Clean energy and mini-grid toolkit

Module 3

Renewable energy and mini-grids

1. General introduction

Green (or clean energy) mini-grids can be distinguished from fossil fuel-based mini-grids by the use of renewable energy carriers (hydro, biomass, wind, solar) to generate and supply electricity to the distribution network. The generator is often a **hybrid** system, mixing different sources of power from renewables, battery and diesel to compensate the fluctuation in availability and supply of the renewable energy source(s) in order to meet the load profile on the energy demand side.

Renewable energy is generally defined as energy that comes from resources which are continually replenished on a human timescale through biological reproduction or other naturally recurring processes. Renewable resources include sunlight (solar), wind, water (hydro), biomass, waves and geothermal energy. As sources of renewable energy are free, fuel cost is often free (the exception being biomass which will have a cost in terms of sourcing pellets, briquettes, wood chips, wood logs or agricultural residues). However, whilst the fuel is free or low cost, the capital investment required to harness the renewable energy can sometimes be quite significant compared to traditional (fossil fuel) based systems.

Generator sets (gensets), powered by diesel (or heavy fuel oil), have been used all over Africa to power mini-grids in remote villages, tourism resorts, and business centres. Operating schedules depend on load requirements, fuel supply and the consumers' ability to pay. With sizes from 10 kW to 10 MW, diesel mini-grids are common in Africa and thousands are in operation all over the continent. If operated by a utility (or rural electrification agency) these are typically subsidised so that consumers in these areas pay the same prices as grid-based consumers; this is common practice in Africa).

Benefits	Challenges
• Relatively low capital investment • Well-understood technology with widespread technical operating and maintenance capacity • Can easily 'hybridised' with solar PV and/or wind, with lower fuel costs • Commercial business models have been developed • Potential to use biodiesel fuels	• High cost for maintenance (overhaul) and costs of fuel • Carbon emissions due to fossil fuel combustion • Irregular supply of fuel to remote areas can greatly increases costs and/or intermittent use times, through regular scheduled or random blackouts

2. Hydroelectricity

An important source of alternative energy is hydropower. All rivers and streams flow downhill across the land surface. This motion which is a form of kinetic energy can be converted into electricity when it is forced to flow through turbines coupled to electric generators. The "turbined" water can be drawn directly from the river for **run-of-the-river schemes** or from a **reservoir** where water is stored behind a dam for use on demand. The best geographical areas for exploiting hydropower are those where there are steep rivers flowing all year round, for example, hilly areas or mountain ranges and their foothills with high rainfall. The amount of power generated from a hydroelectric scheme depends on two variables namely the water flow rate (Q) and the height difference between the level of water at intake and that at the turbine; this is technically referred to as the 'head' (H).

The **available powe**r closely depends on the available discharge (Q in m^3/s) and the available head (H in m), the density of water ρ = 1,000 kg/m3, the gravity acceleration g = 9.81 m/s2 and ή the efficiency of the turbine (this can vary from 75 to 90%). The power in Watts (W) is computed with the following formula:

$$P= Q\ H\ \rho\ 9.81\ \eta$$

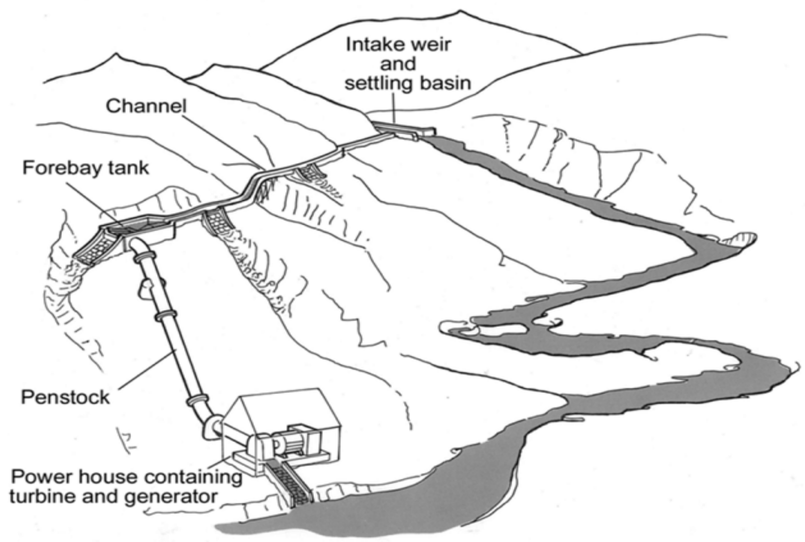
The theoretical power available from a flow of 1 m^3/s water falling 1 m is therefore 9.81 Watt. Hydroelectricity systems are **classified into** different categories based on their installed capacity (power range). Different parts of the world classify them differently. A common classification is as follows:

- Pico-hydro: less than 10 kW
- Micro-hydro: from 10 - 500 kW
- Mini-hydro: from 0.5 - 10 MW
- Small-hydro: from 10 - 50 MW
- Large-hydro: from 50 - 200 MW
- Very large-hydro: above 200 MW[1].

It should be mentioned that sometimes the term SHP (small-scale) hydropower is loosely synonymous with small micro-and mini-hydropower systems are typically used as an off-grid electricity supply to a community.

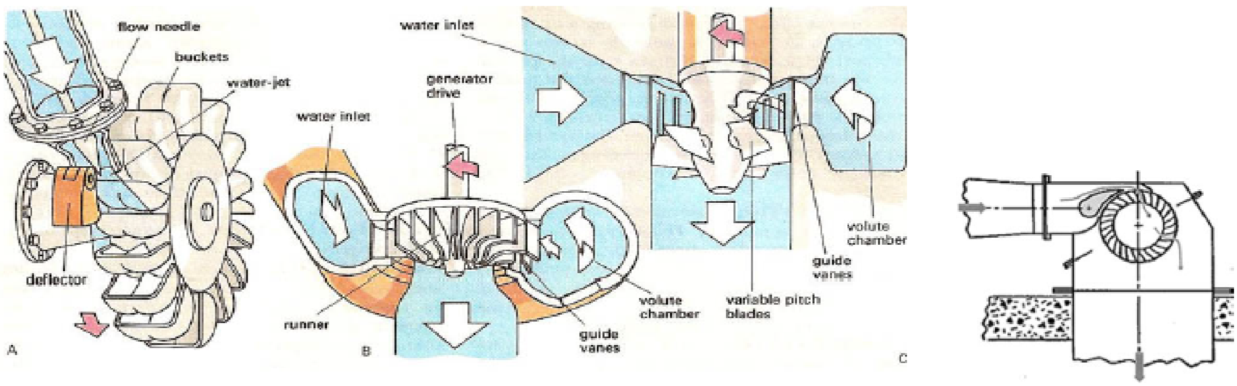
A typical hydro generating station consists of two main components: a) civil works and b) electro-mechanical equipment. The **civil works** will have an intake (where the water comes into the system), a channel and/or penstock to take the water to the powerhouse. The latter houses the **electro-mechanical** equipment, that is the turbine (turned by the movement of the falling water) and the generator (turned by the turbine and generates electricity).

