Ministry of Natural Resources, Energy and Mining
Government of Malawi

Integrated Resource Plan (IRP) for Malawi

Volume II
-
Supply and Demand Resource Assessment

Draft Report - February 2017

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The IRP report is presented in the following volumes:

Volume I – Main Report

Volume I – Appendices to Main Report

Volume II – Load Forecast

Volume III – Resource Assessment (this document)

Volume III – Appendices to Resource Assessment

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Version	**Date**	**Description**	**Prepared by**	**Checked by**	**Approved by**

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1 INTRODUCTION

The assessment of resources in Malawi for the supply and demand of electricity (Supply and Demand Resource Assessment) encompasses an assessment of the hydropower potential by river basin, in situ reserves of hydrocarbons and renewable resources such as biomass, solar, wind and geothermal energy, and demand-side measures. The potential generation of electricity from these resources and the demand-side measures are quantified through a number of candidate projects.

The assessment forms part of the Base-Line Data for preparation of the IRP, i.e. Task 3 and Task 4 of the work program of the Study defined by the following main items:

Task 3.1: Collection of data to a comprehensive assessment of the supply resources

Task 3.2: Assessment of supply options

Task 4 Demand-side management resource assessment

Addressing one of the main objectives of the Study, i.e. diversification of options for meeting electricity needs in Malawi, the candidate projects are identified and described based on information about projects already defined and in various stages of development. Within the various technologies available, the technical characteristics, location, fuel sources, cost, capacity etc. are described. To this end a template/data sheet has been developed to provide an easy overview for comparison of projects. The template defines all the data required as inputs for supply and demand options to calculate the least cost integrated resource plan using the Plexos software. The template/data sheets are included in the appendices of this Volume. The supply and demand options have been defined to accommodate the planning period of the IRP, i.e a 30 years time-slice 2017-37. The reference year of cost data for supply options is 2015.

Data presented are those collated from existing resource assessments, project reports, meetings with stakeholders and other information made available to the Consultant. No independent study or survey of the resource endowment of Malawi forms part of this study. Accordingly, the detail and quality of results vary by source of energy. This is documented in the resource assessments and description of options commenting on the sources of data available. Reference to the source material has been entered in each chapter.

Some hydropower projects are presently in the final stage of feasibility study in parallel to this IRP. This includes the Mpatamanga, Fufu and Kholomibdizo projects. For these projects the most recent data available at cut-off for completion of this Draft Final Report, IRP have been applied. Updates of data relating to these projects will be made for the Final Report to the extent new information have become available.

For confidentiality reasons some information was not released to the Consultant. This applies inter alia to the non-solicited solar projects as release of the information might compromise the need for a level playing field for later competition among the projects. In such cases the Consultant has defined generic projects to represent the supply option. This is detailed in the respective chapters.

The Supply and Demand Resource Assessment also identifies and include projects (supply-side and demand-side) that are committed. Committed projects are those that can reasonably be assumed to take place under all scenarios. Accordingly, no further decisions need to be taken in relation whether or not these projects qualify to be included in the least cost expansion plan of the IRP.

This chapter is organized by resource, viz Hydropower, Hydrocarbons (coal, diesel, natural gas etc), Renewable Energy (RE) and demand-side measures. For each resource the endowment, existing utilisation (projects) and technology options (candidate projects) are presented.

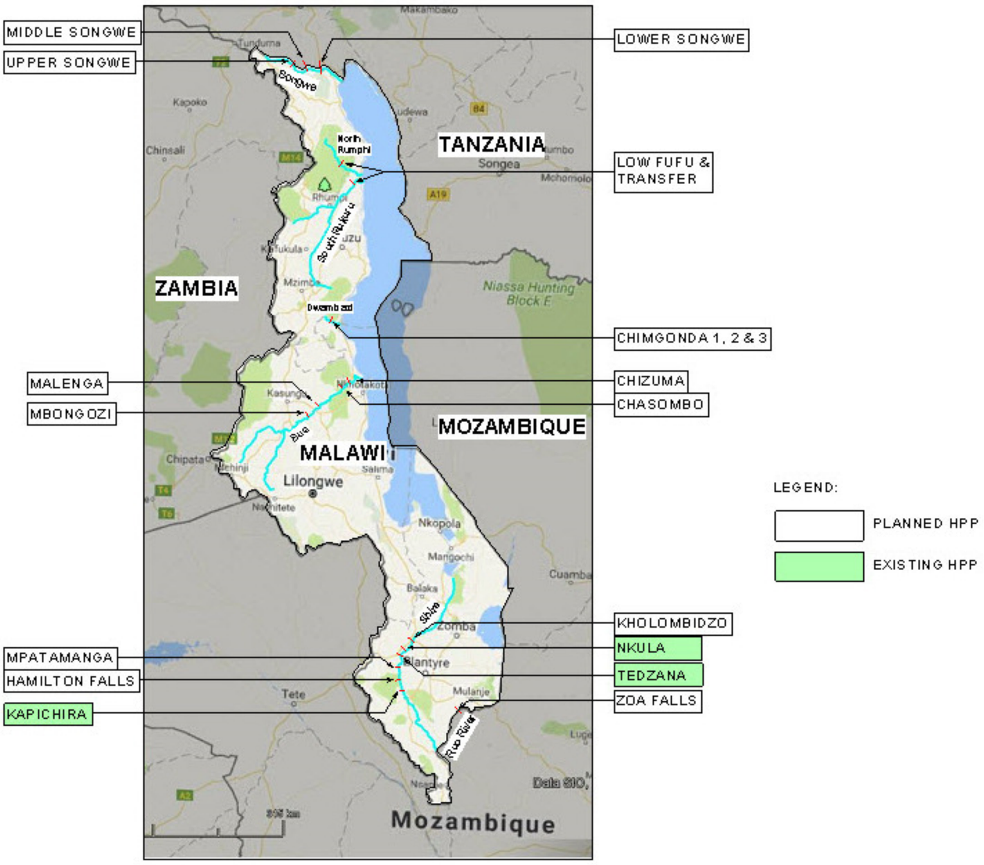
1.1 Hydropower Potential

A general description of river basins, where hydropower potentials have been identified or developed, is presented in the following chapters. The river basins have been listed from south to north of the country. Technical and economic parameters have been derived from studies and report made available to the consultant. The potential social and environmental impacts have only been mentioned where particular information is available. No independent ESIA has been made by the Consultant.

The listed hydropower projects have been studied at different levels ranging from desk studies to projects where detailed design have been prepared. The accuracy and reliability of technical and economic information obtained is thus varying dependant on the planning stage of the various projects.

Summary sheets have been prepared for projects studied at the Pre-feasibility level or higher planning levels summarizing the main project features. Project information obtained from study reports has been assessed and commented on if found relevant.

Location of constructed or identified hydropower projects in Malawi (details in chapter 1.3):



LOCATION MAP HPP MALAWI

1.1.1 Shire River Basin

The Shire River/Lake Malawi catchment covers the southern part of the East African Rift, and stretches in a north-south direction from the headwaters in Tanzania to the confluence with the Zambezi River.

Estimates of the area of catchment to the confluence with Zambezi vary between sources, from 149 031 km2 to 158 000 km2.

The most prominent hydrological feature of the catchment is Lake Malawi, the third largest lake in Africa, with a surface area of 28 750 km2. The catchment area of the lake is about 126 500 km2.

The climate of the catchment is dominated by the Inter-Tropical Convergence Zone (ITCZ) and its movement north to south, and some influence from the Atlantic by systems moving south through the Congo Basin.

Rainfall is highly seasonal, the dry season being from June to October. The length of the wet season varies depending on location, ending in March in the south, but in April/May in the North of the catchment. The rainy season starts in November with convective activity over high grounds, followed by more widespread rainfall in December-March. The wet season tails off towards May, with South-East trade winds.

The area of Lake Malawi is remarkably large compared to the land catchment with a catchment area/lake area ratio of approximately 3.4 to 1. The water balance and the water level in the lake are thus very sensitive to variations and trends in precipitation and evaporation.

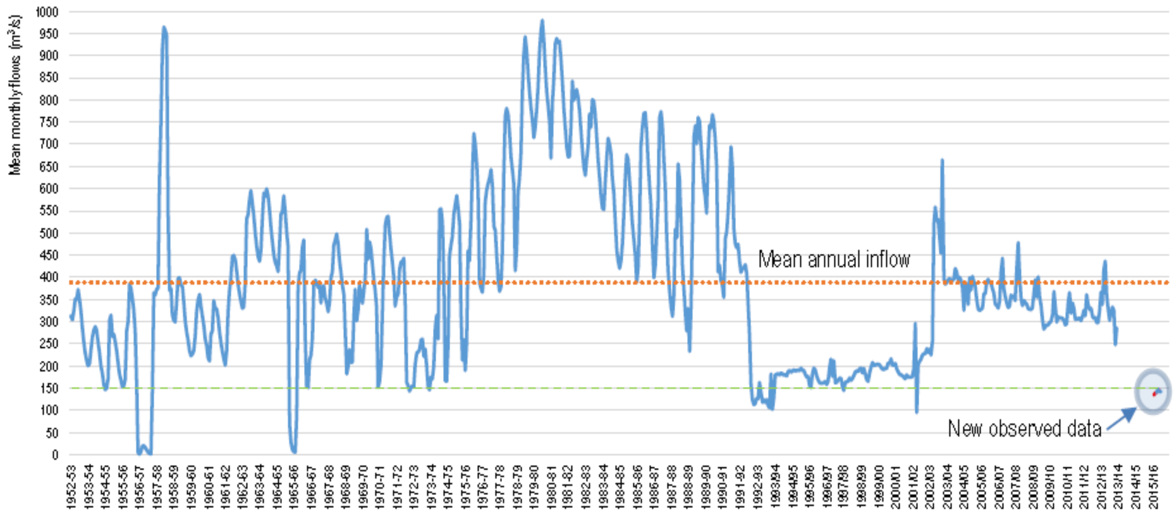
Given the large long term variations in net yield/freewater of Lake Malawi, it is no surprise that estimates of the runoff/yield of the Shire river system varies and is strongly dependent on the chosen data period.

The Malawi Lake water level has varied significant during the last 200 years according to written sources. From 1915 until 1935 there was little or no inflow into Shire River from the lake. The outlet from the lake was silted up and clogged by vegetation. Written information states that as early as year 1830 the lake level was very low and reports state that this has happened several times afterwards with no or limited flow into Shire River for shorter or longer periods.

The lake level has been observed from about year 1900 and Shire River flow recorded from about year 1950. The Kamuzu barrage at Liwonde regulating the lake was put in operation in year 1965.

Observation of the Shire River flow at Matope GS (Kholombidzo intake) and Malawi Lake level is found in COBAS Feasibility Study of Kholombidzo HPP dated September 2016.

The latest observations presented in the report is from the period December 11 2015 to August 31 2016.The average flow for this period is 136 m3/s. Lake Malawi water level was expected to reach a lowest level of 473.13 m in December 2016. The Shire River flow at Matope is shown in the graph below.



Long term mean monthly flow series (1952-53 to 2012-13) and new monthly flows recorded at Matope GS (period from 11 Dec 2015 to 31 Aug 2016)

COBAS concludes that at present the project area is suffering the most severe drought of the past 17 years. It is observed that the monthly flows are well below the estimated mean annual flow (388 m3/s) for this river section, with values comparable to the period of 1991-92 to 2002-03, but still much higher than the years of 1956-57 and 1965-66 [1].

The graph shows that the Shire River flow can vary significant from one year to another.

The Kholombidzo FS reports states that the levels in Lake Malawi for the hydrological year 2015/2016 is expected to continue to be lower than normal. It has been assumed that the Lake Malawi would be at about 473.13 m.a.s.l. in early December 2016 with corresponding low flows in the Shire River.

A drought period with reduced flow in Shire River will impact on the power production of the Shire River hydropower plants. In order to demonstrate what influence a low flow period will have, the IRP includes an alternative scenario to that represented by the long-term hydrology. The alternative is made under the following changed assumptions:

1) The present (2017) low flow of the Shire River flow, assumed to be only 50 % of the long term average flow, is kept constant for five consecutive years (2017- 2022).
2) For the next five years (2022 - 2027), a linear increase from 50 % to 100 % of the long term average flow is assumed.
3) Thereafter the long term mean annual flow is applied.
4) Monthly variation in flow is assumed to follows the same pattern as for mean annual flows.

Results of this alternative Plexos run is described in the Draft Final Report of this IRP.

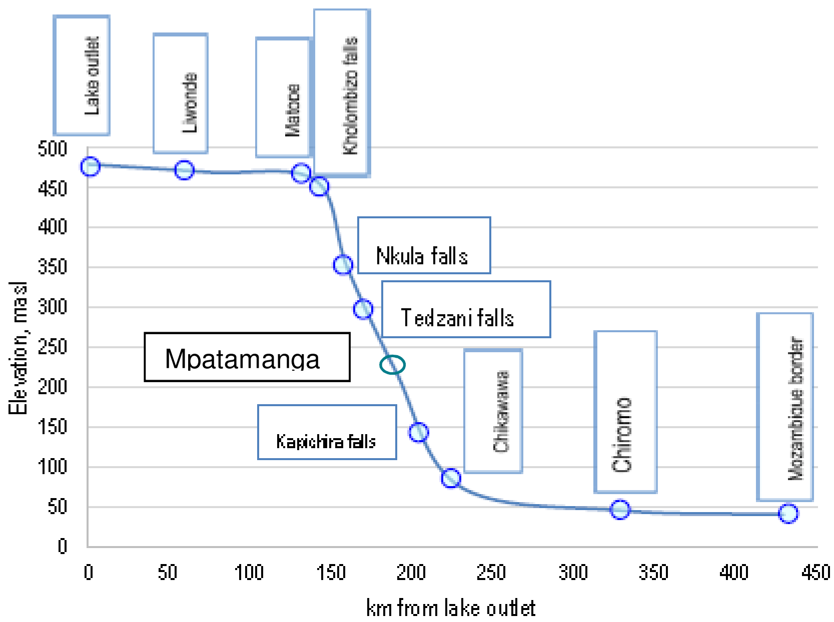
[1] The recent Draft Feasibility Study (FS) of the Mpatamanga HPP by Fichtner provides a detailed assessment of the hydrology of Shire resulting in a mean annual flow of 445 m^3/s at the project site, i.e. higher than at the Kholombidzo site higher up in the in river. A copy of the FS of Mpatamanga was made available to the Consultant just before deadline for submission of this Draft Final Report, IRP and time did not allow for inclusion of the Fichtner assessment and its implications in this report.

