedimentation are issues.

4.1.5 Days with flow below the volume required for hydropower production (%)

The total water usage if all plants are working at full capacity, not considering variation of daily demand and optimisation of usage, would be the discharge of Tedzani, which is 278 m^3/s excluding the requirements for environmental flows. It is clear from Figure 6 that flows from Lake Malawi are occasionally below this threshold; low flows are recorded eight times in the first four years of the time series. There are lateral inflows from tributaries downstream, which are important particularly in the dry season.

4.1.6 Sedimentation and aquatic weed issues

The LTS International et al. (2013) study on Integrated Assessment of Land Use Options in Malawi produced some values for the impact of sedimentation of rivers on both the treatment costs of municipal water supply and costs of hydropower outages in terms of lost energy

[8] NORPLAN, 2013 quotes the supply as around 320 MW with Kapichira II, 91% of design capacity due to hydraulic constraints and outage.

generation (Figure 18). This study suggested that increases in sediment loads would increase operational expenditure and reduce power outputs in the Shire basin.

Aquatic weeds such as water hyacinth have been causing major problems for ESCOM's hydropower plants on the Shire River. The weeds block intakes to the hydropower plants, and can cause vacuum effects in the intakes which damage turbines and also damage intake screens. Large areas of aquatic weeds covering the surface of open water, increase the water loss owing to increased rate of evapotranspiration. They can also reduce the water flow velocity thereby contributing to sedimentation of the river (Kaunda and Mtalo, 2013).

Management involves chopping, trapping and removing the weeds from the river surface. . There have been occasions where whole plants need to be closed down to allow for the weed management to be carried out. ESCOM has estimated that their own losses per day of load shedding was about US$27,000, while the losses to industries experiencing load shedding were ten times as high (Liabunya, 2008).

In 2009, the Government of Malawi and ESCOM spent nearly US$ 1 million on silt and weed management on the three hydroelectric power stations. In the same year, 2009, the total revenue lost as a result of machine unavailability at all the three stations was estimated to be close to US$ 1.2 million (Kaunda and Mtalo, 2013).

4.2 Economic impacts

Malawi has depended so heavily on the existing hydropower dams on the Shire River to date that their fortunes have been inextricably linked. The economic costs of an unreliable and inadequate power supply, as well as the costs of inappropriate pricing and high technical and non-technical losses, are estimated at seven to nine percent of Malawi's GDP (MCC, 2013). The existing plants were able to support growth in demand by increasing output up to around 2011 (Consultees, 2013, Figure 13). Since then there has been no appreciable increase, hence the need for capacity expansion such as Kapichira-II.

The financial performance of ESCOM in terms of cost recovery has prevented timely maintenance and rehabilitation of the existing plants, leading to under performance (Nchembe, 2013).

4.3 Social and environmental impacts

Hydropower development has to date had little negative impact on society and the environment. As the plants on the Shire River are all run-of-river with limited storage capacity, there are not large inundation areas or disruption to the flow regime or downstream water users. There is increasing potential for conflict between irrigation and hydropower however, with the proposals for large irrigation developments upstream through the Green Belt Initiative, for example. By increasing consumptive use of water upstream, less will be available in the Shire River for hydropower generation. Whether this reduces the amount of hydropower which can be generated depends on inflows to Lake Malawi, the volume abstracted for irrigation and the type of irrigation and associated losses through evapotranspiration.

4.4 Water use

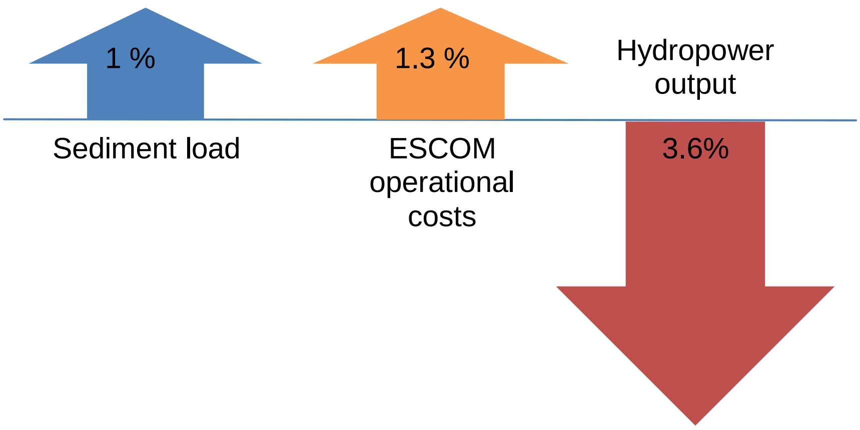
4.4.1 Over-abstraction upstream

There is no evidence that over-abstraction has affected hydropower performance over the last decade but this has been identified as a significant future risk, due primarily to the proposals for increased irrigation from the Lake (see Greenbelt Initiative, Section 5).

4.4.2 Evapotranspiration

Evaporation from Lake Malawi is a major component of the country's water balance and losses from the hydropower schemes are relatively small as these schemes are run-of-river and have a small lake area compared to energy output. Future increases in evaporation from Lake Malawi could significantly reduce flows on the river, as could the implementation of irrigation schemes (see Greenbelt Initiative, Section 5) drawing water from the lake or its tributaries for consumptive use.

Figure 18 Impacts of sediment load on hydropower performance (based on LTS International et al., 2013).



4.5 Greenhouse gas emissions

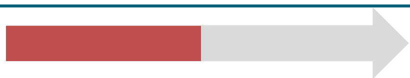
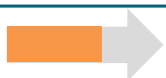
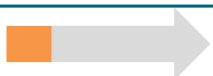
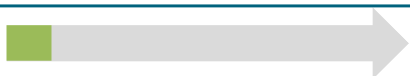
As Malawi's hydropower schemes are run-of-river and do not have reservoirs of large extent or great depth, they are not likely to produce as much methane or carbon dioxide as those with large, deep reservoirs (providing anoxic conditions and stratification) which have recently inundated a highly vegetated area (providing abundant biomass for decay and gas production). In 1994 over 96% of carbon dioxide emissions in Malawi came from land use change and forestry while over 70% of methane emissions came from the energy sector (Ministry of Natural Resources and Environmental Affairs, 2002). However, as biomass was stated to account for 95% of energy use, this is likely to account for the vast majority of the methane production.

4.6 Section summary

This section has shown the following main points:

- Malawi's existing hydropower plants have reached the limit of their generating capacity and are failing to meet peak demands. Under performance is attributed to lack of maintenance and rehabilitation.
- Firm energy generation was more than 60% higher over the final three year period of the records available than over the full period. This suggests firm energy generation performance has increased substantially.
- Erosion of upstream farmlands is leading to economic costs for hydropower generators and reduced output.
- Malawi's existing hydropower plants have been relatively benign, both socially and environmentally. This is largely a function of their limited size and scale. Future developments may have more impact.
- There is currently low competition for water resources quantity between upstream and downstream users, although upstream practices have impacted on water quality for downstream users.
- Malawi's hydropower schemes are not a large source of greenhouse gas emissions.

Table 4 illustrates the baseline and future risks of a range of hydropower performance issues. Grey arrows indicate the possible scale of the performance issue in future, while the size of coloured portions indicate the current scale and traffic light colourings indicate the level of concern associated with it, from red (high) to green (low).