Figure 1 Small hydropower scheme



Source: Practical Action

Figure 2 Types of water turbines



A Pelton B Francis C Kaplan D Crossflow turbine also named Banki

	High head	Medium head	Low head
Impulsive turbine	Pelton Turgo	Cross-flow Multi-jet Pelton Turgo	Cross-flow
Reaction turbine		Francis	Kaplan Propellor

Turbines can either be classified as impulse turbines or reaction turbines. In the impulse turbine, the turbine runner operates in air and is turned by one or multiple jets of water which make contact with the runner blades.

On the other side in a reaction turbine, the turbine runner is fully immersed in water and is enclosed in a pressure casing, the runner blades are angled so that pressure differences across them create lift forces, like those on aircraft wings, which cause the runner to rotate. **Turbine selection** is based on the available water head, and less so on the available flow rate. In general, impulse turbines are used for high head sites, and reaction turbines are used for low head sites.

less than 100 kW; mini-hydropower station is a hydropower station whose installed capacity is not less than 100 kW but is less than 500 kW. It should be mentioned that sometimes the SHP system is loosely synonymous with micro-hydropower system. Micro-hydropower systems are typically used as an off-grid electricity supply to a community.

Costs of hydropower

The cost varies from USD 2,000 to 5000 per kW installed for the construction of a hydropower plant. The unit cost is indeed highly dependent on the site conditions and on the complexity of the associated civil structures. The capital costs are comprised of:

- Civil/structural material and installation (in general 40-50% of the total cost),
- Mechanical equipment, supply, and installation (in general 10-20% of the total cost),
- Electrical instrumentation and controls, supply and installation (5% of the total cost),
- Project indirect costs, fees and contingency, and owner's costs (17-22% of the total cost).

Table 1 Estimates of investment and levelised cost of hydropower

2010	Installed cost (USD/kW)	O&M cost (%, installed cost)	Capacity factor (%)	LCOE (2010 USD/kWh)
Large hydro	1050-3600	2-2.5	20-75%	0.02-0.10
Small hydro	1300-4500	1-4	23-80%	0.02-0.20
Mini	2500-8000	1-6		0.025-0.30
Micro	3500-10000	1-6		0.025-0.32
Refurbish/upgrade	500-1000	1-6		

Taken from WEC (2013) and IRENA RETs (2012): Cost Analysis Series Vol.1 3/5: Hydropower. Levelised cost assume 10% cost of capital and lifetimes of 40 years. Mini and small hydro adapted from IRENA (2015) and data from EU's Technical Assistance Facility (TAF) for SE4All. WEC (2013) mentions for O&M cost: large, 20.000-62.000 USD/MWH/yr and small: ISD 15.000-18.5000 USD/MWh/yr. Source: Van den Akker (2017)

In general, the selection of turbines is done in order to cover the largest range of flow (exceedance varying from 20% to 80%). In some installations the water flow rate can vary by a factor of 100:1 over the course of a year (and sometimes dry-up for a few weeks). For most mini hydro in sub-Saharan Africa, it can be estimated that the load factor may vary from 0.2 to 0.7. This means that an economic arbitrage needs to be done for the selection of turbine technology and the number of turbines.

The technology is quite simple and well mature, allowing local repairing, etc. Internationally, no decline in hydropower capital costs or levelised cost can be expected until 2020. Cost variations would be due to commodity price variations and general civil engineering costs. Investment costs for micro or mini hydro plant are generally claimed to be low but they are often higher than expected, as they are extremely variable and site-specific. The powerhouse is pretty standard hosting one or more turbines, alternators, and control system. However, the infrastructure and civil works can be rather complex and costly depending on the water collection system (pond, weir, channel, forebay, penstock). Moreover, the long preparation time (studies, environmental studies, permits) and the long lead times can often be hurdles

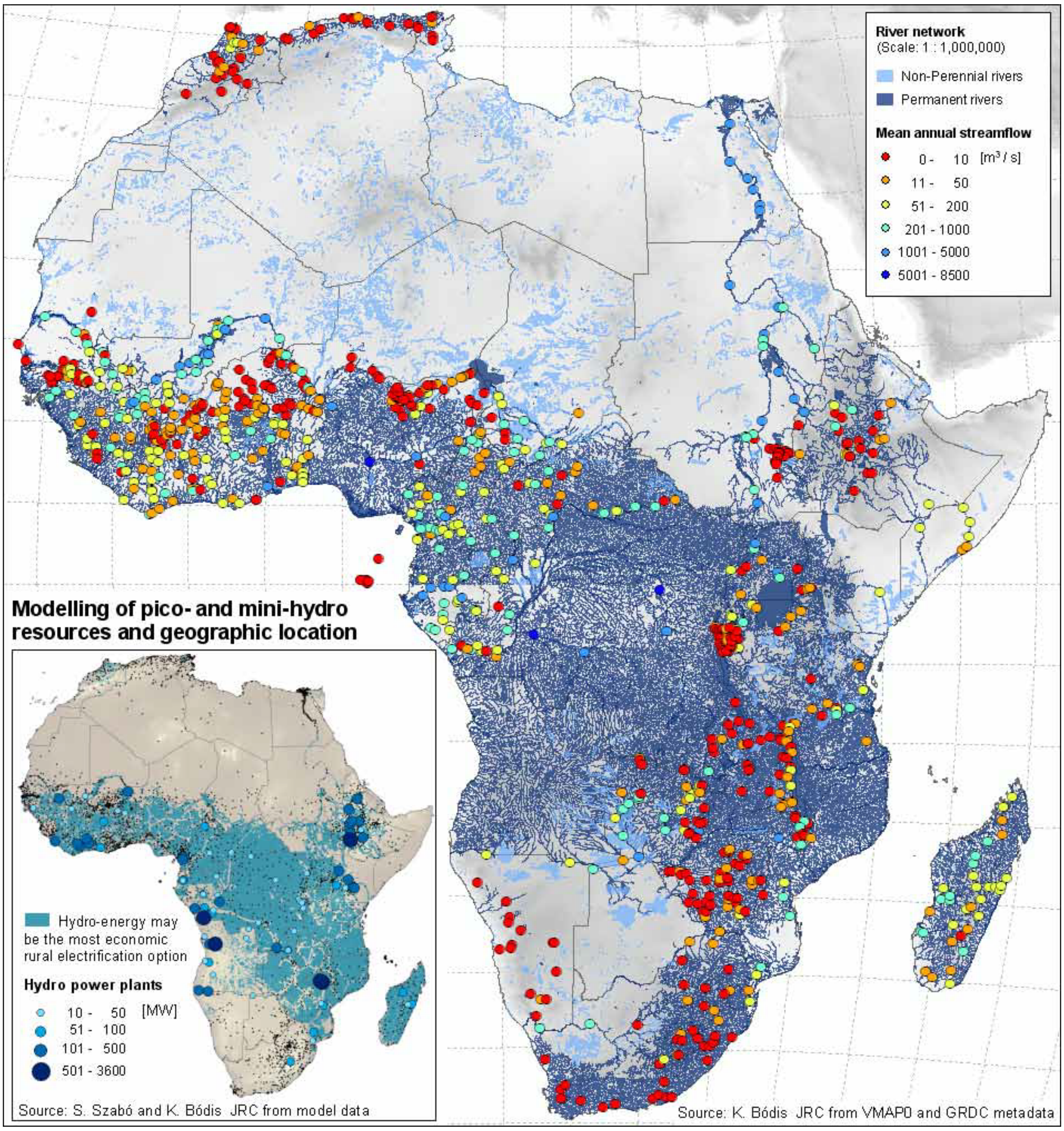
Given the seasonal water flow variations, the actual operating hours of a run-of-the-river hydropower plant will depend on the site and can vary from 3000 to 8000 hours a year. This can considerably influence the flexibility and the supply-demand matching in off-grid systems. A low capacity utilisation will affect the cost-effectiveness of the generating system. Where output exceeds the local demand that could be supplied by a mini-grid, a connection to the main grid may increase cost-effectiveness.