The global warming and its influence on Lake Malawi water level has been addressed by both COBA (Kholombidzo FS) and Fichtner (Mpatamanga Pre-FS). Both conclude that temperature will rise resulting in an increased evaporation, but precipitation will also increase and the two changes to the environment will most likely balance each other. Greater variation in climate including the potential for longer sequences of low or high rainfall may also result from global warning.

Mitigation measures to secure inflow to Shire River during drought periods have been suggested in previous studies, but not implemented. The main measures proposed are dredging the outlet of the lake and upper part of Shire River to increase the flow capacity and/or building a barrier at the lake outlet pumping water from the lake into Shire River during low flow periods.

At present, rehabilitation of the Kamuzu barrage at Liwonde is ongoing. The barrage is regulating the flow from the lake and an increase of the highest regulating water level has been included in the plans.

The Shire River flows from the outlet at the southern end of Lake Malawi to its confluence with the Zambezi River in Mozambique and has a total length of 420 km. The river can be divided in three sections with distinctly different gradients. The Upper Shire over a distance of 140 km between Mangochi (outlet of Lake Malawi) and Matope has a flat gradient, one of the main tributaries in this wide valley is the Rivi Rivi River. The next 70 km from Matope to Maganga, is the Middle Shire, and in this reach the river falls about 370 m in elevation passing through a series of falls and rapids, including Kholombidzo, Nkula, Tedzani, Mpatamanga, Hamilton and Kapichira, making it very attractive for hydropower development. Within this reach, the main tributaries are Lisungwe, Mkurumadzi and the Lirangwe River. In the Lower Shire, below Maganga, the river widens flowing through the Elephant Marsh a broad flat valley up to the Mozambique border at Bangula/Chiromo where it is joined by Ruo River. The next figure shows a schematic longitudinal profile of the Shire River.



Flows in the Shire are dominated by the outflow from Lake Malawi, particularly during the dry season.

The tributaries between the outflow from Lake Malawi and the gauging station furthest down the catchment (Chiromo) contribute on average 22% of the annual flow with, with 5% of the flow during the dry season flow and 38% of the flow during the wet season.

Three hydropower projects are envisaged to be built on Shire River in addition to existing plants.

The Kholombidzo dam site is downstream the Liwonde (Kamuzu) barrage, near the Matope bridge at the upstream end of Middle Shire. Mpatamanga dam site is located between Tedzani and Kapichira hydropower projects whereas Hamilton Hydropower Project is located between Mpatamanga and Kapichira Falls both on the Middle Shire River.

Zoa Falls on Ruo River, a tributary to Shire River, is a joint project between Malawi and Mozambique

Kholombidzo will have daily storage making it possible for the plant to run in daily peaking mode. However, there is a limitation to this peaking mode as downstream Nkula and Tedzani HPP's have limited reservoir and limited installed capacity.

Mpatamanga HPP is expected to improve the availability of both capacity and energy, as this plant has a daily/weekly reservoir. This peaking capacity, even though limited because of the limited reservoir, might prove very valuable as there are limited power generation options in Malawi to regulate the larger thermal alternatives (coal fired) and to firm up intermittent renewable sources of electricity generation (solar and wind).

With the envisaged negligible storage volume of the two downstream plants, Hamilton Falls and Kapichira, these plants will need to operate in parallel with Mpatamanga for optimal utilisation of the water available, i.e. to avoid spilling of water. Accordingly, Mpatamanga HPP will define the optimal installed capacity and operation of the two downstream located plants.

In order to illustrate the impacts of considering the three projects Mpatamanga, Hamilton and Kapichira Extension in combination, the Consultant made some early calculations of alternative options for optimisation of the cascade of plants. These calculations were made on the assumptions available at the time (October 2016) including an installed capacity of Mpatamanga of 365 MW, Hamilton Falls with 50 MW and Kapichira III extension with 120 MW. The figures were obtained from different sources and do not match each other if spill of water is to be avoided for river inflows at Mpatamanga below 700 m3/s. No additional flows from tributaries entering Shire downstream of Mpatamanga were considered in this preliminary assessment. Accordingly, optimisation of the cascade was based on the mean annual inflow to Mpatamanga (571 m^3/s) for all plants. This is a conservative assumption, i.a. Kapichira has a significant catchment area, but is in this study considered justifiable as the purpose of the analysis is to illustrate some of the implications of the potential of the cascade.

Assuming that the installed turbine flow of the two downstream plants should match the Mpatamanga 365 MW turbine flow the calculations show that both projects should have significantly higher installed capacity; Hamilton Fall HPP 112 MW against 50 MW as indicated in existing studies and Kapichira III extension (304 -128 =) 176 MW against 120 MW as indicated in existing studies (details in Appendix 1, ch 1.2). Source of information: Pre-feasibility Study for Mpatamanga Hydropower Project, Option Assessment Report, Volume I- Main Report Final, July 2015, Fichtner.

The figures used to illustrate optimisation of the cascade in the calculations made in October 2016 were very tentative, in particular for Hamilton Falls as no study has yet been done for development of the hydropower potential at this site. Based on these data.

To demonstrate the impact of increased installations, an alternative with increasing turbine flow at Mpatamanga from 700 m3/s to 1000 m3/s was calculated as presented in the data sheet (Appendix 1). In this case the total peaking capability of the cascade increases from 620 MW during the 15 hours(700 m3/s case) to 943 MW during 10 hours (1000 m3/s case). The base load is run 24 hours a day for both alternatives.

Above exercise serves to indicate the options of utilising the three hydropower potentials in the cascade. More detailed analysis is required, preferably a full feasibility study, to identify the optimal installed capacity. Such a study is proposed to investigate how the three power plants run in peaking mode will influence the supply side of the IRP and what the installed capacity of the plants should be.

Since the calculations presented above was carried out the Draft Final Feasibility Study Report of Mpatamanga has been made available. Optimisation of the plant is now based on a lower turbine design flow than previously used resulting in a proposed installed capacity of 300 MW (vs 365 MW in the Pre-FS). Accordingly, the data used in the least-cost optimisation of the power system expansion plan for the Draft Final Report, IRP and reported in the Main Report (Volume I) have been adjusted downwards to the values presented in the table below.

Data on candidate hydropower power projects on Shire River Catchment used in the Draft Final Report, IRP

Project name	Capacity MW	Generation GWH/y	CAPEX mill. USD	Earliest commissioning date	Remarks
Mpatamanga.)	300	1740	522	September 2022	FS ongoing
Hamilton Falls.4)	96	555	200	Not known	Conceptual level
Kholombidzo. 3)	213.2	1212	511.5	March 2023	FS ongoing
Zoa Falls.1)	23	110.8	115	Not known	Border project Malawi/Mozambique.
Kapichira III extension. 4)	112	647	139	Not known	Limited information obtained/available. Figures estimated by the consultant

Source of information:

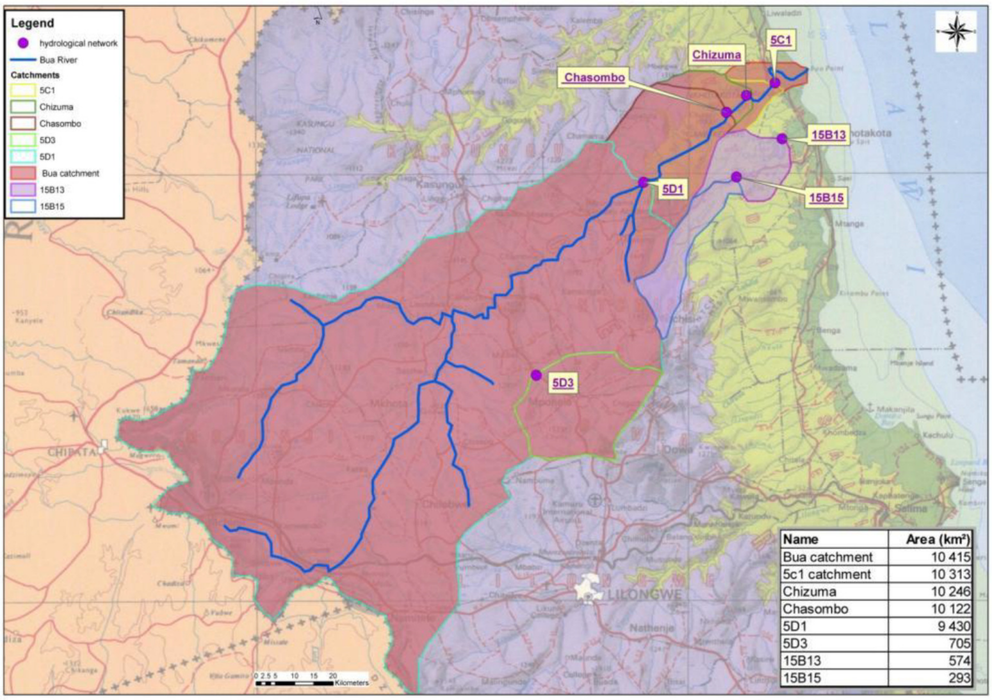
1) Mini Integrated Resource Plan 2016-2020. MNREM, DoE and ESCOM, December 2015
2) Feasibility Study for Mpatamanga Hydropower Project, Option Assessment Report, Volume I-Main Report Final, July 2015, Fichtner
3) Draft Feasibility Study Report Part I for Kholombidzo HEP, September 2016, COBA
4) No Study for Hamilton Falls and Kapachira III Ext. have been made available. Figures in the table above are estimated by the Consultant and some information from the Feasibility Study of Mpatamanga, February 2017, Fichtner

1.1.2 Bua River Basin

The Bua River basin is in the Central Province. The river is flowing into Lake Malawi immediately north of Nkhotakota city. The catchment area of the Bua River extends from the western borders to the lake. The Mchinji Mountains lying to the southwest of the basin near Zambia are the only major highlands rising over 1750m metres above sea level. The drainage area of the Bua River is 10,415 km².

The original vegetation in the catchment consisted of open woodlands. In recent years, large-scale developments of tobacco and maize farming have brought large areas under rain fed agriculture resulting in deforestation of the natural vegetation. The only woodlands remaining in the basin are protected areas: Nkhotakota game reserve on the eastern side, Kasungu National Park and Mchinji Forest on the western side and Ngala Forest in the middle reach of the basin.

The catchment is shown in the figure below:



Four hydropower projects have been envisaged on the Bua River from downstream to upstream; Chizuma, Chasombo, Malemga, Mbongazi HPP.

Chizuma (40.4 MW) and Chasombo (40.4 MW) have been studied to Feasibility level by ARTELIA, whereas little information was found on the upstream plants named Malenga and Mbongozi.

The Mbongozi project has been referred to in the Mini Integrated Resource Plan with an installed capacity of 41 MW and a mean yearly generation of 261.4GWh with a construction cost estimated at 182.1 million USD (excl. price increase during construction and IDC).

Malenga is referred to in the ARTELIA FS report for Chizuma (July 2014) with an installed capacity of 63 MW, mean annual generation of 242 GWh and a construction cost of 570 million USD.

The Chasombo and the Chizuma downstream form a cascade of 2 dams on the Bua River not far from the Lake Malawi. While the Chasombo dam is a storage dam, permitting a flow regulation and maximizing guaranteed power capacity, the Chizuma dam is a smaller dam permitting the diversion of the water to a water intake only.

The Chizuma reservoir without upstream flow regulation has hardly any regulation capacity. Chasombo reservoir would therefore have a very important role to play in the cascade Chasombo - Chizuma. For an average year, Chizuma inflows are entirely regulated by Chasombo reservoir so that the average annual production of Chizuma with Chasombo becomes 200 GWh, i.e. about 35 % more than the production of Chizuma without Chasombo.

The IRP is based on the important assumption that the Chizuma dam construction starts at the same time or after the Chasombo scheme has been implemented.

A “New Chasombo” alternative is proposed in ARTELIA’s report as a replacement of the Chasombo + Chizuma schemes. The New Chasombo underground water conveyance system by-passes the Chizuma dam site to take advantage of the sum of the water head of the original Chasombo plus the Chizuma schemes. It includes a 13.3 km tunnel from the Chasombo reservoir directly to the former Chizuma tailwater discharge in the Bua River.

The estimated construction cost of New Chasombo (about 400 million USD), the installed capacity (83 MW) and the annual average generation are larger than the related values of the other alternatives because this alternative actually combines the Chasombo and Chizuma hydropower schemes. However, this alternative has not been selected by the Client.

Comments: The construction costs figures stated for the Malenga hydropower project could not be verified by any study report.The projet was has not been carried forward as a candidate in the Plexos optimisation.