Performance issues	Baseline and future risks	Comments
Energy outputs		Hydropower has provided almost all of Malawi's electricity and the individual schemes have performed reasonably well, meeting demand until around 2007.
Demand exceeds capacity		The fundamental problem is that demand has outstripped supply, so there is no headroom (usually around 10%) in the system for poor hydropower performance. Demand is suppressed by supply and lack of access.
Generation efficiency		Existing power plants are in need of refurbishment and upgrade.
Other operational issues		There are some issues related to maintaining sufficient water levels at each plant (GoM, 2013) but these may be resolved through optimisation of operations.
Unplanned outage		There have been some unplanned outage events due to low flows, mechanical failures and clearing of weeds and sediment. These may reduce outputs by up to 10%.
Upstream abstraction		The water resources situation is currently good but there are risks of increased/over-abstraction in the medium to long term.

Performance issues	Baseline and future risks	Comments
Heavy silt loads		Heavy silt loads mean turbines must be shutdown to protect them from damage. Silt loads have been increasing with land degradation.
Aquatic weed growth		There are some aquatic weed issues that increase operational expenditure through clearing works and reduce generation capacity.
Evaporation from reservoirs		Impacts of climate variability on evaporation from Lake Malawi are important but evaporation from run-of-river hydropower pondages (100% of plants at present) is not significant.
Low river flows		Over the last few years river flows have been sufficient but there are some future risks related to climate variability and change.
Environmental flows		No evidence was found on hydropower causing significant environmental impacts; flood risks are an issue around Lake Malawi.
Transmission grid		Only 9% of the total population have access to electricity. Transmission losses are estimated at 20-25% (MCC, 2013) (compared to ~6% in USA and ~13% international average) and capacity is limited.
Institutional capacity		Capacity to reform the energy market is severely limited and ESCOM's monopoly over both generation and transmission should be reduced

Notes: The table provides a qualitative summary of the key issues, with traffic lights indicating baseline issues, the width of the traffic light indicating magnitude and the grey arrows indicating the potential for increased risks under some climate or socio-economic scenarios.

Table 4 Summary of issues

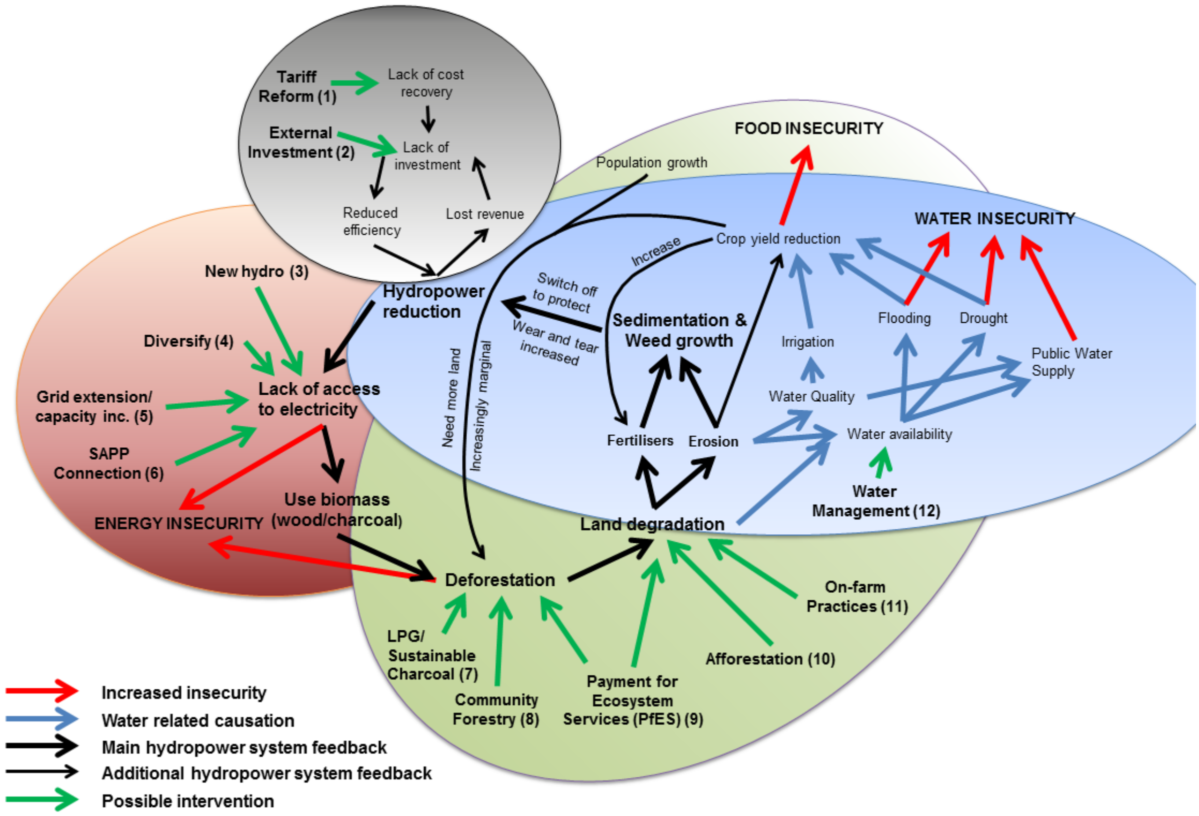
SECTION 5

Ongoing interventions to improve hydropower performance

This section describes some of the interventions that are ongoing or recently completed which relate to the sustainability of hydropower and its interactions with water, energy and food security.

Points of leverage exist within the system originally described by the schematic diagram in Figure 7. These represent opportunities to improve the performance of hydropower in terms of its contributions to water, energy and food security. The locations of some of these leverage points are numbered in Figure 19 with different numbers representing different types of interventions. Table 5 outlines the intervention type which relates to each number, the agencies most likely to take responsibility for it and an indicative rating on a scale of 1 to 5 of both ease of implementation and impact. These intervention types are then discussed in more detail in the sub-sections below.

Figure 19 Hydropower system interactions in Malawi from Figure 7 showing numbered intervention points, described further in Table 5 and the text.



Note: Coloured ovals show areas of the system – red is energy system, grey is financial/regulatory system, green is livelihoods system and blue is water system.

No.	Group Name	Sub-groups	Comments	Agency most likely to lead for Malawi	Ease (1 Low - 5 High)	Impact (1 Low - 5 High)	Priority (Ease x Impact)
1	Tariff reform	a) Full costs recovery	Promotes investment in new and existing infrastructure	ESCOM, Malawi Energy Regulation Authority (MERA), Ministry of Energy	3	4	12
		b) Cost reflective tariffs	Help to spread load more evenly by differential pricing	ESCOM, Malawi Energy Regulation Authority (MERA), Ministry of Energy	3	4	12
2	External investment to maintain and operate infrastructure	a) Public (National/ International)	May require economic measures in-country to achieve development of new and maintenance of existing infrastructure.	ESCOM, Ministry of Energy, International Financial Institutions	1	5	5
		b) Private	A more sustainable solution to securing ongoing investment where there is a return on investment	Commercial banks and investors (National and International)	4	3	12
3	New hydro	a) Storage	Tend to have significant potential environmental and social impacts so consideration trade-offs in design and operation important to maximise win-wins & multiple benefits.	ESCOM, Private developers	3	4	12
		b) Run of river	Low/No storage so tend to have lower environmental and social impacts. Depend on reliable flows.	ESCOM, Private developers	2	4	8
		c) Micro	Best suited to off-grid solutions	ESCOM, Private developers, NGOs	4	4	16
4	Diversify	a) Renewables	Diversification of the sources of electricity can help increase resilience to climate related system shocks.	ESCOM, Private developers, Ministry of Energy	5	4	20
		b) Thermal	Including coal, heavy fuel oil, diesel, waste to energy	ESCOM, Private developers, Ministry of Energy	3	3	9
		c) Nuclear	Although hugely challenging in terms of costs and availability of skills, this is in the electricity investment plan based on the presence of uranium in the country	ESCOM, Private developers, Ministry of Energy	2	2	4