Benefits	Challenges
• Mature technology • Low-cost power (USD/kWh) and no diesel fuel needs • It is a scalable technology, you can generate as low as 200 to thousands of MW • Uses local materials for most of the civil works • With proper maintenance, it can have long service life in excess of 25 years	• Requires hydro resource that is available throughout the year and the terrain needs to have a steep gradient (is location specific) • May not be economically viable if too close to the main grid and too far from the hydro resource • It requires long implementation periods both in the pre-investment and investment phases • High capital cost (USD/kW)

Resources and potential

Hydropower accounts for one-fifth of today's power supply, but less than 10% of the estimated technical potential has been utilised (IEA, *World Energy Outlook*, 2014). Hydropower, excluding pumped storage, is currently the largest renewable power generation source, with a global installed capacity of 1,064 GW in 2015 (REN21, 2016), generating about 3,940 TWh. There is a big difference in cost between small and large-scale hydro. But the investment costs differ also due to the type of the plant, if they are run-of-river plants or if reservoirs are required. There is no good definition of what is large, medium and small-sized, which may differ per country. IRENA (2012) mentions: large hydro: > 100 MW (feeding into grid), medium hydro: 20-100 MW (almost always fed into a grid), small hydro: (1-20 MW, usually grid-connected), mini-hydro: 100 kW-1 MW (stand-alone, mini-grid or grid-connected), micro-hydro: 5-100 kW (usually stand alone or small-grid in remote area) and pico-hydro (below 5 kW)[2]

Figure 3 Potential for small hydro in Africa



Permanent (dark blue) and non-permanent (light blue) river network in the African continent with annual mean discharge data [m^2/s] and areas where mini-hydro results the most convenient rural electrification option (detail). Source: *Renewable Energies in Africa,* JRC (2011)

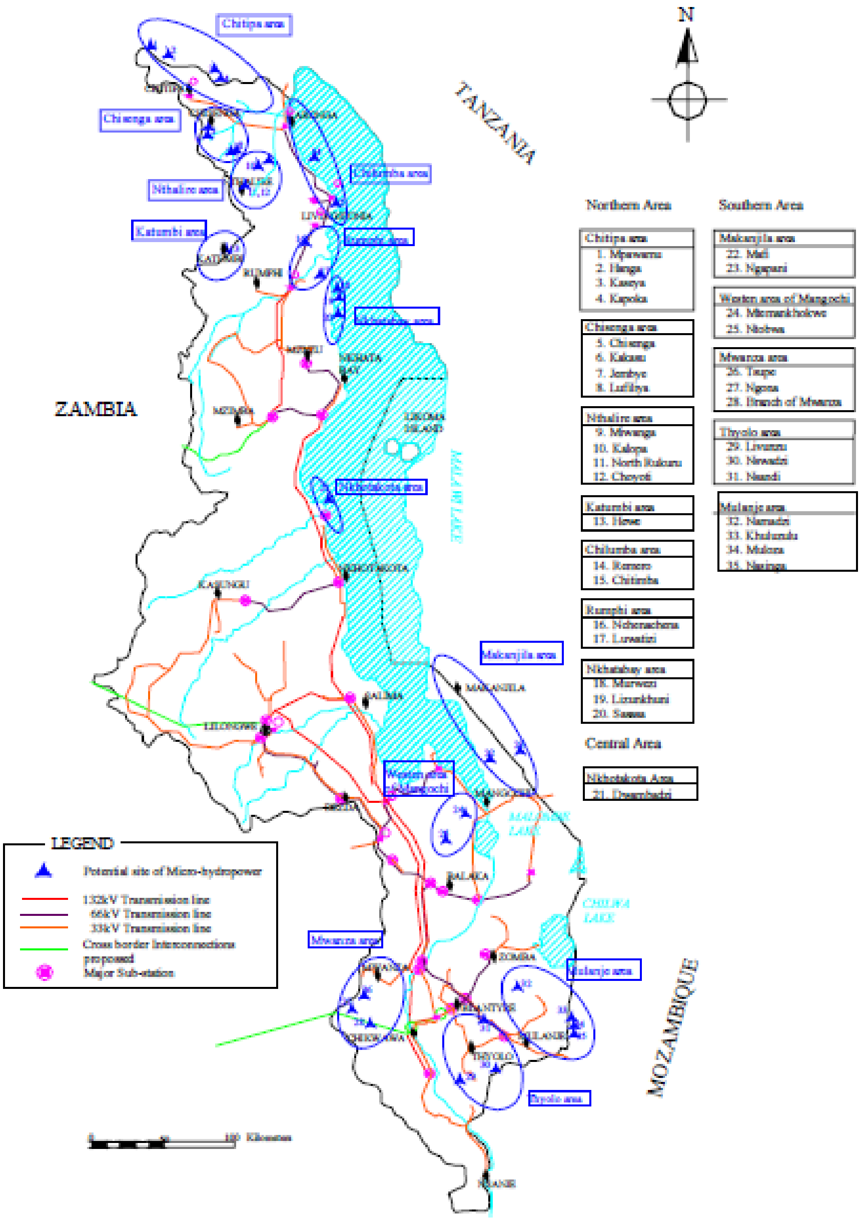
In Africa, huge areas have very good potential for mini-hydropower. Africa has about 10% of the world's theoretical hydropower potential, most of which is located in the sub-Saharan part of the continent, but currently uses only a fraction of this potential. Africa's gross theoretical hydropower potential is estimated at 4,000,000 GWh/year, and the current production of hydropower in Africa is only about 20% of the total potential[3]. A study by the EU Joint Research Centre mentions that nearly 30% of the population lives in areas, where the small hydro-energy options promise the cheapest source for electricity (as compared to diesel, PV or wind).