Candidate hydropower projects on Bua River:

Project name	Capacity MW	Generation GWH/y	CAPEX mill. USD	Earliest commissioning date
Chizuma1)	40.4	200	157.7	2022
Chasombo 2)	40.4	231	389.3	2022
Malenga 2)	63	242	570	2030
Mbongozi 3)	41	261.4	182.1	2019

Source of information:

1) Chizuma Hydropower Project on Bua River in Nkhotakota District Feasibility Studies, Preliminary Design Report, Volume 1, July 2013. ARTELIA Eau & Environment

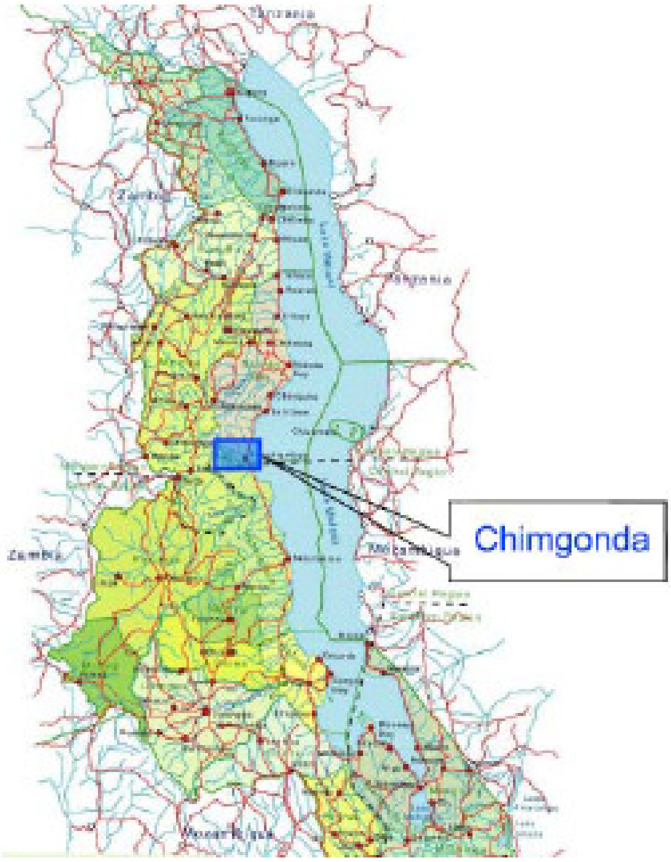
2) Chasombo Hydropower Project on Bua River in Nkhotakota District Feasibility Studies, Preliminary Design Report, Volume 1, July 2013. ARTELIA Eau & Environment

3) Mini Integrated Resource Plan 2016-2020. MNREM, DoE and ESCOM, December 2015

1.1.3 Dwambazi River Basin

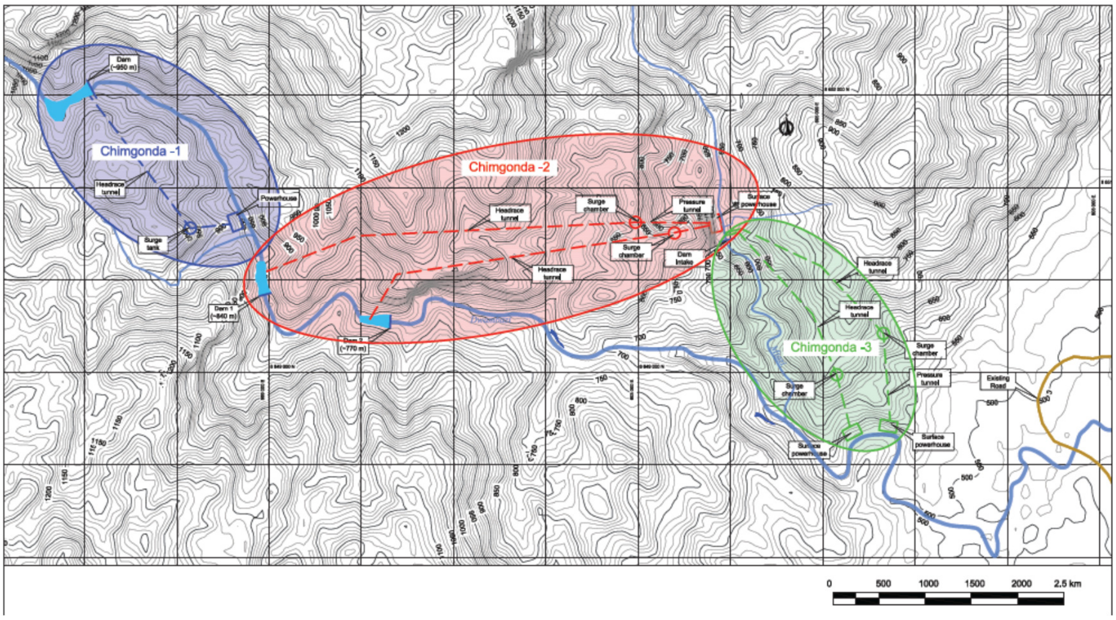
Chimgonda project is located on the Dwambazi River on the border between the Central and Northern regions.

Location of Dwambazi River basin and Chimgonda project:

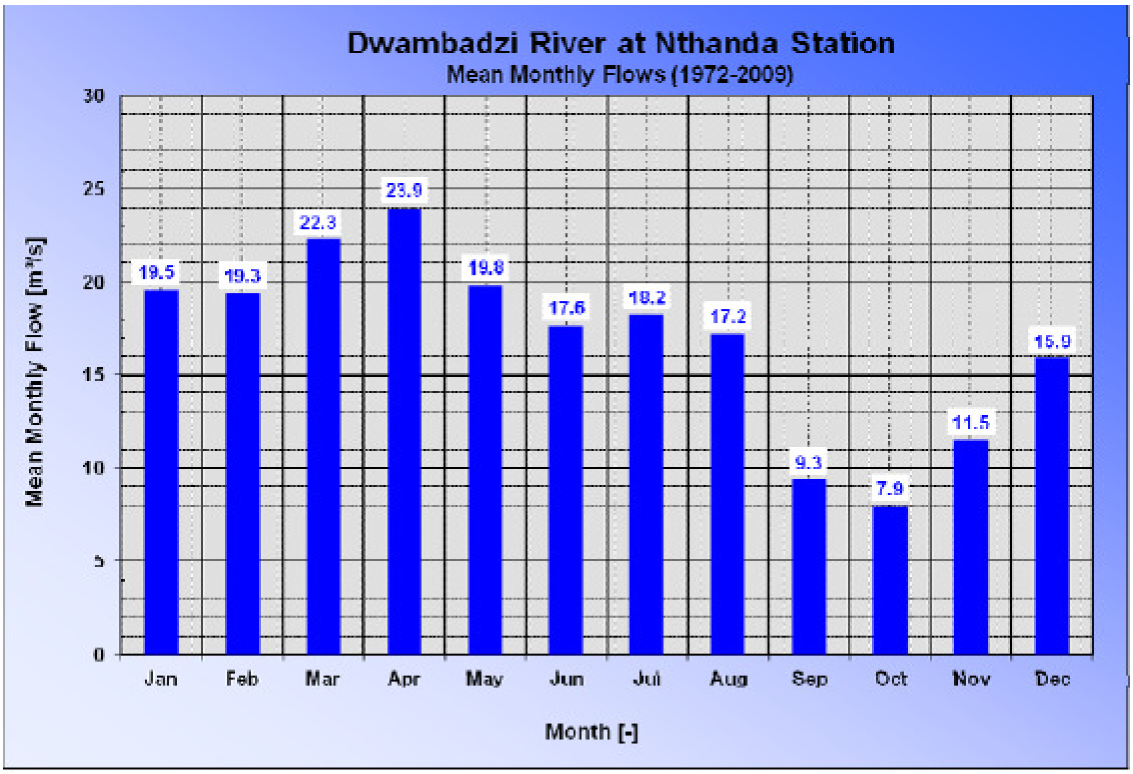


Previous studies have proposed a one-step development of the Dwambazi hydropower potential. However, due to topographical constraints, the site reconnaissance resulted in the definition of an alternative technically feasible and promising layout proposing to utilize the hydropower potential in a three step cascade development.

The following sketch gives the overview to the identified projects at Dwambazi River Cascade.



The basis for the hydrological analysis of the Chimgonda 1, 2 and 3 projects is the available daily flow series measured at the Nthanda Station on Dwambadzi River. The data basis for the project Chimgonda HPP, which is the daily flow series, is shown in the figure below as mean monthly flows.



It should be noted that there are discrepancies or inconsistencies in the available time series for the given period (1972-2009). The flows measured during the period of 1999-2001 are unreasonably high while the flows measured during 2003-2009 are uncharacteristically low. These discrepancies or inconsistencies must be addressed in the hydrological analysis when Chimgonda hydropower projects are studied in more detail. Data available has not made it possible to include these projects as candidate projects.

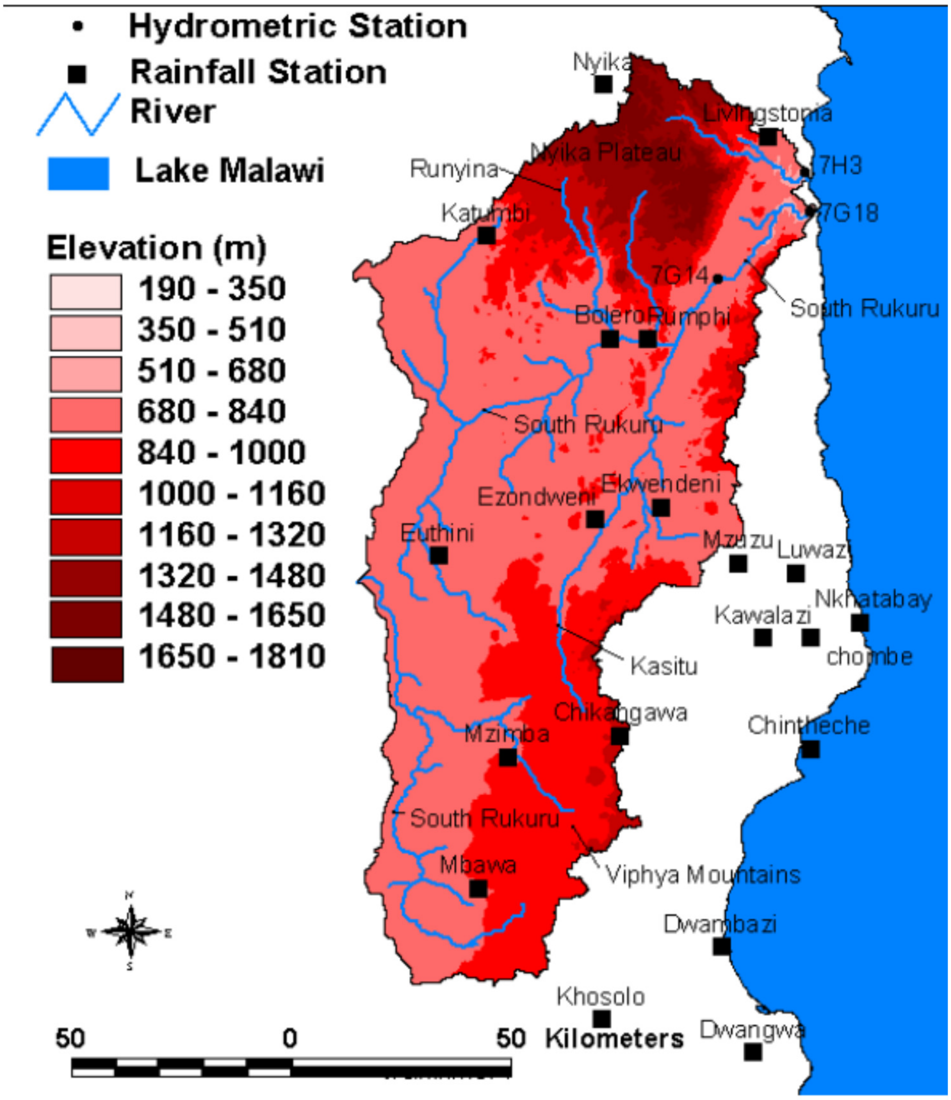
The hydropower potential of Dwambazi River with a total combined installed capacity of 50-60 MW are listed in the table below:

Project	Chimgonda 1	Chimgonda 2	Chimgonda 3
Gross head	75 m	170-220 m	75-80 m
Mean discharge	13-17 m^3/s	17-21 m^3/s	24-27 m^3/s
Installed power	10-12 MW	25-30 MW	14-16 MW

Source of information:

Pre-feasibility Study Report for Chimgonda and Mpatamanga Hydropower Project, Inception Report Part 1 February 2015, Fichtner

1.1.4 South Rukuru and North Rumphi River Basins



Plan showing South Rukuru and North Rumphi River Basins

1.1.4.1 *South Rukuru River Basin*

The South Rukuru River has an elongated catchment, west of the Great Rift Valley, with an area of 12,705 km² running mostly to the North.

The entire catchment is a high plateau with the Vipya Mountain range in the East and the Nyika plateau area in the North. The River originates in the Vipya Mountain range and meanders and flows mostly in a northerly direction until it reaches the Vwaza swamps. Thereafter it flows in a NE direction to discharge into Lake Malawi near Mlowe. The highest point is 1,200 metres elevation.

The main tributaries are the Kasitu River, the Runyina River and the Mzimba River.

The National Water Resources Master Plan estimates 870 mm/year rainfall and 2.9 l.s.km² runoff for the South Rukuru catchment at the 7G14 hydrological station.

The hydropower potentials in the South Rukuru Basin include Fufu, Henga and Rumphi dam projects.

The Fufu dam site location has a surface catchment area of 11,950 km².

The Henga reservoir is located immediately downstream of the Henga Valley, about 25 km up-river from Lake Malawi. The surface catchment area of at the Henga dam site location is 11 770 km².

The Rumphi reservoir is located at the gorge site immediately downstream of Rumphi village, a short distance upstream of the Kasitu confluence. The surface catchment area is 9002 km² at the Rumphi dam site.

1.1.4.2 *North Rumphi River Basin*

The North Rumphi River has a catchment area of 712 km². The catchment is very steep and has a very good draining network. The North Rumphi River originates from the eastern side of the Nyika Plateau and drains into Lake Malawi.

The highest point is 2,607 m elevation and nearly 50 % of the area is above 2,000 m elevation.