No.	Group Name	Sub-groups	Comments	Agency most likely to lead for Malawi	Ease (1 Low - 5 High)	Impact (1 Low - 5 High)	Priority (Ease x Impact)
5	Grid extension/ capacity increase		Extending the grid and increasing its transmission capacity can help get more energy to where it can be used	ESCOM, Ministry of Energy	1	2	2
6	SAPP connection		Connecting to the Southern Africa Power Pool (SAPP) requires investment in standard 400kV transmission lines. This would allow Malawi to both import and export grid electricity.	Ministry of Energy	4	4	16
7	LPG/ Sustainable Charcoal		Replacements or enhancements to current fuelwood use could reduce pressure on forestry resources	Ministry of Energy	2	4	8
8	Community forestry		Land degradation can be reduced and sustainability of benefits increased by giving complete or partial management control of natural resources to the local communities which depend on them.	Forestry Department, Ministry of Natural Resources, Energy and Environment	3	3	9
9	Payment for Ecosystem Services (PFES)		Downstream users of a resource such as water may find it is better value for money to make direct/indirect payments to users/polluters upstream to safeguard the resource quantity or quality.	Ministry of Natural Resources, Energy and Environment, NGOs	4	5	20
10	Afforestation		Direct planting of trees to increase slope stability, reduce erosion and impact on water flows can be integrated in wider programs or implemented in isolation	Ministry of Natural Resources, Energy and Environment	3	5	15
11	On-farm practices	a) Increased irrigation	Could intensify outputs to reduce requirements for new land	Ministry of Agriculture and Food Security, Land Department	5	4	20
		b) Conservation practices	Changes can be made to the way land is farmed or managed which have positive impacts on land quality and runoff generation	Ministry of Irrigation and Water Development	4	4	16
12	Water management	a) Supply	Development of new small and large scale infrastructure to make use of	Ministry of Irrigation and Water Development	4	4	16

No.	Group Name	Sub-groups	Comments	Agency most likely to lead for Malawi	Ease (1 Low - 5 High)	Impact (1 Low - 5 High)	Priority (Ease x Impact)
			available wet season flows.				
		b) Demand	Improving demand management and increasing water efficiency	Ministry of Irrigation and Water Development	3	3	9
		c) Quality	Improving water quality, reducing aquatic weed growth and silt loads	Ministry of Irrigation and Water Development, Ministry of Agriculture and Food Security, Land Department	4	4	16
		d) Capacity building	Increasing capacity of river basin authorities and other water managers.	Ministry of Irrigation and Water Development	4	4	16

Table 5 Description of the numbered intervention points shown in Figure 19

5.1 Power sector structural reform

Tariff reform can facilitate both full cost recovery and demand management, the latter through cost-reflective tariffs. Cost-reflective tariffs price electricity according to demand, so that it is cheaper to use electricity outside of peak times. This can spread the load on the system more evenly making it easier to manage and less costly.

There is currently a very limited extent of grid penetration particularly in rural areas. Transmission losses of 20-25% (MCC, 2013) also limit access, representing inefficiency with technical solutions.

5.2 New hydropower

New hydropower development can take different forms. Storage schemes tend to be larger and require more effort to mitigate environmental and social impacts. Run-of-river generally have lower environmental and social impacts, but are also less effective at regulating highly seasonal flows. Run-of-river schemes can have a relatively small storage associated with them to allow their operation for peaking power, usually less than one day's flow. Small/micro hydropower schemes often involve no more than a diversion weir to allow water to be taken off to drive turbines before being returned to the river downstream.

5.3 Diversification

Malawi has reserves of both coal and uranium, meaning it could supply either a thermal or nuclear power station without expensive fuel imports. There would of course be development costs associated with either of these alternatives. In the 2010 Electricity Investment Plan, the government committed to undertake a feasibility study for a coal-fired power station.

Solar power has already been installed in a number of remote villages and Malawi has considerable untapped solar power potential. Planning and installation periods are relatively short for solar power. In the 2010 Electricity Investment Plan, the government committed to undertake a wind-mapping study to provide potential investors with the information they require to assess project viability. In the medium term, 25 MW of wind generation is planned. Biomass-fired power stations are part of the medium term Electricity Investment Plan and the government is encouraging the agricultural plantation industries to invest in energy production from biomass, starting with a minimum of 50 MW (MNREE, 2010).

5.4 Land management/On-farm practices

Many on-farm practices can make a significant impact on reducing degradation. For example, the traditional practice of ridging is often carried out without any regard to its impacts on water. Existing ridges can channel runoff down slope, and by concentrating runoff in channels, its erosive potential is increased. If these ridges are re-orientated to follow slope contours, then the ridge system can actually help to retain water and increase infiltration (Consultees, 2013).

The sub-sections below outline some of the recent reports on land management and farming practices in Malawi, identifying areas of interest to the Harnessing Hydropower project.

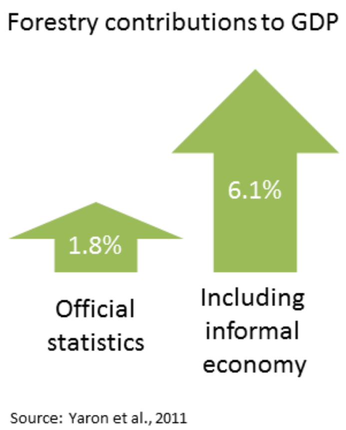
5.4.1 Economic valuation of sustainable natural resource use

Malawi's Ministry of Finance and Development Planning undertook a study in 2011 evaluating the economic impacts of sustainable natural resource use (Yaron et al., 2011).

This initially highlighted the greater contribution of forestry to the economy than is suggested by official statistics, attributed mainly to the non-market value of fuelwood (Figure 20).

The study suggested that if the unsustainable use of forest and soil resources could be reversed, the impact on GDP could almost fulfil the government's annual growth target of 6%. Furthermore, if this had been achieved between 2004 and 2015, the poverty rate could have been halved, with reference to the 1990 baseline (Figure 21) (Yaron et al., 2011).

Figure 20 Contributions of non-market fuelwood to GDP



Soil erosion impacts at the local and national levels, and reduces water, energy and food security simultaneously. Although there is a high degree of uncertainty surrounding soil erosion rates owing to historical lack of data collection and extreme variability over short distances, Figure 22 indicates some impacts for water, energy and food security.

Conservation agriculture has shown good results in Malawi, incentivising farmers to adopt the techniques without project support. This involves interplanting maize with *Tephrosia* (a legume tree from which leaves are used as a mulch on the ground where they fall and wood can be used for fuel) and use of fertiliser but reduced tillage. This is similar to the approach suggested by LTS International et al. (2013). Although labour costs are increased initially, this is balanced in later years by reduced dry-season land preparation. Projects have shown discounted benefits of more than 25 times the discounted costs over a five year period.