2 REN21 (2016), *Global Status Report*

3 FAO (2008), *Water for Agriculture and Energy in Africa: The Challenges of Climate Change;* IIASA (2012), *Global Energy Assessment*

Malawi

The total installed (national grid) electricity capacity was about 351 MW[4] and is dominated by **large hydro** (96%). The government plans to add generation from 351 to 429 MW by 2018 through upgrading hydropower facilities (36 MW), expansion of hydropower (Tedzani, 21 MW). A more drastic expansion of power will be needed therefore in the decades to come. The



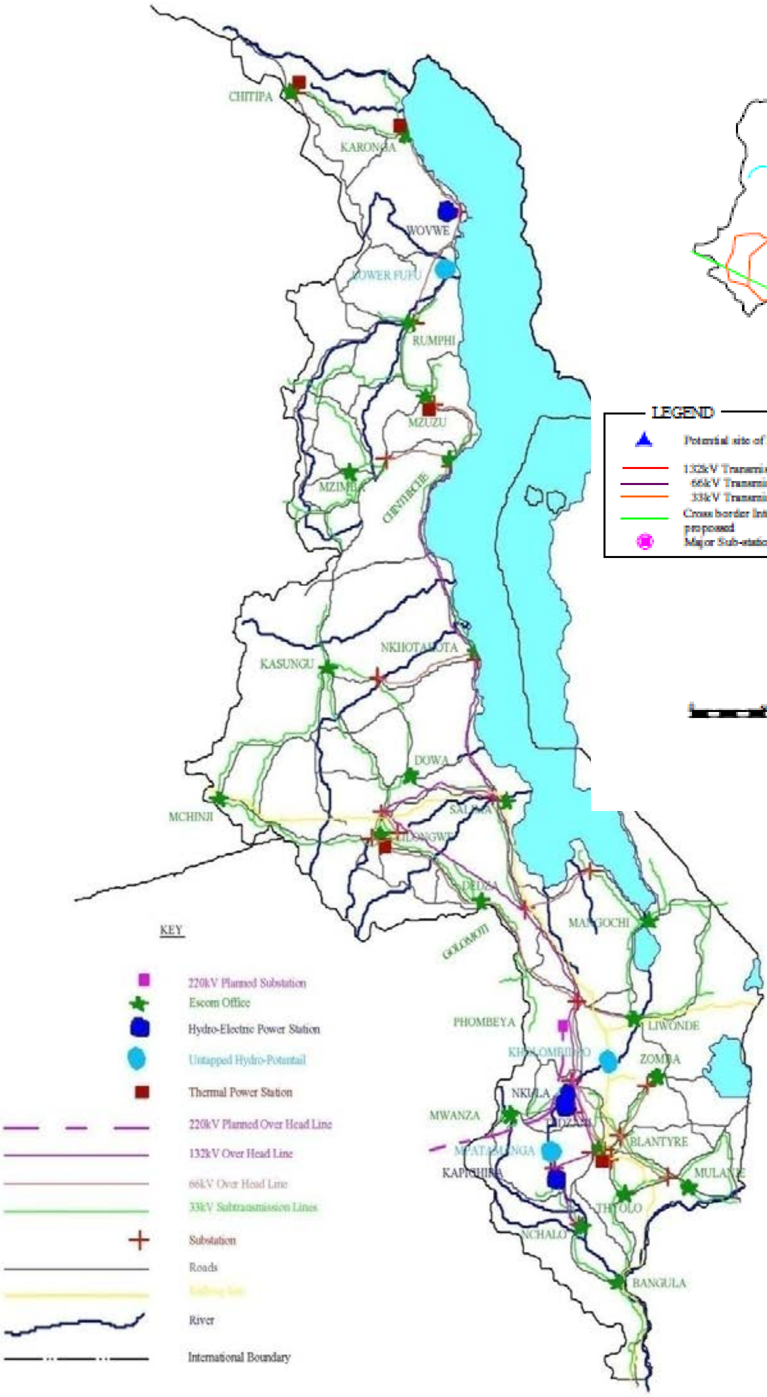


Figure 4 Locations with micro-hydropower potential (right) and ESCOM grid (left)

Source: JICA-commissioned *Master Plan Study of Rural Electrification in Malawi* (2003); MCA *Energy Concept Paper* 2011-2016

M&E Plan for the new draft National Energy Policy (2017) an expansion of 1,860 MW over 2015-2025, consisting of new hydropower facilities (7 stations, totalling 981 MW by 2022) and new diesel plants (4 plants at 48 MW) by 2018, as well as adding new fuel facilities (coal 520 MW), bagasse co-gen (40 MW) and the remainder of geothermal, natural gas, solar PV (270 MW) plus 100 MW reduction due to energy conservation efforts.

[4] Hydro: Kapichira falls, 129.6 MW, Nkula, 124 MW, Tedzani, 92.7 MW, small hydro: Wowve: 4.35 MW

Apart from the large hydropower, Malawi has experience with **small-scale hydropower (SHP)** systems (small, mini and micro hydropower systems); reportedly about 5.8 MW has been installed, of which 4.5 MW at Wovwe)[5]. Many studies and documents report that Malawi is relatively rich in water resources in form of lakes, rivers, and aquifers some of which can be used for small-scale hydro-power generation. Water resource distribution is highly variable both seasonally and geographically and nearly 90% of the runoff in major rivers occurs between December and June. A major inventory of water resources (dams, rivers, and lakes) in Malawi was conducted in 1986 (National Water Resource Master Plan, NWRP) and updated in 2014[6]. Hydrological and topographical information on these rivers can be sourced from the National Spatial Data Centre in the Ministry of Lands Housing Physical Planning and Surveys.

Despite having several perennial rivers, only a few feasibility studies have been conducted to identify potential sites for small hydropower generation in Malawi. The studies seem to indicate a potential of up to 15 MW in total at the sites. A second resource potential assessment study was conducted through a Power System Development and Operation Study A study, carried out with funding from the World Bank, identified some 100 hydropower potential sites for grid connection, using topographical and hydrological maps obtained from the NWRMP. From this study, the Malawi Government eventually came up with a list of potential SHP sites, with a generation potential of about 7.3 MW and potential energy production of 19,300 MWh per year[7]. A more detailed assessment was conducted in 2002 by the Japan International Cooperation Agency (JICA) technical team with some staff from the Malawi's Department of Energy Affairs (DEA) to identify sites that have potential to generate electricity between 5 and 200 kW to be included in the Malawi Rural Electrification Master Plan (MAREP). This produced a list of 12 sites with a potential of 345 kW.

Hydropower is the major source of power for Malawi. However, it is being affected by environmental degradation due to farming activities in upstream rivers, as well as by deforestation due to firewood and charcoal production. Moreover, climate change has a significant impact on small hydropower resources as rivers continue to dry up. The need to update inventories on micro hydropower is required to track the changes of environmental degradation on small hydropower potential. There is also need to explore other SHP sites because the two inventories mentioned above are not inclusive of all SHP sites in the country[8].

The SHP potential in Malawi has so far mainly attracted a few actors, such as tea estates or religious missions. The very first small and mini-hydropower development (SHP) was done by missionaries. However, the maintenance by their owners as well as their limited financial and problems of replacing worn out parts due to lack of technical skills and unavailability of the (foreign) companies that installed the SHPs. Tea estates have installed SHP in their factories; for example, the Mulanje area has two mini-hydros operated by the Lujeri Tea Estate (319 and 650 kW)[9].