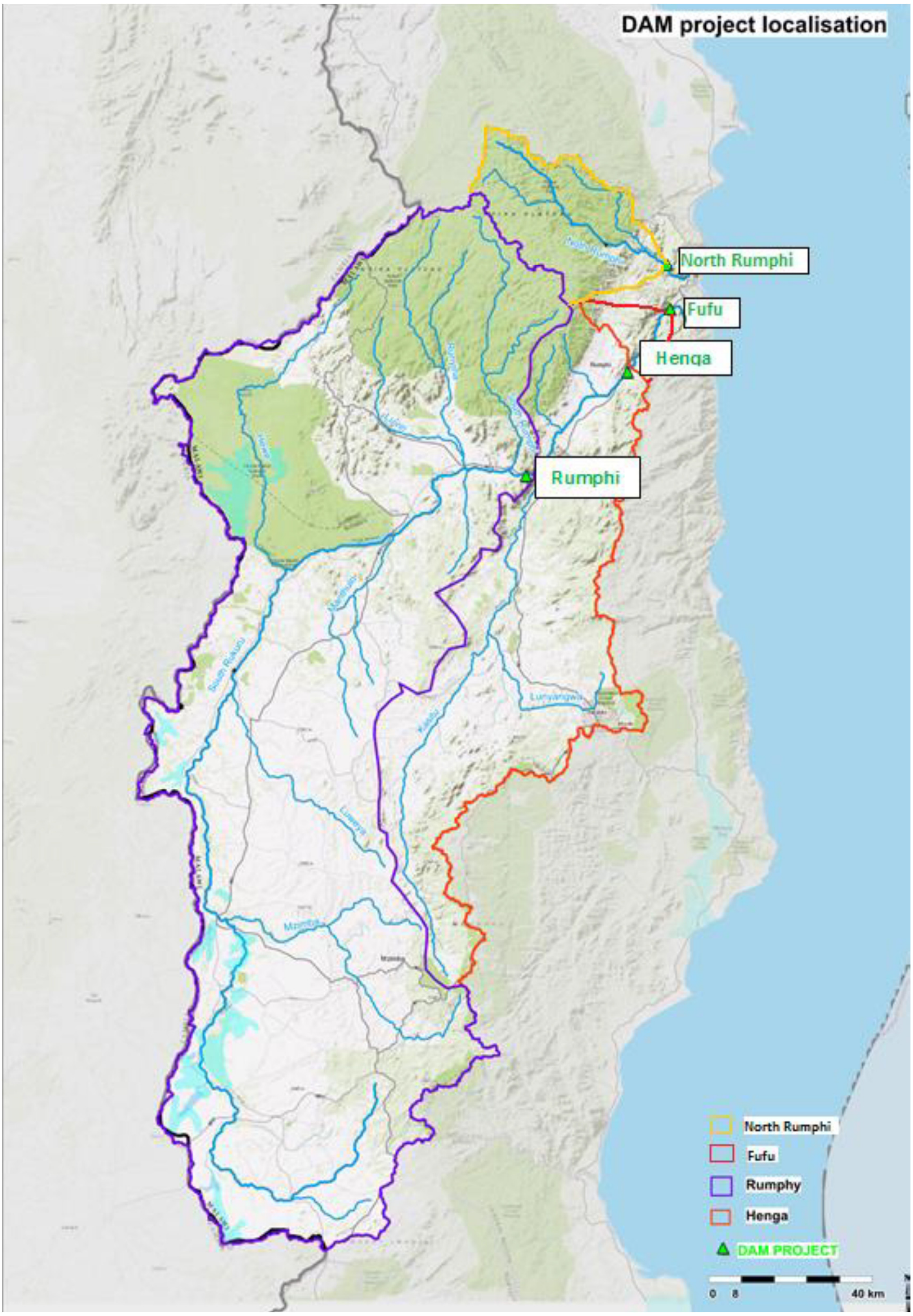
The river flows in a direction SE until it discharges into the Lake. The main tributary is Kaziwiziwi.

The National Water Resources Master Plan estimates 1530 mm/year rainfall and 21.1 l.s.km² runoff for the North Rumphi catchment.

The surface catchment area at the North Rumphi site location is 650 km².

Several alternative developments are proposed in the Feasibility Study.

Source of information: Fufu hydropower project Phase II-Review of Prefeasibility Studies, Final, December 2015, ARTELIA/eDF. All alternatives conclude with the transfer of flow from North Rumphi River to South Rukuru River both for a high and low dam alternative for the Fufu project.



Plan showing the location of the different dam site alternatives.

A tentative EIA study has been carried out for the various project alternatives. As a result of the EIA study findings the Rumphi and Henga Valley schemes were not retained due to the significant environmental and social impacts on land upstream and the need for re-location of many rural communities. The High Fufu Dam alternative will require at least resettlement of 2000 people at the time when construction starts. Such large number of affected people could lead to important social disruption.

Due to considerable environmental and social impact associated with the Rumphi, Henga Valley and High Fufu Dam alternatives, only the Low Fufu Dam alternative has been considered for the time being in the IRP study. It should be noted that a more detailed EIA-study is at present carried out for the High Fufu Dam alternatives[2].

Main characteristic of Low Dam and High Dam Fufu Hydropower alternatives.

Project name	Capacity MW	Generation GWH/y	CAPEX mill. USD	Earliest commissioning date	Remarks
Low Fufu 1)	132	647	350	2023	FS ongoing
High Fufu 2)	169	1008	455	n.a.	FS ongoing

Source of information:

1) Fufu hydropower project Phase II-Review of Prefeasibility Studies, Final, December 2015, ARTELIA/EDF.

2) Note related to the Feasibility Study of the Fufu HPP on Determination of the Recommended Dam Height received on February 9 2017, ARTELIA

[2] The Consualtant received a note related to the Feasibility Study of the Fufu HPP by Artelia on Determination of the Recommended Dam Height on February 9 2017. The note advises that Artelia is recommending the hrigh dam alternative. Data for both the high and the low alternative have been included as candidates in the optimization as presented in Volume I, but time did not allow for an update on the data sheets within the deadline for delivery of this Draft Final IRP report.

1.1.5 Songwe River Basin

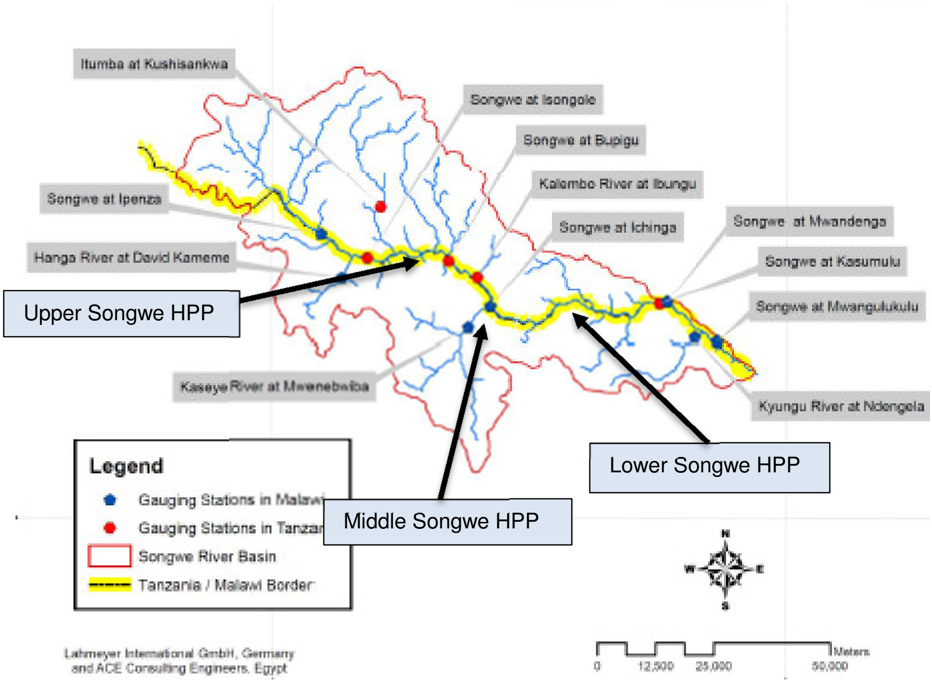
The Songwe River Basin has an area of about 4,200 square kilometres and covers parts of Chitipa and Karonga Districts in Malawi and the Kyela, Ileje, Mbozi and Mbeya Districts in Tanzania. The basin offers associated economic opportunities such as agriculture, hydropower, fisheries, water supply and sanitation, and recreation.

Three hydropower developments are envisaged on the Songwe River, namely Upper, Middle and Lower Songwe HPP. The Lower Songwe HPP has been studied at detailed design level wherea the Upper and Middle Songwe have been studied at desk/reconnaissance level only. These are joint projects to be developed by the Governments of Malawi and Tanzania. Only Malawi's share of the projects are listed in the tables below.

The Lower Songwe HPP has a seasonal reservoir and will supply water to a planned irrigation scheme just downstream of the project. The intake for the proposed irrigation scheme is at the tailrace of the Lower Songwe HPP at a weir structure with an equalizing pond. Feeder canals from the equalizing reservoir will supply a gravity distribution network comprising a main and several secondary and tertiary and field canals.

The Lower Songwe HPP Detailed Design Study is funded by African Development Bank / AWF / NEPAD

Plan: Songwe Catchment with proposed Hydro Power Plant locations:



The hydropower potentials of Songwe River Basin are listed in the table below. The figures shows only Malawi's share of 50 % of the total figures:

Project name	Capacity MW	Generation GWH/y	CAPEX mill. USD	Earliest commissioning date	Remarks
Lower Songwe 1)	90	343	261	2023	Border project 50/50 with Tanzania
Middle Songwe 2)	80			2030	Limited information obtained/available
Upper Songwe 2)	14			2030	Limited information obtained/available

Source of information:

1) Detailed design and investment preparation project for the Songwe River Basin Development Programme. Lower Songwe dam and HPP. Detailed Design Report. June 2015, Lahmeyer International and ACE Consulting Engineers.
2) Pre-feasibility Study for Mpatamanga Hydropower Project, Option Assessment Report, Volume I- Main Report Final, July 2015, Fichtner

1.2 Existing Hydropower Plants

1.2.1 Current Situation

The current power generation system is based mainly on hydropower projects located on the Shire River. The 4.5 MW Wovwe HPP is the only HPP located outside the Shire River basin.

Some mini and micro hydropower plant exist but have insignificant impact on the total energy generation. In general, the development of small hydro power plants in Malawi has been slow. To the knowledge of the Consultant, there is no overall plan for development of small hydro in Malawi.

The present electric generation capacity (2015) of hydropower plants are shown in the table below:

NAME	PHASE (Commissioned)	HEAD m	DISCHARGE m3/s	INSTALLED CAPACITY MW
NKULA	Nkula A (1966)	50	60	24
	Nkula B I (1980)	50	130	60
	Nkula B II (1986)	50	45	20
	Nkula B III (1992)	50	45	20
	Total		**280**	**124**
TEDZANI	Tedzani I (1973)	37	60	20
	Tedzani II (1977)	37	60	20
	Tedzani III (1995)	37	160	52.7
	Total		**280**	**92.7**
KAPICHIRA	Kapichira I (2000)	54	135	64
	Kapichira II (2012)	54	135	64
	Total		**270**	**128**
WOVWE	Mini Hydro			**4.5**
	Total			**349.2**

1.2.2 Planned Upgrading and Extension of Existing Hydropower Plants.

In the following plans for upgrading and extension of existed hydropower plants are listed.

NAME	CAPACITY MW	GENERATION GWH/y	STATUS	EARLIEST YEAR ONLINE	COMMENT
Nkula A upgrade 1)	12	57.8	Committed	2018	Capacity increase from 24 MW to 36 MW. Nkula A out of operation in 2017
Tedzani IV extension 1)	22	170	Under pro-curement	2019	New unit 22 MW
Tedzani III upgrade 1)	10	48.2	Awaiting EPC contract award	2022	

1.3 Overview of Candidate Hydropower Projects

Project name	Capacity MW	Generation GWH/y	CAPEX mill. USD	Status of project	Lead-time planning months	Constructio n time months	Earliest commissioning date
Zoa Falls, Ruo River	23	110.8	115	Seeking funding for FS Study			Not known
Hamilton Falls. Shire River	96	555	200				Not known
Kapichira III extension. 4)	112	647	139	Limited information obtained/available. Figures estimated by the consultant			
Mpatamanga Shire River	300	1740	522	FS finished end 2016	26	42	September 2022
Kholombidzo Shire R 5).	213.2	1212	511.5	FS finished end 2016	26	48	March 2023
Chizuma Bua River	40.4	200	157.7	Awaiting financing	26	42	2022
Chasombo Bua River)	40.4	231	389.3	Awaiting financing	26	45	2022
Malenga Bua River	63	242	570				2030
Mbongozi Bua River	41	261.4	182.1	Off-take agreement signed between IPP and Utility			2019
Chimgonda 1, 2 and 3 Dwambazi River	(1) 10-12 (2)25-30 (3)14-16	-	-	A three-step cascade development proposed. Pre-feasibility report finished end of 2017.	40	48	2026
Low Fufu S. Rukuru River	132	647	350	FS end of 2016	26	54	September 2023
High Fufu S.Rukuru River	169	1008	455				
Lower Songwe Songwe River	90	343	261	Tender Document finished end 2016	12	60	January 2023
Middle Songwe Songwe River	80	-	-				2030
Upper Songwe Songwe River	14	-	-				2030

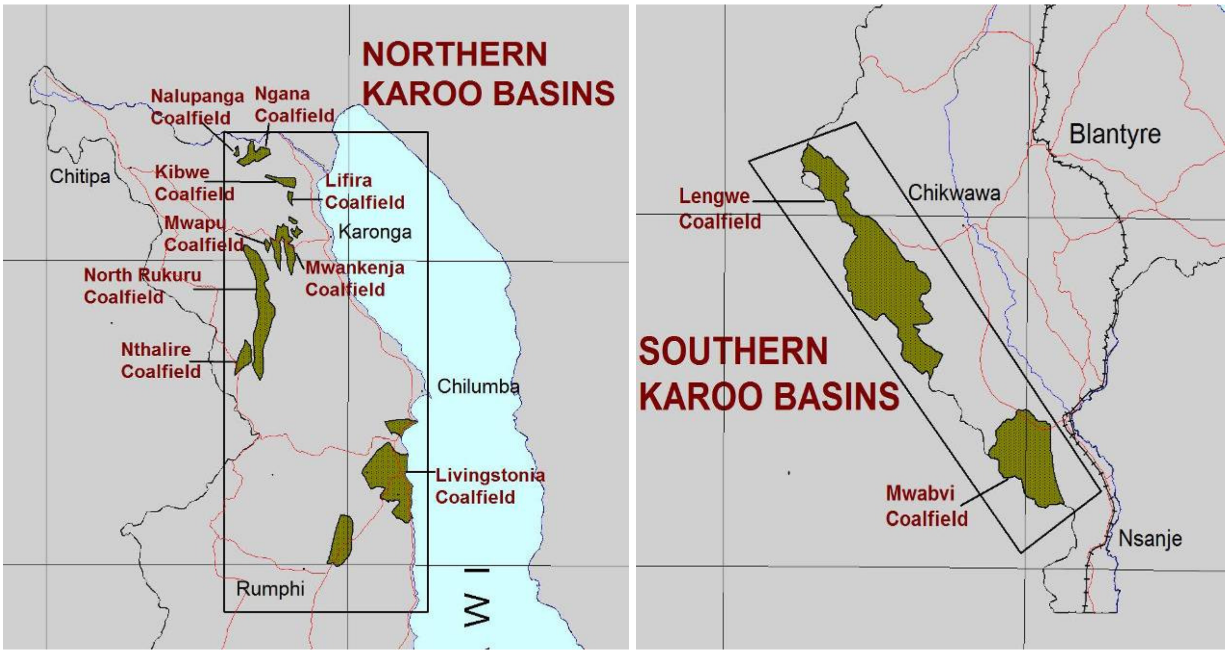
1.4 Data Sheets of Candidate Hydropower Projects

Data Sheets, presented in Appendix 1, have been prepared for projects where information is available to the reconnaissance level or in more detail.