Figure 21 Impacts of sustainable soil and forest use on GDP and poverty

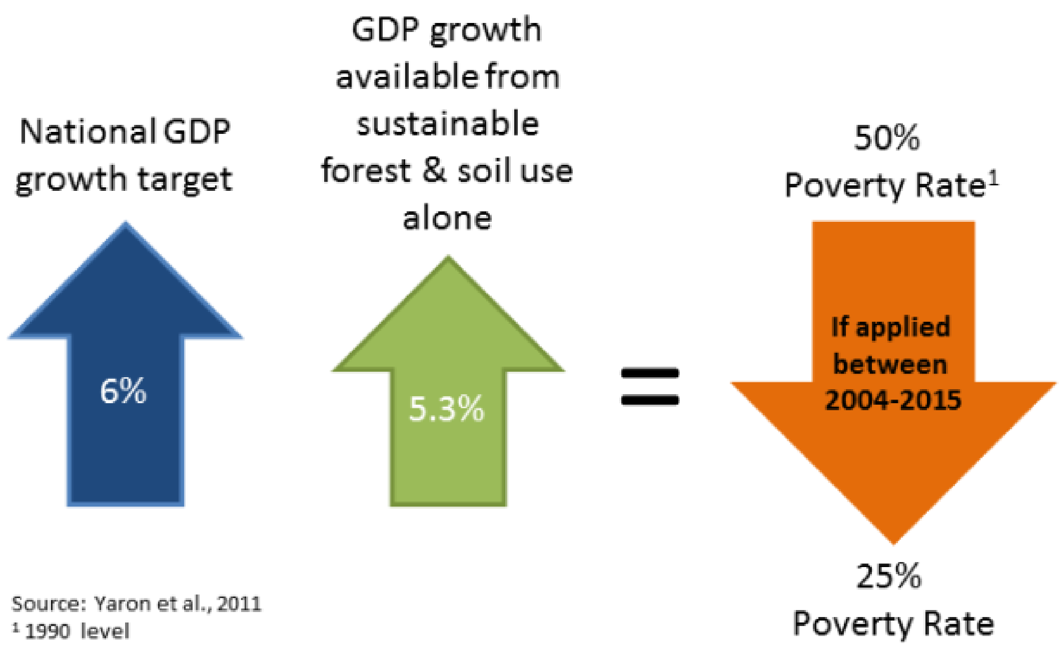
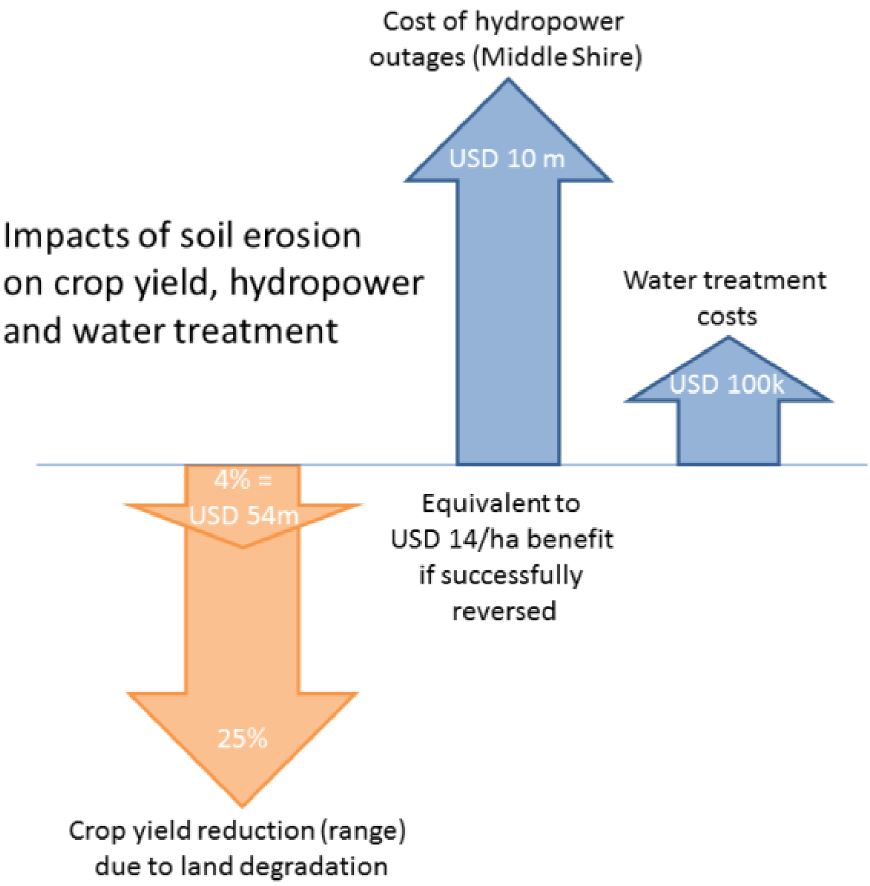


Figure 22 Indicative impacts of soil erosion on water, energy and food security



Two alternative interventions are proposed for reducing deforestation:

1) Increasing the supply of woodfuel by stimulating the planting of sustainable coppicing systems,
2) Increasing the sustainability of charcoal production.

The report concludes that the first option would rely on carbon payments and other financial incentives to make it attractive to farmers. For option 2 to succeed, it is considered that a holistic solution would be needed to address the whole supply chain as demand is expected to double in the next 15 years and technical solutions such as improved kilns could only have a limited impact. Subsidising electricity to compete with charcoal is not seen as a viable option owing to the low rate of domestic grid access and limited supplies.

5.4.2 Integrated assessment of land use options

LTS International et al. (2013) aimed to evaluate the potential costs and benefits of alternative land use management options for Malawi, in the context of climate change. This included both private costs and benefits to land owners from the adoption of more sustainable land use options and wider economic impacts from changes in the capacity of the land to supply other ecosystem services. The study found:

- There are both private and wider economic gains from a future which incorporates sustainable land use practices. This will be the case whether future climate change trends manifest as wetter or drier conditions (Table 6).

- Gains are highest for the forestry scenarios due to increased private gains through the additional value of forestry production compared to agriculture alone. Silt and sediment-related costs for downstream bulk water users, hydropower generation and water treatment, are also lower.
- Dry future climates result in higher economic benefits because soil erosion is less, reducing on-farm costs and losses to downstream bulk water users.
- Because of increased initial outlay to change to more sustainable management practices, benefits do not accrue to landowners immediately but increase over time.
- Financial incentives may be required to motivate farmers to continue with sustainable practices before they see increased benefits.
- Carbon payments could add a small margin 4-10% to the initially reduced income for farmers.
- Payments for Ecosystem Services payments could contribute a substantial value added to landholder profitability (between half and two thirds) with improved fallow treatments with *Gliricidia* and *Tephrosia* (flowering legume plants) and an emphasis on forestry.

	Net Present Value (US$ million)	
Scenario	**Wet climate**	**Dry climate**
Forestry	85	105
Agriculture	50	72
Business as usual (BAU)	25	56

Table 6 Climate dependent net present value and additional benefit resulting from different management scenarios

5.4.3 Improved Forest Management for Sustainable Livelihoods

Forestry co-management initiatives in Malawi have shown the potential to reverse negative trends in water and food security. Forest and watershed management, including the prevention of fires and illicit cutting have restored flows in previously dry rivers. Re-establishment of year-round water flows have prompted local communities to engage in small-scale irrigation farming, allowing local households to harvest crops such as maize, tomato, onion, cabbage and beans twice a year. This has increased food security and improved livelihoods and has the potential if implemented more widely to decrease negative impacts on downstream hydropower facilities (resulting from floods, droughts and siltation-related outages). Experiencing direct benefits is helping encourage active investment in the forest through management and patrols of the resource.

5.5 Ongoing interventions

Table 7 gives a non-exhaustive list of the interventions being carried out in Malawi. The intervention is summarised, a note is given of its status and the numbered intervention point(s) from Figure 19 are referenced to understand where the impact is likely to be achieved within the system. Each intervention is also colour coded for its likely impact on each of water, energy and food security. For example, the Greenbelt Initiative will withdraw water from Lake Malawi for irrigation. This could negatively affect water security downstream of the Lake and energy security if there is a deficit of water for hydropower generation so these columns are coloured light red (bright red would be a strongly negative effect). It would almost certainly increase food security however, so this is coloured bright green. Colour coding is used in a similar way to indicate the resilience of each intervention to climate change and socio-economic change. Bright red would indicate greatly increased vulnerability to climate change whereas bright green indicates greatly increased resilience.