The Malawi Industrial Research and Technology Development Centre (MIRTDC) conducted an energy baseline study for the Mulanje Mountain Conservation Trust (MMCT) and Practical Action in Mulanje and Phalombe districts. The study revealed that the area is well-endowed with SHP potential of up to 104 GWh per annum[10]. Further studies were done on the rivers that run from the Mulanje Mountain, namely the Luchenya, Lujeri and Ruo rivers. Based on these studies, the Mulanje Renewable Energy Agency (MuREA), an NGO formed from the MMCT, developed plans to install mini hydropower plants. This resulted in the establishment of the Mulanje Electricity Generation Agency (MEGA) in 2013 by MMCT and MuREA that has set up the country's first hydro-powered mini-grid for electrification system at Bondo village (with 56 kW capacity). MEGA's now aims to replicate this and provide the rural, off-grid villages of the Mount Mulanje area with access to affordable and available electricity and energy services, locally generated through a series of 40-100 kW micro-hydro schemes. The reader is referred to the Case Study *Mulanje: pioneering a social enterprise approach in clean energy mini-grid schemes f*or more details. MIRTDC also conducted a feasibility study on the Kavuzi River in Kavuzi area in Nkhata Bay District in the northern region of Malawi, for development of the SHP project. This project was initiated by a youth non-governmental organisation of Kavuzi known as Media and Technology Society (MTESO). The study concluded that a 10 kW pico-hydropower system could be developed at the site. Although MTESO's initiative was discontinued, it spurred pico- hydropower development by private artisans in the area, which is described in the Case Study *Kavuzi: pico-hydropower schemes, a people's initiative.*

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5 Kaunda (2013), MCC (2009*)*

6 *Project for National Water Resources Master Plan in The Republic of Malawi,* MoAIWD and JICA (2014)

7 *System Development and Operation Study Project* (1997)

8 Kaunda (2013), UNIDO-ICSHP (2013)

9 The NGO Greening the Tea Industry in East Africa (GTIEA) conducted a feasibility study on two sites on the upper Ruo River and one site at the Lujeri River to develop and improve the capacity of the existing SHP systems (2009)

10 Malawi Industrial Research and Technology Development Centre—MIRTDC, *Energy policy research baseline study for Mulanje and Phalombe Districts,* Prepared for Mulanje Mountain Energy Conservation Trust, Mulanje, Malawi.

3. Biomass mini-grids

Biomass for power generation: technology overview

The use of **biomass products or wastes** to produce electricity for rural settlements is an attractive alternative as the resource can be much cheaper than using fossil fuels.

Biomass feedstock and biofuels

The biomass feedstock for heat and electricity can be originated from waste/residues, dedicated energy crops and plantations, or biomass harvested from natural resources. The potential for these different types of feedstock vary significantly between areas and within areas, as do the production, collection and conversion costs and the market value of end products.

Agricultural residues and wastes are particularly relevant for developing countries as there are important amounts that could be easily mobilized, and this is usually a low impact option. Residues can be split into two types: dry and wet. Wet residues can be used in bio-digesters (biogas). Dry residues usually consist of wood or parts of crops that are not used for the primary production of food or fibre. Included in dry residues are straw, poultry litter, rice and coffee husks, maize stalks stem cotton, etc. Dry residues can be either burned for heating, power, co-generation or gasified.

Biomass harvested from natural resources is another form of bioenergy feedstock. These include forest, woodland, and grassland. Dedicated energy crops are crops grown for energy purposes, notably for the production of biofuels, such as ethanol or biodiesel. Energy crops can be divided into the four groups of sugar crops, starch crops, oil crops and lignocellulosic crops. *Ethanol* is a colourless, volatile and highly inflammable liquid that can be used as a fuel in spark plug engines, either in a blend with gasoline or as straight fuel. It is produced by fermentation of sugars, and starch (after hydrolysis); the (low concentration) ethanol thus produced can be purified to 96% through distillation. *Straight vegetable oil* is a liquid fuel that can be used as a (partial or total) replacement of diesel fuel in diesel engines. In most cases, it concerns oils that are cold pressed from oil bearing seeds using an oil expeller. The oil is then filtered; further refining is often required to reduce fatty acids, phospholipids, and water. Shelf life of SVO is limited as it tends to oxidise and polymerise over time. SVO can be used as a single fuel in diesel engines, but needs to be pre-heated in order to reduce its viscosity. This is typically done using engine heat, but this does require an adaptation of the engine. Some types of SVO can be blended with diesel to a degree that sufficiently reduces its viscosity, and can then be used in engines without modification. SVO is different from *biodiese*l, which is chemically processed. Biodiesel is the product of transesterification of vegetable oil using an alcohol (usually methanol) and a catalyst. The viscosity of biodiesel is close to that of fossil diesel; no engine modification is required.

There are mainly four distinct technologies currently existing to **produce electricity from biomass**: a) direct combustion, b) bio-digester, and d) gasifier. All can produce heat or electricity, or both, in cogeneration (combined heat and power, CHP).

Combustion of biomass with conventional steam cycle for the production of electricity and/or process heat is well proven and commercially available technology. There are many examples of such systems in industry (sugar mills, palm oil mills, sawmills, etc) and as stand-alone units for grid supply. Systems typically consist of a boiler plant in which the hot flue gases from biomass combustion produce high pressure, high-temperature steam. The steam passes through a turbine, which in turn drives a generator. The expanded steam is either used for process heat or condensed. Many types of (dry) biomass can be used, including wood, bagasse, empty palm fruit bunches, stalks, shells, husks etc. Ash (melting behaviour) can be a limiting point. The biomass should preferably be available year-round, in order for the power plant to operate at high availability. In general, the drier the biomass, the better.

Biogas is produced by means of anaerobic digestion (i.e. in the absence of oxygen) by bacteria of animal waste and the organic content in municipal waste or wastewater. It is a versatile fuel that is suitable for fuelling stationary engine applications. It can be used in dedicated (spark plug) gas engines and as a co-fuel in diesel engines, making it a practical fuel for stand-alone generators used in off-grid electricity supply and mechanical power applications (e.g. grain mills, rice decorticators, motorised water pumps). Biogas can be produced in a range of system types, including (stirred/unstirred) tank reactors, plug flow systems, and lagoon type systems. Simpler systems have no stirring and heating devices installed, but these are generally less versatile with respect to feedstock. In some cases, biogas conditioning (dewatering, desulphurisation) is needed in order to avoid damaging engines.

Applicable system scale depends on the power/energy requirements, but typically ranges from 10-1000 m^3/day of biogas for power systems being able to produce 5-200 kW of electricity. Several types of genset can be used to transform the biogas into electricity and heat using internal combustion engines. Possibly the biogas should be filtered and/or upgraded removing corrosive gas. and increasing its heat value before being combusted. Small diesel and gasoline genset (1-5 KW) can be easily be adapted to run also with biogas.