2 THERMAL GENERATION

2.1 Hydrocarbon Resources

According to the Malawi Power System Project Studies – Phase II Integrated Resource Plan (IRP) for Malawi [3] "*Malawi has two main coal fields, one in the north and one in the south. The northern coal fields have proven coal reserves of about 17.5 million metric tonnes and probable reserves of 66 million tonnes and the southern coalfields have estimated reserves of 5 million tonnes and probable reserves of 10 million tonnes*". In Exhibit A5A-18 of the above report the "Coal Basins for Potential Coal Power Plants" are depicted as follows;



In Exhibit A5A-19 the Characteristics of the Main Coal Deposits in Malawi are outlined as follows;

Deposit	Moisture (%)	Ash (%)	Volatiles (%)	Fixed Carbon (%)	Calorific Value (Kcal/kg) (MJ/kg)	Sulphur (%)	Total Resources (mill. Ton) Inferred
Ngana	4.5	30.2	24.9	32.8	4,708 19.71	2.2	65.0
Lufira	6.6	35.0	25.9	31.8	3,819 15.99	0.77	0.6
Livingstonia	3.0	20.0	22.0	45.0	4,780 20.13	0.5	26.4

[3] Millennium Challenge Corporation, 2011

North Rukuru	4.2	32.4	23.7	40.6	4,781 20.17	0.6	155.0
Mwabvi		45.2	5.8	50.5	4,173 17.47	0.76	4.70
Lengwe	1.7	59.2	10.5	30.3	2,746 11.50	0.51	10.0

The larger deposits and better quality coal for power generation is in the North and the ICF/Core team expressed the opinion that it might be beneficial to consider a coal-fired plant of 300 MW there. The expected coal consumption of a 2 x 150 MW coal power plant will be about 25 million tonnes over a 25 year life – there is thus more than sufficient coal to support such a project.

As can be deduced from the information above the identified proven reserves of Malawi can only sustain in the order of maximum 3 coal-fired plants of 300 MW each. The “Inferred” coal resources, as used in the table above, is by definition the part of a mineral resource for which tonnage, grade and mineral content can be estimated with a low level of confidence. It is not known to what extent the certainty of these resources has been estimated.

Malawi does not produce any oil or gas at present and imports all petroleum products although there are good geological indications that locally produced gas or oil might play a role in future. With no hard information about the quantum, if any, and cost of production available, this resource is not factored into the study. For standby or peaking purposes, the use of imported fuel oils will be considered.

2.2 Existing Thermal Generation

2.2.1 Coal-fired Plant

Malawi has as no existing coal-fired generation although Kammwamba, a 300MW plant burning coal from the Moatize field in Mozambique is considered committed with construction expected to start in 2017. This project will be discussed along with other new plant in Section 4.3.

2.2.2 Reciprocating Engines

The information on existing ESCOM reciprocal engines were extracted from a provisional Plexos input sheet as revised by ESCOM.

Plant	Units	Installed Capacity Total (MW)	Sent-out Capacity Total (MW)	Commissioning Date
Mzuzu - Old Town (Decommissioned)	1 x 1.1	1.1	1.067	1958
Mzuzu - Luwinga	3 x 2	6	5.82	June 2017

Lilongwe A (Being rehabilitated)	3 x 2	6	5.82	1958 1958 1972
Mapanga - Blantyre	10 x 2	20	19.4	U1-5: 2016/17 U6-10: 2017/18 Fin. Year
Likoma Island	3 x 0.2	0.6	0.58	2000
Chizumulu Island	2 x 0.137	0.274	0.266	2000
Kanengo – Phase 1 Kanengo – Phase 2	1 x 10 1 x 10	10 10	9.7 9.7	2016 2017

The bulk of these engines are being refurbished or yet to be commissioned and no detailed information on the models, performance, load factor or cost of generation for these plants could be obtained except that the average efficiency is believed to be around 35%. This is low compared to reciprocating engines now generally available.

2.3 Overview of NEW Thermal projects

Malawi has relatively large coal reserves but no proven gas or oil resources. Coal-fired plants are therefore included as options in the candidate generation mix whilst large scale thermal power generation in Malawi with gas, probably by means of Combined Cycle Gas Turbines (CCGT) to achieve optimal efficiency, is unlikely because it would imply importing natural gas by pipeline from Mozambique whereas it would be more cost effective to import electricity via the proposed interconnectors.

2.3.1 Coal-fired Plant

Construction of Kammwamba, a committed 6x50 MW coal-fired plant, is expected to start in 2017 with commissioning in 2019 to 2020.

Pamodzi IPP is the only coal-fired project where enough information in the form of a pre-feasibility study is available for analysis and inclusion as a specific candidate project. Other projects have been investigated by different developers but little or no information is available. However, within the time horizon of this investigation it is worth considering coal-fired projects comprising of larger units with the advantages of economies of scale and higher efficiencies. Generic 2 x 150 MW coal-fired projects have therefore also been included as candidates.

The expected performance and associated costs included in this assessment have been based on the information available in the Feasibility Study for Kammwamba and the Pre-Feasibility study for Pamodzi. Unfortunately, all aspects were not necessarily covered in sufficient detail in these studies and it was therefore necessary to extrapolate some data. Additionally, some of the information required further interpretation by the Consultant. All estimates derived through extrapolation or interpretation are identified in the description of the projects contained in this assessment. The generic 2 x 150 MW plant performance and costs were based on plant designs and configurations explored in the region.

A coal price of $25 to $35 per ton, plus $13 to $15 per ton for transport, was provided by Kammwamba. An overall coal price of $50/ton which translates to $1.971/GJ is assumed in the evaluation of the project. (The upper limit is deemed more likely if this price is compared with South African export coal prices). As coal prices are not available for Pamodzi and the generic coal-fired project, the coal price for these projects is based on the $1.971/GJ energy price for Kammwamba. The calorific value of the coal for these two projects are substantially lower than that of Kammwamba coal and the price per tonne for Pamodzi and the Generic plant consequently lower at $39.31 and $39.68 respectively.

Capital costs for coal-fired plant on a USD per kW installed basis varies substantially depending on a number of factors. Super-critical plant is more expensive than sub-critical plant, larger units are usually less expensive on a USD per kW than smaller ones and EPC costs for European / American supplied plant are higher than Indian plant with Chinese plant often having the lowest EPC costs. However, depending on the codes and standards used in the design and manufacture, different Original Equipment Manufacturers (OEM's) would also offer very different prices, notwithstanding the country of origin. Given these unknowns, an EPC price of $2,200 / kW installed (consistent with the Pamodzi EPC cost and similar projects in the region) is assumed across the board for the purpose of comparing the three projects. Although this approach could be perceived as disadvantageous to the Generic option as its 150 MW units are substantially larger than Kammwamba and Pamodzi units, it errs if anything on the conservative side. To the EPC price other costs such as project development, financing, project establishment, other owner's costs and transmission infrastructure are added to arrive at a total capital cost for each project.

Utilities: The purity of the sorbent (in the form of limestone) is based on information obtained from Kammwambe (90%), Pamodzi (95.3%) and assumed for the Generic project (92%). A price of $85 / tonne was assumed in all three cases. Sufficient water was presumed to be available for all three projects at a supply and treatment cost of $0.19/m^3. Fuel Oil (diesel) for start-ups and flame support was estimated at $900/m^3.

Significant issues with regard to the three new coal-fired projects include;

- The unit sizes of Kammwamba (50 MW) and Pamodzi (40 MW) are small and possibly based on older designs, consequently their efficiencies are not optimal - Kammwamba at 23.31%, Pamodzi at 28.06% compared to the generic project's unit size of 150 MW at an efficiency of 36%.
- Care should be taken in boiler design to ensure compatibility with Southern African coal as local characteristics may cause problems in standard designs based on Northern Hemisphere coal, especially in the Pulverised Fuel configuration.
- The airshed classification for any new coal-fired generation project in Malawi need to be established as early as possible to define the impact on desulphurisation costs.
- Experience in the region has shown the importance of good quality control in the manufacturing and erection of power plants and this should be managed carefully.
- The social impact of large scale construction, possibly involving extensive expatriate labour, needs to be planned for and managed.

Recent information obtained from reliable press cuttings indicate that developers of the Pamodzi plant (now stipulated at 120 MW) will source its coal from its Tancoal mine in Tanzania and not from the Malcoal mine in Malawi.

2.3.2 Fuel Oil Plant

Oil or gas is attractive for dispersed standby or peaking but it is doubtful that relatively small installations would warrant the expenditure associated with a dedicated fuel pipeline. Within the time horizon of this study it is thus assumed that fuel oil rather than gas will continue to provide standby or peaking generation and then most likely through the use of reciprocating engines. The latter invariably have a better efficiency than Open Cycle Gas Turbines (OCGT) and are easier to maintain and operate.

Given the relatively high cost of Light Fuel Oil (LFO) at $900 to $1000 per m³, compared to Heavy Fuel Oil (HFO) at an estimated $380 per m³, HFO should logically be considered. However, HFO requires additional handling equipment and this is usually not practical or cost effective for smaller plant, especially if the plant is intended in a standby role. On the other hand, larger units running at a slower speed are normally more efficient although they tend to be more expensive than high speed plant for the same output. Generally, as for coal plant, larger engines have a lower cost per kW installed. Apparently at least two developers, Aldwych Africa and Impact Energy, are investigating HFO for possible projects in Blantyre, Lilongwe and Mzuzu, but no details are immediately available.

Based on current commitments in Malawi and experience in sub-Sahara Africa, the preferred size for peaking / standby plant is around 10 MW or multiples thereof. Really slow (<300 rpm) or high speed (>1000 rpm) engines or are not ideal for this application. (The slow speed engines are large and expensive and require sophisticated maintenance whilst high-speed engines are less efficient and have a limited life).

Two generic fuel candidates which can serve as basis for the inclusion of standby / peaking plant in the system optimisation, incidentally also illustrating the advantage of HFO over LFO, have been developed, one with two 10 MW HFO driven engines and one with four 5 MW units running on LFO. Engine speeds in the 500 rpm to 750 rpm range are envisaged which would classify them as medium speed engines. The generic models were loosely based on Wartsila 12V32, 12V46 and 20V32 prototypes, all with efficiencies of around 45% to 46%. These two alternatives, both based on a 50% load factor, are indicative only and different configurations and load factors may be considered should the demand/supply analysis require it.

In summary, the new projects present the following characteristics;

Prime mover		Coal			Fuel Oil	
Status		Committed	Candidate	Generic Candidate	Generic Candidate	Generic Candidate
Project		Kamm-wamba	Pamodzi	Generic 2x150	HFO	LFO
Capacity	MW	300 (6 x 50)	133.5 (3 x 44.5)	300 (2 x 150)	20 (2 x 10)	20 (4 x 5)
Net Output	MW	258.2	120	273.2	19.4	19.4
EAF Energy Availability factor	%	85%	90.5%	89.4%	91.5%	91.5%
Load Factor	%	80%	85%	85%	50%	50%

Prime mover		Coal			Fuel Oil	
Status		Committed	Candidate	Generic Candidate	Generic Candidate	Generic Candidate
Project		Kamm-wamba	Pamodzi	Generic 2x150	HFO	LFO
Net Energy production at LF	GWh/yr	1,807.7	893.5	2,035.1	34.97	34.97
Net Efficiency Heat Rate	% kJ/kWh	23.31% 15,445 (HHV)	28.06% 12,829 (HHV)	36.3% 9,931 (HHV)	46% 7,826	45% 8,000
Capex	$m $/kW	852.56 2,842	383.19 2,870	843.62 2,812	32.60 1,630	32.74 1,637
Coal Consumption	/ hr / kWh / year	157.2 ton 0.609 kg 1.100 mt	77.2 ton 0.643 kg 0.575 mt	134.5 ton 0.492 kg 1.001 mt	3.586 m³ 0.185 litre 15,706 m3	3.666 m³ 0.189 litre 16,055 m³
Fuel Cost	$/MWh	30.93	25.78	19.7	70.24	170.05
Fixed O&M	$/kW-yr	48.38	46.56	44.76	46.05	47.05
Variable O&M	$/MWh	2.19	2.16	1.64	5.12	6.03
Lead Time	Months	-	54	54	24	24
Construction	Months	33	36	36	12	12
Earliest COD		2019 2020	-	-	-	-

2.4 Description of New Thermal Projects, Committed and Candidate Plant

Data Sheets, presented in Appendix 2, have been prepared for projects where information is available on the reconnaissance level or in more detail.