5.5.1 Proposed hydropower schemes

There are proposals for a Hydropower scheme on the Bua river, which flows into the western side of Lake Malawi (Box 8). Although this project has been granted all necessary approvals by the Malawian government, the detailed feasibility study refers only to impacts of the proposed scheme on mitigating climate change. There appears to have been no analysis of how climate change might impact on the performance of the scheme in terms of its multiple benefits.

There are a number of other schemes which have been identified as feasible, but no feasibility study has been carried out as far as this study was able to ascertain. It is important that the possible impacts of climate change are properly taken into account when assessing the feasibility and planning these projects. This can help to ensure that the approaches taken to development are climate resilient.

Funding agencies and other agencies have climate risk screening tools to apply to infrastructure investments including hydropower. It is advisable that these be consulted during the project concept development stage to ensure that any project is likely to be fundable in the form proposed. Examples of these screening tools are the African Development Bank's Integrated Safeguards System (AfDB, 2013) and Energy Sector Management Assistance Program's (ESMAP) Hands-on Energy Adaptation Toolkit[9] (HEAT). The World Bank's Climate Change Knowledge Portal[10] has more examples.

[9] http://www.esmap.org/node/312
[10] http://sdwebx.worldbank.org/climateportal/index.cfm

Agency	Intervention	Status	Intervention point(s)	Impact on:			Resilience to:	
				Water Security	Energy Security	Food Security	Climate Change	Socio-economic Change
AfDB	Interested in funding hydropower project – require further ESIA assessment and due diligence on existing investors	Under review – AfDB will provide US$1M for ESIA	3a					
	Supporting development of Kholombidzo barrage feasibility study & assigned US$30M for construction	Ongoing	3b					
	Contributing to SAPP connection from African Development Fund	Inter-governmental negotiations ongoing	6					
	Involved in Songwe River Studies on Malawi-Tanzania border	Ongoing	3b					
ESCOM	Carrying our river water quality improvement – in place of financially challenged Water Resources Board	Ongoing	12c					
Greenbelt Initiative (GoM)	Aiming to increase agricultural production and efficiency through irrigation in 20km belt around Lake Malawi	In initial stages of implementation	11a, 12a					
HE Power (independent power producer)	Trying to obtain funding for their government approved 42MW project including a range of co-benefits (See Box 5)	In progress – feasibility study completed, funding application under consideration by AfDB	3					
	Adding a 3MW scheme to the spillway of Kamuzu water supply dam and 0.6MW scheme to the environmental release offtake.	In progress	3					

Agency	Intervention	Status	Intervention point(s)	Impact on:			Resilience to:	
				Water Security	Energy Security	Food Security	Climate Change	Socio-economic Change
MuREA/ Practical Action	Supporting Mulanje Electricity Generating Agency (Box 4) in developing micro-hydro community schemes	First scheme operational, others in planning	3c					
JICA	Water Resources Masterplan	In progress, based in Ministry of Water Resources	12a,b,c					
Malawi Energy Regulatory Authority (MERA)	Revising tariffs following application by ESCOM	Ongoing	1a,b					
Millennium Challenge Corporation	Power Sector Revitalization Programme	Ongoing	1,2,5,6,9,11					
Ministry of Agriculture and Food Security	Working with farmers to reduce erosion, afforestation, produce community land-use plans	Ongoing	9,10					
Scottish Government	Supporting MEGA through SE4All. Interested in transplanting to other areas.	Ongoing	3					
Tearfund	Promoting use of manure to combat land degradation	On-going	10					
UNDP	Supporting climate change planning with the Ministry of Environment	Ongoing	12					
	Sustainable Energy Management Support Project (Box 7)	Ongoing	7					

Agency	Intervention	Status	Intervention point(s)	Impact on:			Resilience to:	
				Water Security	Energy Security	Food Security	Climate Change	Socio-economic Change
World Bank	Shire River Basin Management Program (Phase-I)	Ongoing	2a,10					
	Reviewing Laws relating to energy sector regulation (with MCC)	Ongoing	1, 2b					
	Irrigation and rural development programme – erosion reduction	Ongoing	11a,b					

Table 7 Interventions planned or ongoing. Impact and resilience scale is red (strongly negative) to green (strongly positive) via amber (no impact).

Box 7 Mulanje Electricity Generation Agency (MEGA)

Mulanje mountain (Figure 2) is the wettest in Southern Africa, receiving around 2,000 mm of rainfall per year. The nine perennial rivers identified represent a significant potential micro-hydropower resource. A large population of poor smallholder farmers have no access to electricity, so depend for energy on fuelwood and kerosene, which are associated with environmental and health problems. MEGA aims to utilise the potential for hydropower to alleviate poverty in the area by providing "*an energy supply that is* ***widely available*** *and* ***reliable*** *at an* ***affordable*** *cost and supplied in an* ***environmentally and financially sustainable*** *business model."* MEGA will be set up as a social enterprise and plans to be an independent supply company, generating and supplying electricity on its own networks (mini-grids), independent of the national grid.

Households, businesses and community assets will all be supplied, although the latter will be charged a lower rate. Tariffs for households and businesses will be greater than the subsidised ESCOM grid rates which do not recover full costs. Alternative sources of fuel for lighting are substantially more expensive than the electricity supplied will be.

MEGA has begun production testing at one site pending approval and projects expansion to a number of sites on the mountain in coming years. Beyond six sites it is expected that economies of scale will be captured in terms of operation and management costs. Until that point donor-funding is sought for both overheads and infrastructure capital funding.

Based on a business model which may be updated once operation begins, the overall project is forecast to save rural households a net present value of over US$12.5million for a donor investment of US$3.5miliion. This is a directly measurable return which is complemented by an array of no less significant development benefits resulting from the availability of a dependable electricity supply, particularly a marked increase in small-scale business activity

(Source: Consultees, 2013)

Box 8 Mbongozi Hydropower Scheme, Bua River (Upstream of Lake Malawi)

In March 2011, approval in principle was granted for developing the 40MW Mbongozi Hydro Electric Project on the Bua River, upstream of Lake Malawi, on a Build Own Operate (BOO) basis. The proposed project takes advantage of the 2003 reform in the power sector allowing private investors to develop, build, own and operate power generation plants. These reforms were driven in part by ESCOM's inability to recover sufficient costs to maintain and expand generating capacity. There has been little uptake on the reform however, making this the first grid-connected project of its kind.

The Project will construct two earth dams, one on the Bua river and one on a downstream tributary, the Chimbwazi. Generation will be in two stages; the first on an inter-valley transfer from the Bua river storage to the Chimbwazi storage, the second downstream of the confluence of Bua and Chimbwazi rivers on the release from the Chimbwazi dam. Operation will be for peaking power, so from 12 to 24 hours per day throughout the year with a total output of 261GWh. This helps address the peak demand shortfall and maximise revenue as higher rates can be charged for supplying peak power to the grid.

The following innovative subsidiary projects and co-benefits are associated with the hydro-electric scheme, stimulating the local economy and encouraging community support:

Agriculture and irrigation
This will help to mitigate the threat to reservoir capacity and water quality from land degradation and erosion. The project will work with local communities to develop soil conservation and land-use measures which simultaneously provide economic opportunities. Current plans include buffer zones around the reservoirs where fruit trees and citronella grass are grown to provide pulp and oil commodities respectively. Processing and marketing of these products will be provided by another subsidiary project. It is suggested by the developers that these approaches will help to decrease climate change vulnerability of local communities by enhancing their livelihoods and promoting reforestation of currently denuded land.