Gasification is a thermochemical process that converts solid fuels into a combustible gas (or syngas). Syngas is a mixture of carbon monoxide, hydrogen, methane, carbon dioxide, water vapour, and nitrogen. It is a low calorific gas with an energy value much lower than that of natural gas. Nonetheless, the gas can be used in gas engines, diesel engines, and (industrial) thermal processes such as heating and drying. The gasification process takes place in a gasifier. There are several types of gasifiers. A large range of feedstocks is suitable for gasification, including wood chips, nut shells, maize cobs, and rice husk.

Despite cheap feedstock and low production cost, many other problems have been reported with existing plants. Most gasifiers are sensitive to fuel quality (particle size, moisture content, ash content), in particular, fuel management (regular supply, collection, and storage of biomass) is also a challenging task (often underestimated). There are many examples of large use of gasifier by rural industry for their self-consumption (rice millers, wood industry, tea estates), The use of a biomass gasifier specifically dedicated to pure rural electrification (without anchor customer) and thus to mini-grids is a new challenge and the technology for such application is less proven.

Cogeneration is often used for isolated agro-industries to self-generate their electricity in areas where national grids suffer to extend. The CHP co-generation (heat and power) is a long-proven technology with a lower capital cost (USD 1000 to 2000 per kW) than hydro, which has been developed by a certain number of agro-industries (sugar, timber) using conventional steam turbine systems with boilers and a variety of fuels or wastes. Electricity is used first for the self-consumption and then, if excess power is available, for employees' supply (often free of charge). Payback time is usually under 5 years and technology risk is low. Getting an agro-industry to invest in rural distribution and to have a commercial activity to sell electricity to the grid or to surround rural settlements is very well possible, but not very common. They would perhaps sell to a rural distributor (off-taker), if receiving an adequate revenue from it. Thus, there is a potential to have rural electrification with co-generation-based mini-grids around some specific agro-industries.

Costs of biomass technology for power generation

According to IRENA, biomass technologies will not see the lower range for their levelised cost shift significantly by 2020, given that today's cheapest options rely on very cheap or even zero-cost feedstock supply. Most biomass combustion technologies are mature, although the projected growth in the market will allow modest capital cost reductions of between 10% and 15% by 2020. The cost reduction potential for gasification technologies, excluding anaerobic digestion, is higher and, if deployment accelerates, capital cost reductions of 10% to 20% might be possible by 2020.

Table 2 Estimates of investment and levelised cost of biomass-fired power

Bio-power technology and feedstock	Typical plant size	Conversion efficiency	Capacity factor	Capital cost (USD/kW)	LCOE (USD/kWh)
Gasification	1-40 MW 0.2-5 MW	30-40%	40-80%	2050-5500	0.06-0.24 0.08-0.12
Bio-methanation (anaerobic digestion) - Large - Small	1-20 MW	25-40%	50-90%	500-6500 600-900	0.06-0.19 -

Compiled from IRENA (2014), table 1 and IPCC (2011), table 6.3; WEC (2013). Fixed O&M cost are typically 2-6% of CAPEX, while variable O&M cost are around USD 0.005/kWh.

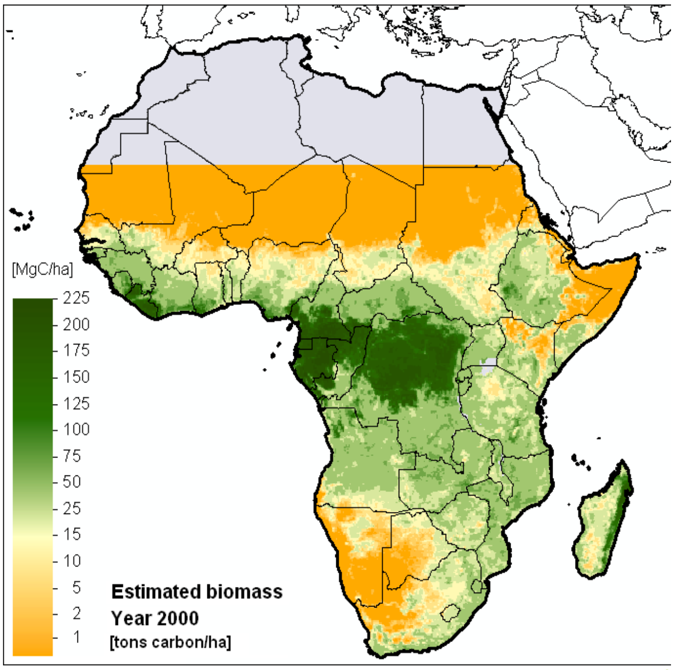
Benefits	Challenges
• Relatively low-cost power for combustion-based systems • Bioenergy system must be well-maintained and cleaned out	• Medium to high cost for gasifier based systems • Limited African experience to use this technology for rural electrification • Location-specific; It needs a constant source of feedstock to keep the system working which needs to be purchased if not on-site available (agro-processing companies have some control over on-site fuel feedstock)

Resources and potential

Africa has abundant biomass, sometimes called "the green gold" of Africa, but its distribution varies considerably, with the grassland regions of the Sahel and the dry land savannas being particularly low and the humid tropical forest regions having very high biomass values. The forest area of Africa exceeds 235 million ha. Other wooded land and shrub savanna cover over 830 million ha. The dry forests and woodlands are the main source of wood fuel. The potentially available stocks for energy purposes in sub-Saharan dry forests and woodlands range from 11.7 tonnes per hectare in the semi-arid dry forests of the East Africa Somali-Masai region to 136.3 tonnes per hectare in the sub-humid dry forests in the Congo-Zambezian region.

Traditional sources of energy in the form of firewood and charcoal account for over 80% of the total energy use in sub-Saharan Africa. Charcoal meets most of the gap and more than 95% of the urban demand. Sub-Saharan Africa produces around 600m m^3 of wood fuel per year, which covers 60% to 85% of the energy needs, depending on country and region. Wood fuel consumption far outweighs other uses as fuel in Sub-Saharan Africa. Biogas and landfill gas are widely used for power generation in many parts of the world and biomass gasification is widely deployed in, for example, India. In Africa, some countries have tried to generate power using these technologies but without any large-scale success. Only bagasse plays an important role in power generation. Bagasse is the most important source of bioenergy power in Africa, accounting for 94% of the 860 MW of installed bioenergy power generation capacity in 2011. The technical potential for the use of bioenergy for power generation is estimated to be 2,374 TWh, with 66% of this potential in Central Africa (IRENA, 2012)[11].

Figure 5 Estimated biomass stock (2000), sub-Saharan Africa



Source: EU-JRC (2013)

Whether this technical potential to meet Africa's future primary energy supply could be used, will depend on the following factors: i) the availability of land; ii) the productivity of the biomass grown upon it; and, iii) competition for alternate uses of the land and/or the biomass, and for the waste materials derived from the biomass (including crop residues, forest residues, and organic waste) to be used as food, feed, fibre or fuel.