3 RENEWABLE ENERGY

The Government of Malawi is aware of the importance of the country's renewable energy resources, including for the future electricity generation portfolio [4]. At the same time, an increase in the share of renewable power generation, other than from large-scale hydro power and other non-intermittent renewables, must be planned in a way to ensure that the integration of such resources into the national grid is cost effective and takes account the intermittent nature of solar and wind energy.

Generally, Malawi's potential of solar, wind and biomass resources is substantial. Despite their relative abundance however, these renewable resources are largely undeveloped.

The remainder of this section covers the solar, wind, bagasse and biomass resource potentials and candidate projects. It also mentions both geothermal and municipal waste resources, which may make contributions to Malawi's future electricity supply mix if the requisite efforts are initiated to further develop them.

As mentioned in the introduction to this Volume II a number of developers have been in contact with the Government of Malawi (GoM) to develop Independent Power Projects (IPPs), mostly for Solar PV plants. For confidentiality reasons data on these projects were not made available to the Consultant. The Renewable Energy candidates are therefore represented by generic projects within sizes that can be immediately accommodated within the existing system (max 70 MW according to a recent study).

3.1 Solar

3.1.1 Resource Endowment

The International Renewable Energy Agency's solar global horizontal irradiation profile for Malawi implies untracked solar photovoltaic yields ranging between some 3.8 to 4.8 kWh/m^2/day [5]. This resource estimate is derived from a map developed by GeoModel Solar, as part of a World Bank Group project which was funded by the Energy Sector Management Assistance Program (ESMAP) [6]. It represents an un-validated, satellite-derived estimate of averaged irradiance.

It is important to note that both location- and technology-specific differences, including the possible use of single or double-axis tracking, necessitate that site- and project-specific verification must be undertaken prior to the commencement of solar photovoltaic projects [7].

[4] **Malawi's Draft Renewable Energy Strategy**, Government of Malawi, 2016
[5] International Renewable Energy Agency, 2016, www.irena.org, accessed on 31 October 2016
[6] **Energy Sector Management Assistance Program**, http://www.esmap.org/re_mapping_malawi, accessed on 31 October 2016
[7] The country's solar direct normal irradiance (DNI) resource, which is a measure of relevance to the use of concentrating solar power plant has not yet been assessed. However, based on regional assessments it is expected that Malawi's DNI potentials are satisfactory and suffice to render future CSP projects viable, provided that future technology costs decrease as expected in international markets.

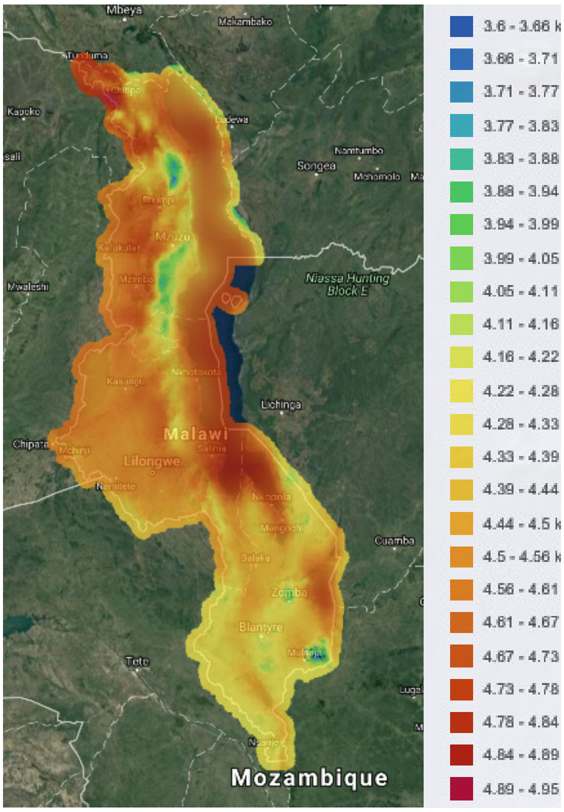


Figure 1: Solar PV output across Malawi, in kWh/m²/day (IRENA Global Atlas for Renewable Energy)

The section below only considers the addition of solar photovoltaic (PV) plant, as these are mature, cost competitive and have well-established regional supply and support structures.

Solar PV Power Generation

There are several different solar PV power technologies in the market, all of which operate on the principle that the irradiance from the sun is used to produce electrical energy. The most common contemporary solar PV panel technologies are crystalline silicon modules, and thin-film modules. In addition, various technologies that track the sun are available, and are implemented to improve the overall energy conversion efficiencies of a solar PV plant. Typically, power production from solar PV plant is higher at mid-day than the morning and afternoon, and tends to match well with diurnal demand profiles.

Solar PV plant produce electricity across an almost unlimited range of outputs, from a few Watts to several MW. As the technology is mature, solar PV plant can be readily integrated in step sizes into Malawi's electricity system. In addition, solar PV projects in the MW-range will in most instances be realised within one year.

3.1.2 Candidate Projects

Data Sheets, presented in Appendix 3, have been prepared for projects where information is availableon the reconnaissance level or in more detail.

3.2 Wind

There are several different wind power technologies on the market, and they operate on the principle that involves the conversion of the wind's kinetic energy into electricity using wind energy converters, or wind-powered turbine-generators. Today, the most common wind energy conversion technology on the market is the horizontal axis wind turbine, which has a rotor and nacelle that houses the main rotor shaft and electrical generator at the top of a tower. Computer controlled yaw motors and pitch mechanisms allow the nacelle to turn and pitch as and when the wind direction changes. Most contemporary wind energy converters have a gearbox, which controls the rotational speed of the blades, and many contemporary models are available with direct drive systems which eliminate the need for a gearbox.

Wind energy converters used for the commercial production of electric energy are usually equipped with three-bladed rotor systems, which are characterised by high tip speeds and low torque ripple. Blades are usually coloured white or light grey, to blend in with the clouds, and range in length from 20 to more than 50 metres. Tubular steel towers range from 50 to more than 100 metres in height. Contemporary wind energy converters are equipped with protective features to avoid damage at high wind speeds, which is usually achieved by feathering the rotor blades into the wind, which then ceases their rotation. Often, such a mechanism is supplemented by brakes.

Wind power technology is mature. A wind power plant can produce significant amounts of electricity, ranging from a few Watts to few hundred MW for a wind farm. Within the Malawian power system, wind power projects can be integrated, provided that grid stability criteria as discussed in the solar section above are taken into consideration.

As a result of the intermittent nature of the wind resource, the electrical output of wind energy converters is highly variable. This intermittency necessitates that the transmission system operator must have regulating measures, for example in terms of quick response generating stations, to ensure that the system's total supply can be effectively matched with prevailing demand requirements.

3.2.1 Resource Endowment

Malawi offers some potential for the beneficial use of wind energy converters. However, site-specific wind resource assessments are very limited, and bankable site data appears to be unavailable.

According to the International Renewable Energy Agency's Malawi Country Profile [8], the country's wind profile offers a mix of sites with limited suitability (i.e. average annual wind speeds at 80 meters hub height are between 4 and 5 m/s) as well as good suitability (i.e. sites where average annual wind speeds at 80 meters' hub height are between 5 and 7 m/s). Wind data originates from the Global Wind Atlas Project which provides high-resolution wind climatology at relevant hub heights above ground level. These have been used in the Wind Atlas Analysis and Application Program (WAsP), and capture small-scale spatial variability of winds speeds due to existing terrain elevation, surface roughness and surface roughness change effects. It is to be noted that the data provided in the IRENA Global Atlas has a 1km spatial resolution, and is therefore indicative only.

[8] International Renewable Energy Agency, 2016, www.irena.org, accessed 31 October 2016

Indicative mean wind speeds across Malawi are also provided by other entities, such as VORTEX, as shown in Figure 2.

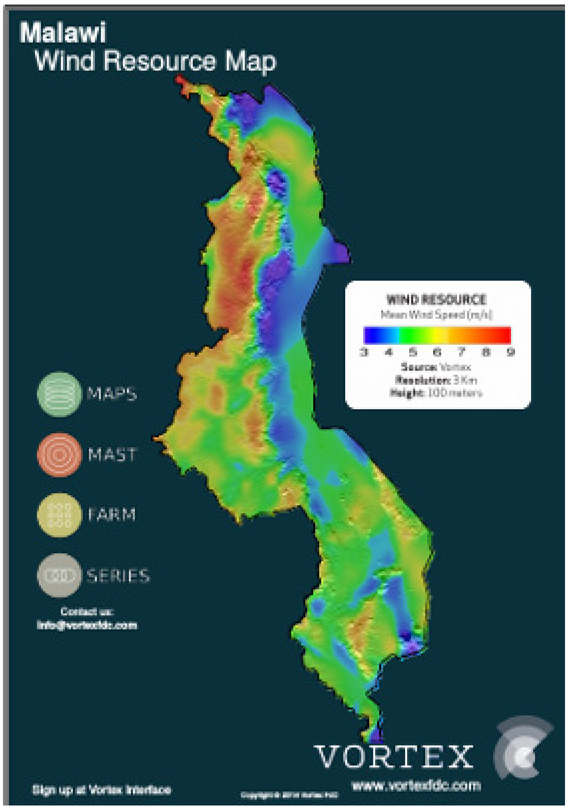


Figure 2: Malawi's wind speed resource map at 100m height, in m/s (VORTEX, www.vortex.com)

A preliminary assessment some 30 km north-east of Mzimba in the Northern Region monitored wind speeds over a 12-month assessment period using a single mast of 70m height (between May 2014 and 2015). The assessment yielded a long-term wind speed of 7.89m/s, with a P90 energy yield of 222.2 GWh/annum and a capacity factor of 25.4% [9].

In view of the location-specific requirements of wind energy converters in general, and turbine-specific requirements in particular, a site-specific verification will be essential for each project prior to financial close. This implies that the candidate projects identified below will be sited in areas offering reasonable to good wind resources, even though specific sites are yet to be identified, and site-specific resources verified. Also, and to minimise grid integration costs, project sites should preferentially be located at or near existing load centres and/or the existing transmission infrastructure.

[9] **Energy Yield Assessment Mzimba Wind Farm**, University of Starthclyde, Report 15/6594/001/GLA/O/R/001, July 2015

3.2.2 Candidate Projects

Data Sheets, presented in Appendix 3, have been prepared for projects where information is available on the reconnaissance level or in more detail.

3.3 Bagasse and Biomass

Malawi is well endowed with natural forests and has an active sugar cane industry and both offer potential for electricity generation projects, either from woody biomass or from bagasse.

Biomass, in the form of wood fuel, remains Malawi's main energy source. Trade in such biomass is therefore a major source of employment and income. While the country is well endowed with wood resources, the long-term yield of these resources is important. In addition, the impacts of a changing climate will also have an impact on the long-term yield of woody biomass and bagasse, which implies that these resources must be managed to remain attractive from the point of view of future electricity generation projects. But, provided that such resources are managed, woody biomass resources are and will remain available, and could be used for the generation of electricity ion future.

Bagasse is a waste product from the sugar cane industry, and represents a potentially renewable resource for the generation of both heat, steam and electricity, as is already practiced at sugar mills in the country.

Bagasse and biomass projects would likely bring about several important benefits, including the creation of new value chains and employment opportunities in the country's rural areas. Typically, the scale of bagasse and biomass combustion power plants varies from a few MW up to several tens of MW, depending on the long-term resource availability. In principle, smaller/larger plant sizes are possible, although plant sizes exceeding 30 MW are not considered here.

For the purposes of this IRP, bubbling fluidised bed (BFB) biomass combustion technology is selected for bagasse/biomass power plants, each with a size of either 5MW or 10MW. Although several potential project sites exist, especially in areas where sugar cane is grown and rice husks are available, only one potential Independent Power Producer has so far registered their interest to build, own and operate a biomass energy conversion plant in Malawi. In addition, several sugar cane producers have undertaken preliminary resource assessments, but it is not known whether and to what extent these entities intend to implement such generation plant, unless being offered firm feed-in tariffs or similar incentives.

3.3.1 Resource Endowment

Based on an assessment presented by the International Renewable Energy Agency, Malawi's bioenergy resource potential comprises of sugar cane, uncultivated woody biomass, soybean and Jatropha [10]. Generally, and irrespective of the type of biomass that is considered, accurate resource estimates are complex, especially because of changing agricultural practices and preferences, the availability of water, and the impacts from a changing climate.

[10] **Estimating the Renewable Energy Potential in Africa**, International Renewable Energy Agency, 2014, http://www.irena.org/DocumentDownloads/Publications/IRENA_Africa_Resource_Potential_Aug2014.pdf, accessed on 31 October 2016

Recently, Development Environergy Services Ltd undertook a cogeneration feasibility study, covering the Dwangwa and Nchalo sugar mills that are owned and operated by Illovo Sugars Malawi Ltd [11]. From the owner's perspective, these sites are attractive, as additional self-generated heat and power could optimise other investments, and thus offer attractive financial returns, especially through an increase of self-reliance of electricity for irrigation purposes. The study concluded that techno-economic feasibility exists to develop over 50MW of cogeneration capacity between the two mills, and resulting in an export of over 36MW of power to the grid, mostly during the dry months. Specifically, an upgrade at Nchalo, from 7.6MW to 35.3MW, thus adding 27.5MW of additional generating capacity would result in an annual surplus of 108.5 GWh. In the case of Dwangwa, an upgrade from 5.5 to 18.9 MW was considered, thus adding some 13.3 MW of capacity, which would result in an annual surplus of 64.8 GWh.

However, while the above illustrates that some electricity generation potentials from bagasse exist, location-specific requirements of bioenergy converters and local agricultural and others conditions necessitate site-specific verification in the run-up to developing bagasse/biomass project in future.

3.3.2 Candidate Projects

Data Sheets, presented in Appendix 3, have been prepared for projects where information is available on the reconnaissance level or in more detail.