Aquaculture and irrigation
Taking advantage of the conversion of the lower Bua into a perennial river as a result of the project and the fish ladders to be installed, fisheries will be developed in the reservoirs. Particularly valuable are Lake Salmon which inhabit the Bua river. Angling will be promoted alongside community fish farms and prawn cages. Processing and marketing of the resulting produce will be facilitated by the same subsidiary company as from agriculture and irrigation schemes above. The increased availability of fish protein will help to improve the diet of impoverished local communities.

Recreation and tourism
Project camps at Malomo and Miombo will be established in such a way that some of the premises can be converted into tourist lodges with facilities for boating, angling and other water sports activities. Facilities for excursion tours into Nkhotakota Game Reserves will also be available at these lodges.

The project is currently waiting for a response to a loan application to the AfDB and private equity investment to be able to mobilise for construction. AfDB is likely to request that a more thorough Environmental Impact Assessment (EIA) is carried out than was required for approval by the Malawian government. A contribution to funding this EIA may be provided by AfDB as part of its response to the loan application. This requirement will inevitably lead to further delays however.

Box 9 Outline of the Millennium Challenge Corporation's Power Sector Revitalisation Project

Based on an agreement first signed in 2011, before being delayed then reinstated in 2013, the Millennium Challenge Corporation of the USA is investing US$350million to address both infrastructure and policy issues in order to:

- increase the throughput capacity and stability of the national electricity grid;
- increase efficiency of hydropower generation; and
- create an enabling environment for future expansion by strengthening sector institutions and enhancing regulation and governance of the sector.

Under the infrastructure development activity, the project will:

- Rehabilitate Malawi's oldest hydropower plant – Nkula A. Rehabilitation is necessary to reduce power outages and maximise the output from the turbines. Furthermore there is some concern that the plant could fail either in whole or part and thereby limit the returns on the other parts of the project's investment.
- Upgrade the backbone of the transmission network to improve quality and reliability of supply, increase capacity to distribute power in the central and northern regions remote from hydropower plants in the south and reduce technical transmission losses.
- Help the government address the sedimentation and weed infestation issues affecting hydropower production at the Shire River plants. This will be done both by direct mitigation measures, providing dredgers and weed removal equipment and by developing an Environmental and Natural Resource Management Action Plan (ENRMAP). The ENRMAP will facilitate improved understanding of and action on the factors leading to these problems.

As part of the sector reform activity, the project will:

- Help restore ESCOM's financial health and turn it into a strong, well-managed company by supporting improved financial management, change management and corporate governance
- Support the government's policy reform agenda by building capacity in regulatory bodies to promote private sector investment and supply at affordable cost. This will include funding a study to establish appropriate tariffs for full cost recovery, build capacity at the regulatory body (MERA) and support the implementation of a suitable market model.

(Source: MCC, 2013)

Box 10 UNDP - Sustainable Energy Management Support to Malawi

In partnership with the Ministry of Energy, UNDP is investing in a project between 2012 and 2016 to "*facilitate a process of change from unsustainable use of biomass for energy to a sustainable use thereof, and from lack of modern energy sources for productive end-uses and clean household utilisation to a situation with access to modern energy*." Recognising the currently low level of engagement by the private sector, the project will pay attention to creating a conducive environment to attract greater private sector investments and involvement in the provision of technology development and supply. The project description recognises the role of productive end-use of energy in increasing financial viability, maintaining suitable levels of technology and acting as an agent for change.

The project will aim to pilot energy-efficiency technologies (e.g. enhanced cookstoves) for continuing use of biomass and promote increased access to electrical energy. Pilots are expected to enable development of a national programme.

(Source: UNDP, 2013)

5.6 Section summary

This section has shown the following main points:

- A broad range of international agencies are undertaking development assistance in Malawi with implications for the system of water, energy and food security in which hydropower operates.
- Extensive efforts have been made to identify ways of improving land management, addressing on of the major challenges facing Malawi and impacting on hydropower production.
- There is a good understanding of the types of approaches which are likely to provide win-wins for both farmers and downstream water users, including incentives for improving farming practices such as payments for ecosystem services.
- Approaches to conservation agriculture have been identified which may not require incentive schemes to be devised as the returns on investment are sufficient to motivate farmers to make the change.

SECTION 6

Conclusions

Malawi is severely under developed and its economic growth is hampered by a lack of electricity. The issues most severely impacting the water, energy and food security of the rural population are deforestation and land degradation. Developing large scale run-of-river grid connected hydropower is unlikely to have significant benefits for Malawi's broader WEF security in the short term. Planning and implementation timescales are long and the energy is not accessible to the majority of the population. New storage schemes have potential to provide multiple benefits to local communities in addition to supplying peaking power to the national grid, but will require some resettlement and rehabilitation of those displaced . At the smallest scale, schemes can contribute more directly to energy and food security, providing electricity to communities, homes and businesses and pumping water for irrigation, for example. The direction of climate change is uncertain, so it is important that any further water resources development is adaptable and resilient to a wide range of conditions.

This section concludes the case study, identifying six prioritised recommendations for improving the performance of hydropower in Malawi, based on the key issues identified by the case study. An assessment of the ease of carrying out each intervention, multiplied by an assessment of the likely impact of that intervention gives an overall priority score. The scoring system assumes that easily implemented interventions with a high impact are preferable. The opportunities are summarised in Table 8 in order of priority and indicating their impact on water, energy and food security and resilience to climate and socio-economic change. Each is described in more detail under a sub-section heading, identifying the logic behind them and any precedent for this kind of intervention.

6.1 Expand small off-grid hydropower sector

Small off-grid hydropower has the potential to provide relatively low cost access to electricity to those in remote, off-grid areas of the country which have perennial rivers and elevation changes to exploit. Grid expansion can be costly and time consuming, and ultimately adds further demands to a grid system at the limits of its capacity. Similarly, expanding grid capacity to meet additional and growing demands from rural areas would take much higher investment funding and planning time. Collingridge (1980) described four technical indicators of inflexibility which can be related to hydropower projects where higher inflexibility leads to increased risk of failure :

1. Large-scale
2. Long lead time
3. Capital intensive
4. Requiring major infrastructure early on

This indicates that small off-grid hydropower schemes by contrast, are likely to be low risk and therefore relatively safe investments.

The MEGA project at Mulanje mountain (Box 7) provides a good example of what can be achieved in Malawi, albeit in areas with the perennial river flow to sustain a hydropower system and make it economically viable. There are further positive examples of small community run hydropower schemes in Nepal (Hurford et al., 2014a)

6.2 Harmonise national EIA requirements with those of international funding agencies

The HE Power proposal for hydropower development on the Bua River (Box 8) has received all necessary approvals from the Malawi government, including for its Environmental Impact Assessment (EIA). However, in order for the developers to obtain funding through the African Development Bank (AfDB) they will need to fulfil the stricter EIA conditions of this lender. This prolongs the planning process and delays the expansion of grid capacity as well as creating inefficiencies in the system of development by duplicating studies. It would be much more efficient if Malawi harmonised its EIA requirements with those of international funding agencies, to ensure that one study is sufficient to gain all necessary approvals. EIA requirements of international funding agencies are publicly available and Skinner and Haas (2014) have analysed the proliferating standards and guidelines surrounding dams making recommendations for applying these frameworks to human welfare and sustainability figure in decision-making.