Malawi

Much of Malawi's population in urban as well as rural areas still rely on firewood and charcoal, with 86% of the country's total energy use coming from biomass and 96% of households using firewood or charcoal for cooking. The overall consumption of wood exceeds sustainable supply to such an extent that the net loss of forest reserves in Malawi each year is over 50,000 hectares (REEEP, 2012). Deforestation not only harms natural habitats and destroys a natural store of carbon, it also removes the structure from the soil which leads to erosion and increased flood risk as well as having the effect of increased siltation in rivers during the rainy season. Siltation frequently interrupts water supplies and affects power generation in the hydro schemes, such as the ones on the Shire River. Given the above, the Government's rural energy efforts have more focussed on making the current use of biomass as fuel more sustainable, rather than as a source for power in (off-grid) rural electrification. For example, Malawi has set an ambitious target to sell 2 million cleaner cookstoves by 2020 and for all households to use all households off the grid to be using cleaner cookstoves by 2030, together with measures that ensure the production of the wood fuels from sustainable stock or sourced in a sustainable way (see draft *Malawi Renewable Energy Strategy*, 2017).

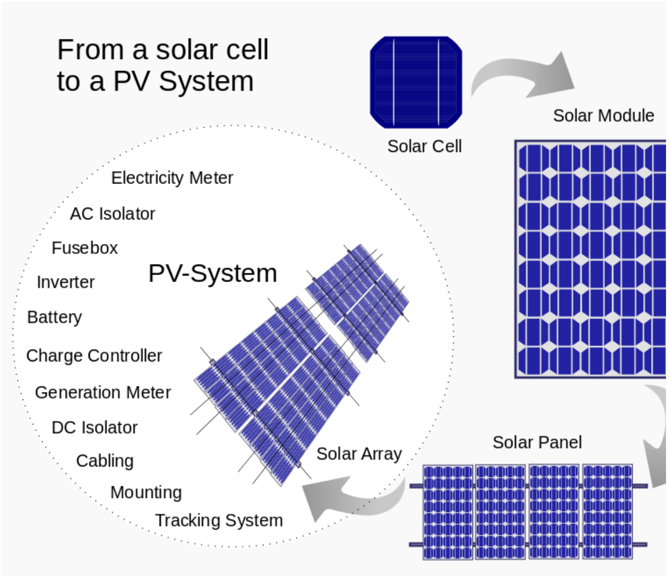
[11] For comparison, Sub-Saharan Africa, concentrated solar power, 3,784 TWh, 5,477 TWh solar PV, 2,809 TWh wind and 1,766 hydropower. Source: IRENA (2012) *Prospects for the African Power Sector*
Global bio-power capacity was an estimated 106.4 GW in 2015 (up from 68 GW in 2010), and generation 464 TWh (The leading countries for electricity generation from biomass in 2015 were the United States (69 TWh), Germany (50 TWh), China (48 TWh), Brazil (40 TWh) and Japan (36 TWh) followed by the United Kingdom and India. Source: REN21, *Renewable s Global Status Report 2015;*

4. Solar and wind mini-grids

Solar energy: technology overview

Photovoltaic (PV) is one of the fastest growing renewable energy technologies and it is expected that it will play a significant role in the future global electricity generation mix. PV technology can be used on a variety of scales, from an integrated solar cell in a solar lantern to a battery-operated solar system on a house or school or even a large grid-connected solar power plant with a capacity of several MW.

Figure 6 Solar PV cells and panels

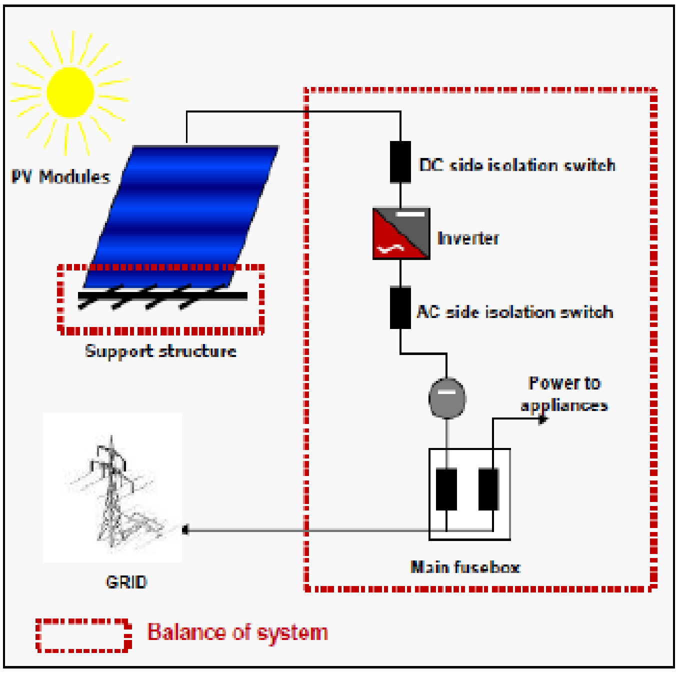


Source: Rfassbind

Photovoltaic systems (PV) are made of PV modules. The smallest unit in a PV module is the solar cell, which converts the light into electricity. The direct electric current (DC) produced varies constantly depending on the intensity of the incoming solar light. Also current is depended of the incoming solar energy. A PV module consists of many solar cells connected to achieve a higher voltage. A module for off-grid application normally is adapted for a voltage of 12 V or 24 V (with respectively 36 and 72 cells in serial). When modules are used for grid-connected systems with higher voltage and alternating current (AC), an inverter is needed to change the DC current into AC current. Also, the voltage needs to be converted to at least 230 V depending on the system it is connected to. When the cells are connected to a module, also different losses lower the module efficiency from the cell efficiency.

Solar irradiance is the radiation emitted by the sun that has been transmitted through the atmosphere of the earth. Depending on scattering and absorption in the atmosphere the final irradiance value reaching the ground and what PV modules can utilize, is about 1000 W/m^2 at the equator at peak hours of sunshine.

Figure 7 Solar PV system components



Source: energypedia.info/images/4/41/
SBC_Energy_Institute_Solar_PV_FactBook.pdf page 12

Direct normal irradiation (DNI) is the amount of solar radiation received per unit area by a surface that is always held perpendicular to the rays that come in a straight line from the direction of the sun at its current position in the sky. Africa is particularly rich in solar energy potential, with most of the continent enjoying an average of more than 320 days per year of bright sunlight and experiencing annual global irradiation levels of almost 2 000 kWh per square metre (kWh/m^2)

Due to a wide range of factors, such as light absorption losses, mismatch, cable voltage drop, conversion efficiencies, temperature influences and other parasitic losses, there are losses between the Direct Normal Irradiance (DNI) and the actual AC power delivered to the grid. The best efficiency currently available for commercial solar panels is of the order of 16%-22%. Thus, one square meter of photovoltaic panels can, at best, provide an electric capacity of 220 W. In sunny conditions, this can generate about 250 kWh annually. In moderate, cloudy climates, the modules may reach only 50% or less of this output.