3.4 Others

Several other potential renewable energy generation options exist in Malawi that may be developed in future. For now, however, the options discussed below are characterised by an absence of reliable resource data, and country-specific technology and financing information is also largely unavailable. The future renewable energy options considered in this section include the generation of electricity from to-be-developed geothermal fields and the use of municipal waste in waste-to-energy plants. The sections below provide a brief introduction to each of these topics, but do not attempt to discuss any candidate project information as provided for the renewable energy options discussed in previous sections. Accordingly, no candidate projects have been included for these other sources of energy.

3.4.1 Geothermal

Malawi has several locations where terrestrial heat flows suggest a potential for future geothermal energy applications. However, as yet, the country's heat flow resource has not been quantified, and first measurements of such potential remain limited to a recent high-level assessment undertaken by ELC [12]. Regional subsurface temperature maps from one dimensional heat flow modelling indicate that temperature potentials exceeding 100℃ may well exist, even though the number and concentration of such sites remains unspecific.

As data relating to geothermal gradients, heat flow patterns and other information of relevance to Malawi's geothermal potential is limited, a sound scientific assessment of the country's geothermal

[11] **Consultancy Services to Carry Out Power Cogeneration Feasibility Study**, Development Environergy Services Ltd, for the Ministry of Natural Resources, Energy and Mining, July 2016
[12] **Assessment of Geothermal Resources in Malawi: A Reconnaissance and Pre-feasibility Study**, ELC-Electroconsult, 2016, Report No.: 1763-E-1-R-GE-0004-00_Reconnaissance_Study_Report

potential remains outstanding. In future, reconnaissance level heat flow coverage of the entire country would be desirable, but such an undertaking is likely to take several years before it is available for power project development. Once more detailed data is at hand it can be decided whether temperature regimes are sufficiently developed for the use of conventional steam turbines, or whether binary-cycle turbines which can operate at temperatures as low as 85℃ should rather be used.

Based on the above it is noted that considerable Government engagement will likely to be required to finance, coordinate and evaluate the country's geothermal potentials. Foreign funding support may also be available, specifically focusing on evaluating the power generation potential offered by Malawi's geothermal resources.

3.4.2 Waste-to-Energy

Increasingly, municipal solid waste is recognised as a fuel source for waste-to-energy plant. Such plant has a dual function in that it is used to dispose of municipal waste, while producing electricity and heat as by-products of the incineration process. Similar to developments in other African countries, Malawi experiences a high urbanisation rate, especially in the country's main centres. This rural-to-urban migration results in – amongst others – new urban streams of solid waste, as is generated by domestic, commercial, industrial and institutional consumers.

In many countries, solid waste disposal sites grow at considerable rates, necessitating ever-more land to cope with urban waste streams. In this regard, municipal waste management becomes essential, and using waste-to-energy plant, such waste streams can contribute to generate new revenues while reducing the cost for additional land for waste disposal. Internationally, it is becoming increasingly evident that the coupling of ordinary waste incinerators to electricity generation plant is both viable, and effectively reduces the overall cost of waste management and disposal in landfills.

Various waste-to-energy plant are in operation internationally: on the one hand, mass-burn plant are a common waste-to-energy technology, in which municipal solid waste is directly combusted, similar to the way that fossil fuels are used in contemporary direct combustion technologies. In this way, municipal waste is used as a fuel source, which once combusted, is used to generate steam, which drives a turbine connected to an electricity generator. On the other hand, refuse-derived fuel facilities process the input waste prior to combustion. While the level of pre-combustion processing varies among facilities, it often entails the shredding of waste, removal of recyclable materials such as metals and others. While other types of waste-to-energy plant exist, including pyrolysis and thermal gasification plant, these are not yet considered as mature as mass-burn and refuse-derived fuel facilities are.

While Malawi may not be able to support several large-scale municipal waste-to-energy plant as waste resources remain concentrated in the urban areas, these generating plant may nevertheless become a future option for the country's main centres. In order to realise such developments, it will be important to assess the actual waste streams available in the main urban centres, and their composition, to assess whether sufficient amounts of suitable waste products can be available to justify investments in such power plant in future.

4 INTERCONNECTORS

At present, the main transmission grid in Malawi is not connected to any of the other networks in the region. Previous pre-feasibility and feasibility studies have considered interconnections to Mozambique, Zambia and Tanzania at different voltage levels and transfer levels. Such interconnections may not only provide opportunities for trade in surplus capacity and energy, but also increase security of supply (not least in view of dependency of hydropower in Malawi). Furthermore, interconnections would also stabilise the frequency of the system and possibly open up for higher levels of integration of renewable intermittent power generation.

Details on transfer capacity and investment costs for the interconnections have been assessed as part of the transmission planning covered in the Main Report (Volume I) together with details on the generation planning carried out in PLEXOS. The following clauses outlines some technical characteristics of the main options for regional trade. Further analyses is covered in the Main Report. Assumptions on cost of imports and price for exports are presented at the end of this Chapter.

4.1 Mozambique – Malawi

The main interconnection of interest in the context of the IRP for Malawi, is the link from Matambo/Tete to Phombeya. This line has been considered for a number of years and could realistically be implemented on short term. Such a line would tap into a region with potential for significant power generation from hydro resources on the Zambezi and also coal fired generation from the coal fields in the Tete Province. At the same time, this interconnection would provide a relatively strong link to the SAPP market via the link to Songo and HVAC and HVDC lines from Songo to neighbouring utilities. On short term, the existing 220 kV lines in this part of Mozambique could limit trade, but planned reinforcements and extensions that are foreseen on medium term would likely provide high capacity for trade even for Malawi or could tentatively do so with relatively minor additional investments if required to facilitate such trade.

A 220 kV link from Matambo/Tete in Mozambique to Phombeya in Malawi has previously been considered as an option for import to Malawi. Even extending this line from Phombeya to Nampula in Northern Mozambique has been seen as an alternative for further integration of the systems in the region. According to information provided, the feasibility study for the Tete – Phombeya section is being updated, and it is likely that the link will be designed for 400 kV to fit into future plans for the region (initial operation could be at 220 kV depending on timing of 400 kV grid development in Tete in Mozambique – but as the voltage levels in the Phombeya substation will be 400 kV and 132 kV, adding a 400/220 kV transformer in Mozambique to allow for 400 kV operation seems the most likely option).

The technical transfer capacity of such a link – both for import and exports – will be high compared to the load level in Malawi on short to medium term. If (as long as) such an interconnection is the only interconnection to neighbouring utilities, the power flow will have to be limited to avoid excessive frequency variations on the grid in Malawi following outages of the line. If load shedding is not accepted following loss of the interconnector, the maximum import level will be close to the limit set for intermittent renewables, i.e. about 70-80 MW as discussed for the PV plants on the existing system. Loss of the interconnector will be a relatively rare event though, and it may therefore be considered acceptable to shed load on the system following such an event as long as the stability of the system is not put at risk. With proper system protection schemes in place, import could therefore be significantly higher and may even reach the 300 MW or so mentioned in the Mini IRP in case of severe droughts affecting the generation on the Shire River.

It should be noted that many areas of the grid in Malawi will be subject to supply interruptions due to line faults as the transmission grid does not meet "N-1" planning criteria. Neither will it be economical to establish such high reliability levels in all areas. Allowing for import levels that would require load shedding if the interconnector is tripped, may therefore be considered acceptable, at least if this is a temporary or short-term condition until the system is further reinforced and expanded.

As the study period for the IRP covers the next 20 years, the assumption is that load shedding following loss of an interconnection should not be accepted (although it could possibly be as a temporary measure on short term of required to meet demand). As long as there is only one interconnection, the import limit has therefore been set to 10 % of the peak demand in Malawi. On short term, the system in Tete in Mozambique could likely meet such imports (if found economically attractive). On long to medium term, it would likely require additional generation and/or grid reinforcement in Mozambique. Such expansion of the system may certainly be an option based on both hydro and coal resources as mentioned above, but also generation from gas. Such imports are therefore included as one of the options considered in the generation planning – see the simulations presented in the Main Report – Volume I.

4.2 Zambia – Malawi

An interconnection between Malawi and Zambia has previously been considered at 132 kV from the Lilongwe area to Chipata in Zambia. Up until recently, Chipata was fed at 66 kV from the 330/66 kV substation at Pensulo in Zambia. This weak link meant that the transfer capacity on such an interconnector would be very limited – only in the range of 20-30 MW (at best and depending on load levels on the north-eastern grid in Zambia).

ZESCO in Zambia has now extended the 330 kV grid from Pensulo to Chipata and with the development of a 400 kV grid in Malawi, future extension of the 400 kV system in Malawi to Chipata provides a good option for a link with relatively high capacity. The supply towards the northeast in Zambia is still constrained and the import capacity is therefore likely less than the export limit on this link. Similar constraints as commented on for the interconnection from Mozambique to Malawi would naturally apply for this link as well if it is the only link to neighbouring utilities – i.e. the system in Malawi must be able to handle a sudden loss of the interconnector.

The initial development for an interconnection with Zambia may still be based on 132 kV as considered previously. Such an approach may very well be the least-cost alternative if the expected trade levels are relatively low as the investment costs would be comparably much lower than a 400 kV solution. However, if Malawi is linked to Tete in Mozambique, a 132 kV link to Zambia would have to be operated with an open point somewhere along the line or the line would have to be inter-tripped following faults on the main grid. The reason is that faults on the 330 kV system in Zambia may isolate a large load that would cause overload and/or voltage instability on the grid in Malawi, and similarly outages in Malawi may cause overload or voltage instability in the grid in Zambia. Synchronous operation of the two systems via 132 kV is therefore not realistic, but could still provide valuable support – in particular during maintenance and emergency operation.

Synchronous operation via a link at 400 kV from Malawi to the 330 kV substation at Chipata in Malawi would be feasible, but still likely see more limitations than a link to Mozambique. This is linked to the relatively weak 330 kV system in Zambia feeding the line to Chipata. On short term, the single 330 kV line from Kabwe to Pensulo and from Pensulo to Chipata in Zambia would limit the import to Malawi via this link to 100 MW or less without significant additional reactive power support in Zambia. On medium term and assuming the grid between Kabwe and Pensulo is reinforced by adding of a second 330 kV line, the export limit could possibly be raised towards 150-200 MW – partly depending on whether other interconnections are established as well. Actual limit would be highly dependent on load growth in this part of Zambia, and the support from small, local hydropower plants in the area between Pensulo and Chipata would also impact on actual transfer limits.

4.3 With both Malawi – Mozambique and Malawi - Zambia

If or when the system in Malawi is interconnected to both Mozambique and Zambia (for instance via a 400 kV line from Phombeya to Matambo/Tete in Mozambique and a 400 kV link to Chipata in Zambia, there are certain operational challenges that will have to be considered carefully and that may impact on the export and import limits. The link from Tete via Malawi to Chipata would present a parallel path to Tete-Songo-Zimbabwe-Zambia. Regional trade could therefore upload the grid in Malawi, and certain outages may pose a risk to the system. Imports for instance from Mozambique to Malawi would immediately be transferred onto the link via Zimbabwe and Zambia back to Chipata. High imports prior to such an outage would clearly put the system in the Chipata area at risk of a voltage collapse. Other limitation for instance on the grid in Zimbabwe could also limit trade in Malawi. Another issue could be loss of the link from Kabwe to Pensulo in Zambia – potentially islanding the north-eastern grid in Zambia on supply via Malawi.

Interconnections to neighbouring utilities would therefore have to be carefully coordinated with developments outside Malawi to ensure that the export and import requirements are met and that such trade and wheeling do not put the system in Malawi at risk of black-outs even due to events outside Malawi.

Such operational issues will be avoided or at least simpler to manage if for instance adding the second interconnection to a strong point in the SAPP system rather than interconnecting to different points in the SAPP system and thereby creating the potential for operational challenges as outlined above.

4.4 Tanzania – Malawi

The Mini IRP prepared by MoNREM, DoE and ESCOM in December 2015 states that studies are ongoing for a 400 kV link from Nkhoma (i.e. the northern substation on the ongoing 400 kV line from Phombeya to Nkhoma) via Songwe to Tanzania. Presumably, such a link will connect to a future 400 kV substation in the Mbeya area in Tanzania on a future interconnection between Tanzania and Zambia forming part of the planned Zambia-Tanzania-Kenya project. Although the length of such a link will limit the transfer capacity between Tanzania and Malawi, the line will likely provide significant capacity compared to the load level in the area and the generation projects that may be connected to such an interconnection.

Investment costs for such a 400 kV link will be very high though, and initial development in the area (including cross-border power exchange) may therefore be based on further development of the 132 kV systems in Malawi and Tanzania to connect load centres and potentially also the small to medium sized generation projects in the northern part of Malawi. Larger coal-fired generation in the north would likely require one or more 400 kV lines to evacuate the power. These issues including the timing of the projects are dealt with in the Main Report – Volume I.

4.5 Two or More Interconnections

As commented above, transfer limits on individual interconnections may depend on the use of system protection schemes in Malawi. Sudden loss of high levels of import may cause severe frequency drops unless shedding significant loads. Likewise, high levels of export (although not a realistic scenario on short term until new plants come online in Malawi) may require generator tripping if such export is interrupted – as will be the case from time to time if relying on just one interconnection for such export.

Once a second interconnection is added, such limitations may diminish. However, as the system in Malawi is and will be small compared to the SAPP and EAPP grid, a sudden loss of an interconnector means that the power flow on the faulted line will immediately be transferred to the remaining interconnector(s) – as discussed in Clause 5.3 above for a system interconnected to both Mozambique and Zambia. The incremental capacity by the addition of a second interconnector may therefore be considerable less than what may appear to be the case if adding up the capacity of individual interconnections (and may require system protection schemes to realise such benefits).

These issues will be accounted for in the further evaluation of supply-demand scenarios and the assessment of transfer capacity on future interconnections.

5 DEMAND-SIDE MEASURES

This final section describes the demand-side measures that have been considered as candidates for the least-cost planning analysis. The demand-side measures are assessed in more-or-less the same way as the supply-side measures including their characteristics, potential MWh or MW contributions and their costs. As described below, many of the demand-side measures that were considered have already been implemented or are committed and are therefore not included as candidates in the subsequent least-cost analysis.