6.3 Develop national compensation standards for involuntary displacement

The Malawi government currently has no policy for compensating people who are displaced involuntarily by infrastructure developments such as hydropower dams. This has not been problematic thus far, but with plans afoot to develop new storage type hydropower schemes upstream of Lake Malawi, this is set to become an issue. Developers need to be able to factor in the costs of compensation to assess the financial viability of different schemes. Uncertainty can lead to problems such as delays or withdrawal of developers due to the objections of local people. This has been a problem in numerous cases worldwide (International Rivers, 2014) and is best avoided. The Harnessing Hydropower case study in Himachal Pradesh, India found examples of innovative compensation payment schemes being developed. These are being used to try and better balance the benefits of development between local people (often sacrificing land and livelihoods) and the wider population who benefit from grid electricity (Hurford et al., 2014b).

6.4 Research and develop payments for ecosystem services approach

It may be possible to increase incentives for farmers to undertake soil and forest conservation measures if payments for ecosystem services (PES) can be negotiated between them and those who stand to benefit downstream.

The Millennium Challenge Corporation (MCC) has included the concept of payments for ecosystem services in its compact with the Malawian Government to revitalize the power sector (MCC, 2013). This is intended to address sedimentation issues in the Shire river by having hydropower producers fund catchment conservation measures by farmers in the upper catchment. This can help incentivise making the investment in changing practices. There are positive examples from Cambodia (Arias et al., 2011) and the South West of the UK where a water company has for example, paid for adaptation measures on farms upstream of reservoirs to improve water quality arriving at the reservoir and thereby reduce their water treatment costs (South West Water, 2014). Measures have included fencing off rivers to prevent cattle incursion and providing covered sheds so that heavy rainfall does not lead to runoff highly polluted with dung. Overall it is cheaper for the water company to carry out these measures than pay for the increased water treatment costs.

6.5 Analyse trade-offs associated with water resources developments to ensure sustainable resource use and equitable sharing of benefits

Owing to Malawi's water resources system being primarily focussed on a single basin, Lake Malawi, its tributaries and the downstream Shire River, there is significant potential for conflicts to emerge between different uses and users of this system. The interaction between farming practices and downstream water quality is an example of this already manifested. 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.

Different approaches to trade-off analysis are being developed in the research literature (e.g. Räsänen et al., 2013; Gómez et al., 2013; Hurford and Harou, 2014). IUCN is leading an innovative project in Kenya's Tana Basin and Ghana's Volta Basin using many-objective trade-off analysis to identify portfolios of built and natural infrastructure which achieve the best possible (i.e. Pareto-optimal) trade-offs between a broad range of benefits including hydropower (IUCN, 2014).

6.6 Promote soil and water conservation practices

There are significant issues with lack of soil and water conservation in Malawi which need to be addressed to increase resilience to climate change. Without this, floods and droughts could increase in frequency and or intensity. Upstream catchment conditions dictate to some extent the response of the catchment to intense rainfall and drought. There is plenty of knowledge within Malawi and internationally (Consultees, 2013) which is available to be implemented. The payments for ecosystem services recommendation above may support this recommendation, but there are also other incentives which may be useful in persuading farmers to invest in more sustainable practices (LTS International et al., 2013).

Intervention	Intervention point(s)	Impact on:			Resilience to:		Ease (1 Low to 5 High)	Impact (1 Low to 5 High)	Priority (Ease x Impact)
		Water Security	Energy Security	Food Security	Climate Change	Socio-economic Change			
Expand small off-grid hydropower sector	3c						4	5	20
Harmonise national EIA requirements with those of international funding agencies	2a						4	5	20
Develop national compensation standards for involuntary displacement	3a						4	4	16
Research and develop payments for ecosystem services approach	9, 11b, 12a, 12c						3	4	12
Analyse trade-offs associated with water resources developments to ensure sustainable resource use and equitable sharing of benefits	3a, 3b, 9, 12a						3	4	12
Promote soil and water conservation practices	11a, 11b, 12c, 12a						4	3	12

Note: Impact and resilience colour scales for climate and socio-economic change are red (strongly negative) to green (strongly positive) via amber (no impact). Ease of implementing the type of intervention is scored from 1 (low) to 5 (high) as is Impact on hydropower performance. Ease and Impact scores are multiplied to give an overall priority rating from 1 (low) to 25 (high).

Table 8 Priority interventions identified for improving hydropower performance.

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Appendix A People and organisations consulted

This appendix lists the people and organisations consulted as part of this research.

Name	Position	Organisation
Kerry Johnstone	Private Sector Development Adviser	DFID Malawi
James Mambulu	Water Adviser	DFID Malawi
John Mussa	Director of Land Resources and Soil Conservation	Ministry of Agriculture and Food Security
Russell Broadhead	Chief Executive Officer	Symbion PNC (PTY) Ltd
Hemant Bhagat	Managing Director	HE Power Ltd.
Jonathan Banda	Senior Private Sector Officer	African Development Bank
Karen Smith	Senior Consultant	Imani Development
Peter Killick	General Manager	Mulanje Energy Generation Agency (MEGA)
Roza Mgwadira	Licensing Officer	Malawi Energy Regulatory Authority
Alastair Anton	Team Leader	GOPA Worldwide Consultants, Improved Forest Management for Sustainable Livelihoods Programme, Phase II
Dr. Henrie Njoloma	Acting National Coordinator	Green belt Initiative, Office of the President and Cabinet
Joseph Kalowekamo	Deputy Director	Ministry of Energy
Vincent Moyo	Country Representative for Malawi	Tearfund, Eastern and Southern African team
Tawonga Mbale	Assistant Director (EIA & Pollution Control)	Ministry of Environment and Climate Change Management
Jan Rijpma	Assistant Resident Representative	United Nations Development Programme
Mr Kaluwa	Deputy Director of Water Resources (Surface Water)	Ministry of Water and Irrigation
Piasi Kaunda	Assistant Hydrological Officer	Ministry of Water and Irrigation
Penny George	Senior Policy Adviser on Sustainable Energy for All	Scottish Government/ Sustainable Energy 4 All
Mr Kanchedza	Principal Water Resources Officer	Ministry of Water and Irrigation
Jenner Edelman	Deputy Resident Country Director	Millennium Challenge Corporation - Malawi
Lameck Nchembe	Director of Development and Planning	ESCOM
Philippa Buckley		InfraCo
Andreas Koall		InfraCo

Table 9 Consultees for the Malawi case study

Appendix B Key Strategies

This appendix contains a table of the key strategies for addressing non-energy Key Priority Areas of the Malawi Growth and Development Strategy II (MGDS II, 2012)

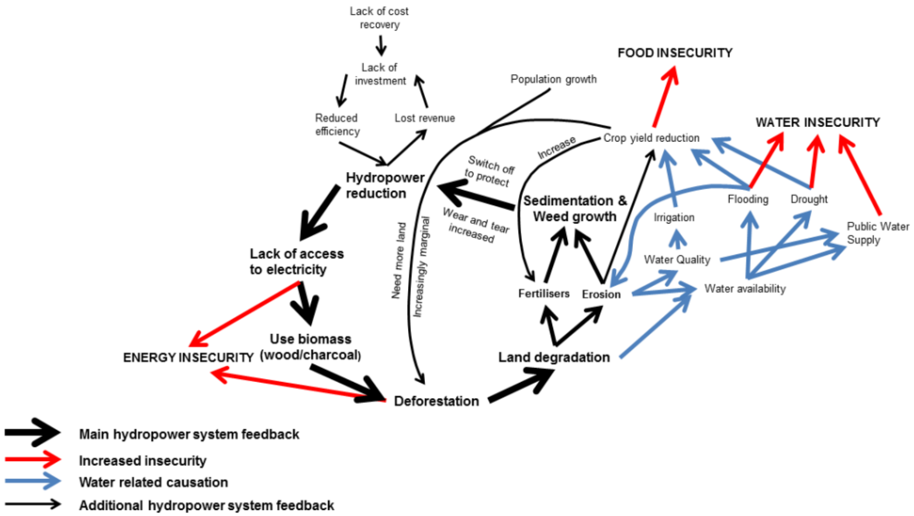
Agricultural productivity and diversification	• Providing effective extension services; • Strengthening linkages of farmers to input and output markets; • Enhancing livestock and fisheries productivity; • Promoting appropriate technology development, transfer and absorption; • Improving access to inputs; • Promoting contract farming arrangements; • Promoting irrigation farming; • Promoting production of non traditional crops; • Improving agricultural production for both domestic and export markets; • Strengthening farmer institutions; and • Promoting soil and water conservation techniques.
Food Security	• Improving the functioning of agricultural markets; • Ensuring an effective early warning system; • Promoting income generating activities; • Increasing national food storage capacity; • Promoting dietary diversification; • Improving agricultural market systems; • Improving coordination and management of food aid and imports; • Implementing policies to reduce dependency on food aid; • Strengthening and scaling-up market based risk management initiatives; • Reducing post harvest losses; • Strengthening PPPs in agriculture; • Providing technical and regulatory services; and • Strengthening farmer-led extension and training services.
Green Belt Irrigation	• Promoting development of areas with irrigation potential; • Promoting rehabilitation of irrigation infrastructure; • Promoting research and use of appropriate technologies in irrigation; • Enhancing IEC on irrigation; • Enhancing technical and administrative capacities in irrigated agriculture; and • Promoting the establishment of a well coordinated marketing system for products from irrigation farming.
Water development	• Promoting development of potential multi-purpose dam sites and groundwater resources; • Improving existing water infrastructure; • Enhancing water resources monitoring, preservation, development and management; • Promoting user friendly technologies for water resources conservation and utilization;

	• Promoting the empowerment of local communities in water resources development and management; • Strengthening research in water resources development and management; • Increasing number of people connected to piped water supply systems in both urban and rural areas; • Strengthening institutionalization of practical operations and maintenance framework at all levels; • Strengthening and institutionalizing monitoring and evaluation system for water services; • Enhancing information, education and communication; • Promoting private sector participation in the provision of water services; • Promoting equitable distribution of water points to rural areas through GPS mapping; and • Enhancing institutional capacity at all levels.
Climate change	• Improving weather and climate monitoring, prediction systems, and information and knowledge management systems; • Promoting dissemination of climate change information for early warning, preparedness and response; • Developing and harmonizing climate change related strategies, policies and legislation; • Mainstreaming climate change issues in sectoral policies, plans and programmes; • Promoting climate change related education, training, awareness and capacity building; • Enhancing implementation of climate change mitigation and adaptation programmes; • Implementing a comprehensive national climate change investment plan; • Enhancing cross sectoral co-ordination of climate change programmes; • Enhancing legal and regulatory framework on climate change; and • Developing and implementing appropriate green house gas mitigation programmes and actions.
Natural resources and environmental management	• Improving coordination of environment and natural resource programmes; • Developing capacity for Environment and Natural Resource Management (ENRM); • Enforcing compliance to environmental and natural resource management legislation; • Enhancing mainstreaming of environment and natural resource management issues in sectoral policies and programmes at national and local levels; • Promoting biodiversity conservation programs; • Promoting development and implementation of Clean Development Mechanism (CDM), voluntary carbon markets and Reduced Emissions from Deforestation and Degradation of Forest (REDD) projects; • Promoting projects on waste management; • Harmonizing environment and natural resources management policies and legislation; • Strengthening education and public awareness programmes on environment and natural resources management; • Promoting use of environmentally friendly technologies and practices; and • Enhancing environmental protection, restoration and rehabilitation.

Table 10 Key strategies for addressing non-energy Key Priority Areas of the Malawi Growth and Development Strategy II (MGDS II, 2012)

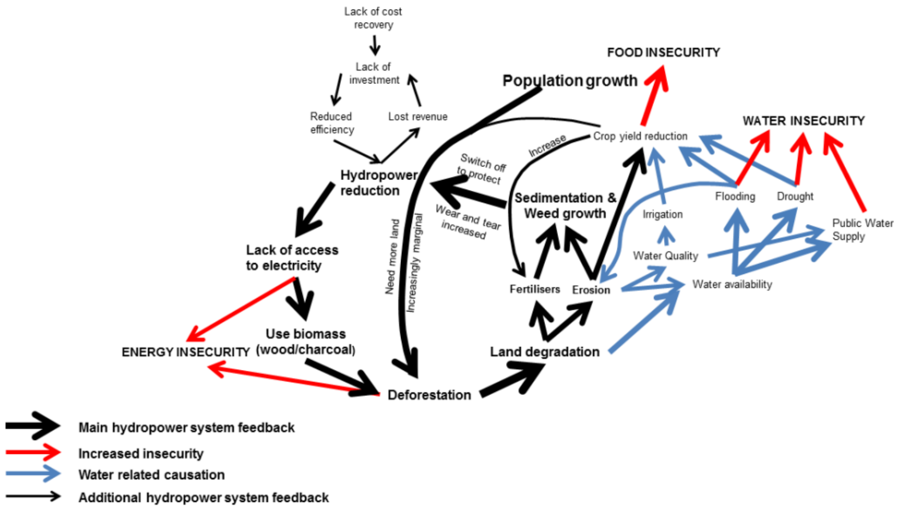
Appendix C System schematic diagrams

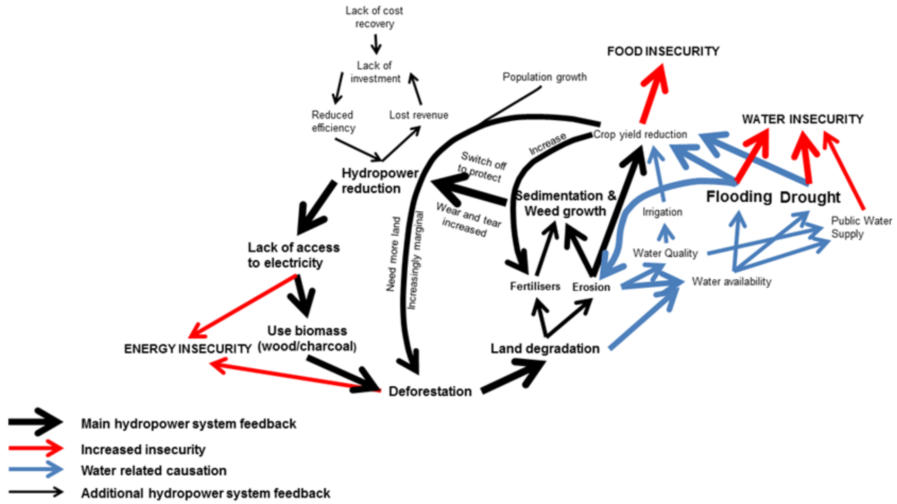
This Appendix displays the three system schematic diagrams from Figure 7, Figure 8 and Figure 9 to facilitate direct comparison of the changes in arrow thicknesses representing the changing influence of different factors. The top figure on the next page is the current situation and the other two figures are labelled above them according to the type of changes they represent.



Socio-economic change

Climate change





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