5.1 Efficient Lighting

5.1.1 Dissemination of subsidized LED lightbulbs

The reduction in demand through the encouragement of energy efficient lighting products is often the most cost-effective demand-side measure in many developing countries because lighting is the key driver of maximum demand and energy efficient lighting is generally the first demand-side measure to be introduced. This also proved to be the case in Malawi where an Energy Efficient Lighting Program (EELP) was implemented by ESCOM as the implementing agency and the then Ministry of Natural Resources, Energy and Environment as the executing agency. The program involved the distribution of 2 million compact fluorescent lamps (CFLs) to residential customers, small enterprises and public buildings who were offered the bulbs free-of-charge. Commercial and industrial customers had the option of purchasing CFLs at subsidised prices. The program was implemented over a three year period from 2011 to 2013. The program is estimated to have lowered peak demand on the interconnected system by approximately 15% (51 MW) during the evening peak period and by 65MW during the morning peak period[13].

A continuation of the earlier program is about to be initiated by MNREM that will distribute free or subsidised bulbs using light emitting diodes (LED) to industry and commercial consumers. This new program will also distribute around 2 million LED lightbulbs to electricity users throughout the country.

Information from participants at the Stakeholder Workshop in October 2016 indicated that the new program will go ahead and for the purposes of the IRP study is therefore considered as committed.

The program will impact on the load forecast and load pattern and this has already been factored into the assessment of the system load shape. We have assume that the benefits will begin to be visible by 2018 and the full benefits will be seen in 2020.

To the extent that the industrial and commercial consumers have load patterns that are concentrated less in the evenings and are spread more over 24 hours than residential customers, this new programme will have a lesser impact on peak demand than did the residential programme (51 MW). On the other hand, these consumers will tend to use the LED lightbulbs more effectively[14] and the impact would therefore potentially be greater. Overall we have assumed that the measure will achieve a saving of 40 MW at peak.

[13] Project Completion Report: Energy Efficient Lighting Program; prepared by Evidence on Demand on behalf of DfID, November 2013.
[14] i.e., they will tend to place them in locations that maximise the impact on electricity consumption and demand.

5.1.2 Minimum Energy Efficient Performance Standards

A second energy efficient lighting measure had been considered earlier when developing the EELP DSM program described above, which involves the introduction of national standards/regulation governing the import and sale of lightbulbs and other lighting products and the introduction of lower tax rates on imported energy efficient lighting products[15]. This is known as the Minimum Energy Efficiency Performance Standards (MEPS) regulation. The measure would prohibit, among other things, the sale of incandescent lightbulbs in Malawi.

We understand from participants at a Stakeholder Workshop in October 2016 that a regulation has been drafted and is being reviewed prior to approval and implementation. Details were not available to the Consultant.

Because the scheme is planned to be implemented, we assume that it is committed and we have therefore factored it into the demand forecast and the analysis of the system load shape.

The impact of this measure would be felt gradually as the existing stock of incandescent lightbulbs would gradually be phased out as they reach the end of their natural life and are replaced by CFL and LED lightbulbs. Because the MEPS measure is assumed to be implemented after the energy efficient lighting programme and because the latter should already have resulted in the replacement of many incandescent lightbulbs, the benefits of MEPS will be lower than if there had been no energy efficient lighting programme. (The efficient lightbulbs should be used in those rooms that use lighting more frequently or for longer periods).

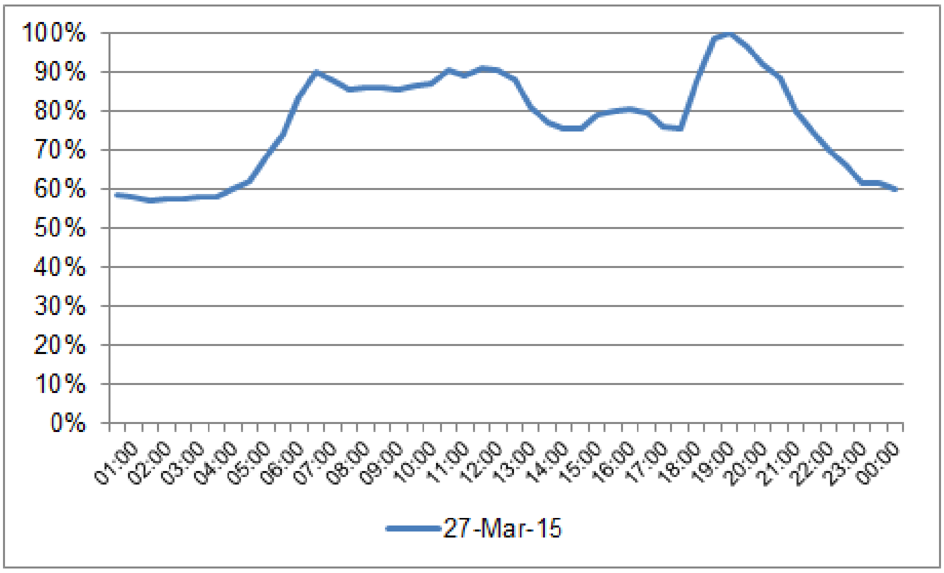
We have assumed that MEPS will achieve a reduction of 10 MW in system peak demand by 2021.

5.2 Time-of-Use Electricity Tariffs

Another essential measure in the DSM toolkit is the implementation of electricity tariffs that are cost reflective and, in particular, that apply differential tariffs to consumption at different times of the day or year. Malawi's electricity demand has a clear evening peak and a relatively long peak period beginning in the early morning and lasting through to mid-day. This is illustrated in the Figure below. The pattern in this case reflects a period when load shedding was relatively low and the pattern is not too seriously distorted.

[15] The measure was described in the Project Completion Report for EELP – see footnote 13.

Typical daily load pattern in Malawi



Time-of-Use (TOU) electricity tariffs impose higher charges on consumption at times when the costs of supply are highest – and this typically means times of highest demand. In Malawi this would mean higher tariffs during the peak evening and daytime hours and lower tariffs at night. The effect of TOU tariffs is to encourage consumers to use electricity more efficiently during the peak hours and, potentially, to use more electricity during the off-peak hours. This lowers peak consumption and increases off-peak consumption, and lowers electricity supply costs.

There are relatively few African countries that have implemented TOU tariffs.

Malawi introduced TOU tariffs for larger industrial customers in 2009. This was mandatory for customers in the ET10 (11 kV and 33 kV) and ET9 (3-phase, metered at 400 V) 'maximum demand' categories. These included 894 customers (from a total of 624,000) and accounted for 41% of energy sales[16] .

The TOU tariffs applicable from January 2016 for ET10 customers are shown in the Table below. The tariffs for ET9 (LV) customers have the same fixed charge as ET10 customers but the other components of the tariff are a little higher.

The key points to note about the Malawi TOU tariff designs are:

- There are two time periods within the day and no seasonal variation in the tariff. The peak hours are 07:00 to 12:00 and 17:00 to 20:00 on weekdays; all other time periods are classified as off-peak.
- There is a relatively high ratio of peak to off-peak energy charge (the peak is 3.6 times the off-peak).
- The tariffs applies to a relatively small group of large customers and is mandatory.
- The TOU tariff is per kWh but ESCOM charges a demand charge and a fixed charge per declared capacity, as well as a TOU kWh charge. The demand charge and capacity charge are not differentiated by time-of-use.

[16] Year 2015-16

TOU tariffs for ET10 (MV customers) in Malawi:

Tariff component	Tariff (Kwacha)
Fixed charge per month	26,000
On-peak unit charge per kWh	65.0
Off-peak unit charge per kWh	18.0
Capacity charge per kVA – annual declared demand	2,788
Demand charge per kVA – actual monthly demand	4,271

Source: ESCOM website - http://www.escom.mw/tariffs_January_2016.php

The absence of seasonal charges appears consistent with the pattern of demand (although seasonality in hydrology could impact on seasonal supply costs) and suggests that the adoption of a uniform tariff structure across the year makes sense. The tariff structure also appears consistent with the load pattern and probably marginal costs by time-of-use. The demand charges should probably also vary by time-of-use, but do not. Although the tariff design may not necessarily be perfect, it appears reasonable.

The tariff in the peak periods is nearly 4 times the tariff in the off-peak period. This provides a significant incentive to switch load to off-peak periods.

Because TOU tariffs were implemented in Malawi in 2009, it is clearly a committed demand-side measure. And because consumers would by now have recognised the financial benefit to moving load away from peak hours, we assume that load patterns have already adjusted to this measure and no further adjustments are needed.

5.3 Information dissemination

Information dissemination is another standard demand-side measure in the energy efficiency toolkit. Although energy efficiency should be a natural response of electricity consumers to electricity prices that reflect the true cost of production, it often takes users some time to recognise the benefits of energy efficient technologies or energy efficiency practices. Information dissemination is designed to expedite the take-up of energy efficient practices and measures by informing users of their benefits.

This information dissemination service is often provided by a Ministry or by the utility, or both. It involves a programme to provide information to electricity consumers describing the potential to reduce consumption of electricity or to alter electricity consumption patterns.

ESCOM already provides some information to consumers, particularly residential consumers, about measures they can take to lower their electricity consumption. The Energy Efficient Lighting programme also included information dissemination to residential and small commercial users.

The 2nd phase of the Energy Efficient Lighting programme targeting industrial and commercial electricity users will also provide information and will demonstrate the benefits of energy efficient lighting.

We are not aware of other measures taken to disseminate information to larger electricity users about the potential for energy efficient technologies. There does therefore remain some opportunity for an information dissemination campaign to provide additional information to industry and commercial users. A program targeting industrial and commercial users will typically comprise a range of measures including leaflets, websites, downloads of case studies, pilot projects and subsidised energy efficiency audits. We are not aware of any programme of this type existing or proposed for Malawi.

The costs and benefits of such a new program are unknown but there remains an option for an information dissemination measure to be included as a candidate in future IRP studies if the costs and benefits of such a program could be costed and assessed.

5.4 Solar water heaters

Solar water heaters offer the potential to replace electric geysers and lower the consumption of electricity in general and partially during the peak electricity consumption hours. They are particularly attractive as a cost-saving and demand-reduction measure in countries with relatively high electricity supply costs and good solar radiation.

Solar water heaters are passive solar and use the heat of the sun to raise the temperature of water, as opposed to solar PV which produces electricity.

Solar water heating was proposed in SE4ALL's Agenda Action (AA)[17]. AA also reports that the Government of Malawi has agreed in its Intended Nationally Determined Contributions submission to UNFCCC that it will replace 20,000 electric geysers with solar alternatives by 2030.

The World Bank had previously proposed a different (non-solar) approach focusing on replacing electric heater elements with 2.5 kW elements combined with ripple control[18]. While this is not a solar alternative, this does provide useful information on the use of electric geysers in Malawi.

To our knowledge, no specific solar water heating programme has been elaborated by any of the stakeholders in Malawi.

The scheme described below for a solar water heating programme is indicative based on available information on the number of households estimated to have electric water heaters.

The World Bank had estimated that there were 23,000 electric water heaters in 2011 and the Agenda Action estimates that this may have increased to 30,000 to 40,000 by 2015. There were around 330,000 residential electricity consumers in mid-2016 suggesting that only 10% of households with electricity access have electric geysers.

Indicatively, we assume a programme comprising:

- Partially subsidised solar hot water heaters for residential users
- 16,000 solar hot water heaters (approximately 5% of all households with electricity but around 50% of households with electric geysers)
- The programme managed by ESCOM (as it has the relationship with electricity consumers)
- Particularly targeting the replacement of existing electric hot water heaters

We have based the costs of the solar hot water heaters on some work undertaken by the Consultant (ECA)in Jordan in 2015 and we estimate that the program would cost approximately $11.2 million and this would be paid for partly by users and partly by subsidy (e.g., international financing institutions or Government of Malawi).

[17] SE4ALL Draft Agenda Action, Deloitte/Econoler, June 2016
[18] Energy Sector Support Project (ESSP), Project Appraisal Document, World Bank, June 2011

The impact of the programme would be gradual as existing electric hot water heaters are replaced and new hot water heaters that might otherwise have been electric become solar. We estimate a peak demand reduction of 21 MW by 2021. We assume that electric hot water heaters would be replaced gradually over a period of up to 5 years and that the earliest benefits would appear in 2018.

5.5 Off-peak Water Pumping by the Water Boards

Malawi has five water boards responsible for potable water supply across all of Malawi including:

- Lilongwe Water Board
- Blantyre Water Board
- Central Region Water Board (CRWB)
- Southern Region Water Board (SRWB)
- Northern Region Water Board (NRWB)

The water boards are major users of electricity. Some, such as the Lilongwe and Blantyre Water Boards have large pumping stations and electrical loads. The regional water boards tend to had smaller dispersed pumping stations and loads, but nevertheless sizeable demand. Demand-side measures to help lower the consumption of electricity during peak hours on the electricity system and could be cost-effective for the water boards and for Malawi.

Reductions in electricity consumption during ESCOM's peak period could be achieved if the water companies have spare storage and spare pumping capacity such that water can be pumped overnight and stored and then distributed to customers during the day. Alternatively, the water boards might have to invest in additional storage capacity and additional pumping such that they can pump sufficient during, say, a 12 hour period and distribute water over a 24 hour period.

Information was obtained through a short questionnaire submitted to the five water boards. Other information was obtained from the Lilongwe Water Board Tariff Review and Willingness to Pay Study, by ECA, finalised in September 2014.

Unfortunately, at the present time, the water boards are financial constrained and generally have insufficient capacity to be able to supply customers with a regular supply even when consuming electricity 24/7 hours per day (in recent experience the electricity supply has not in any case been able to supply electricity to the water boards continuously).

It should also be noted that the water boards are already incentivised through the time-of-use tariff to reduce their consumption during ESCOM's peak hours.

A demand-side program focusing on off-peak water pumping therefore appears problematic at the present time. A programme would need to be properly developed and designed. For the regional water companies, one or more demonstration projects also might be implemented to show to other water companies the benefits of load management measures.

This is not a demand-side measure that could be included as a candidate in the IRP study at the present time, but should be considered in future when the IRP program is updated.