The main **components** of a solar PV system are:

- **Solar modules**
  A solar module consists of solar cells that have semiconductor materials that convert sunlight directly into electricity. The output of the solar module depends on many factors: its size (installed capacity), efficiency of the technology, irradiation at the site, cleanliness of the surface, and eventually on a tracking system (untypical for rural electrification). Most commercially available solar modules are capable of producing electricity for at least twenty years. The typical warranty given by panel manufacturers is over 90% of rated output for the first 10 years, and over 80% for the second 10 years. Maintenance of PV modules is relatively easy (can be easily cleaned with water and a sponge) and the most common technical problems occur due to misplaced, stolen, or dirty modules and can be identified visually.
- **Balance of system (BoS)**
  - Ground-mounted solar power systems consist of solar panels held in place by racks or frames which are attached to ground-based mounting supports and include pole, foundation, or ballasted mounts *(support structure*).
  - PV systems use *rechargeable batteries* to store a surplus to be later used at night. Batteries used for grid-storage also stabilize the electrical grid by levelling out peak loads. Common battery technologies used in today's PV systems include the valve regulated lead-acid battery (a modified version of the conventional lead-acid battery) and lithium-ion batteries.
  - Other components are *inverters* (devices that transform DC voltage to AC voltage). Battery backup inverters, are special inverters which are designed to draw energy from a battery, manage the battery charge via a *charge controller*, and export energy to the grid system. The charge controller is a device that regulates the charging and discharging of batteries. A solar *cable* interconnects solar modules and other electrical components in the photovoltaic system (a three-core AC cable is used for connection to the grid if a single-phase inverter is used, and a five-core cable is used for three-phase). The *fuse box* houses the fuses (that are designed to protect the system from currents that are too high).

Costs of PV technology

The overall cost breakdown of a PV system is as follows:
- Capital cost comprising:
  - PV modules,
  - Supply and installation of inverter equipment, electrical instrumentation, and controls,
  - Battery banks
  - Support structure (mounts)
  - Project indirect costs, fees and contingency, and owner’s costs
- Operation and Maintenance costs (O&M).

Operating cost is usually low, as plants are automated and have little personnel on site during normal operation. The replacement of essential parts (batteries, inverters) forms important costs elements that occur after 5-7 years of the system’s life.

Internationally. solar PV module costs have declined so rapidly in recent years. Balance-of-system costs are becoming a more crucial determinant of the levelised cost (LCOE) of solar PV, maybe determining as much as 80% of the cost reduction potential for solar PV. The typical LCOE range for solar PV will decline from between USD 0.12-0.36/kWh in 2012 to between USD 0.09-0.30/kWh in 2020.

Benefits	Challenges
• No fuel requirements • No pollution • It has a long lifespan • The PV technology is reliable • Low running and maintenance costs	• Performance is weather related, no sun = no electricity • High capital cost • Requires battery storage if power is needed continually or at night when there is no sun; • Batteries need to be replaced during the lifetime of the system. Most solar systems will need a large number of batteries in series and most batteries used have a short lifespan

Solar resources and potential

The Photovoltaic Geographical Information System (PVGIS) has been developed in the EU-Joint Research Centre (JRC) and provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems.

Figure 8 Photovoltaic electricity potential as computed by PVGIS and cost of electricity (in 2012) of a 15 kW off-grid solar system

Source: *Renewable Energies in Africa,* reports EU-JRC (2011) and EU-JRC (2013)

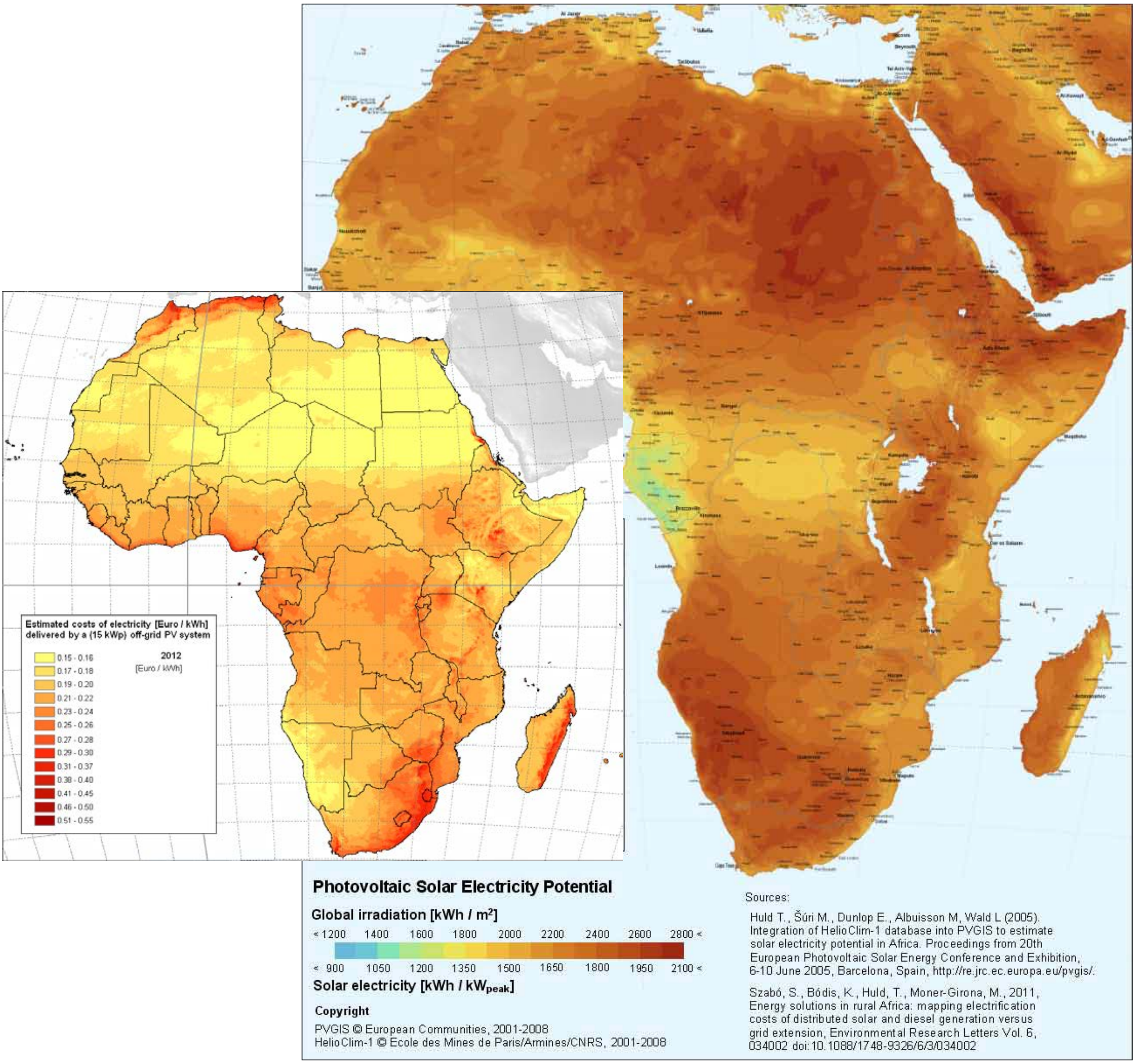


Table 3 Estimates of investment and levelised cost of solar PV

	Installed PV system cost (USD/kW)			Levelised cost of energy USD/kWh)		
Installed PV system cost	Utility scale	Residential (w/o battery)	Residential (w/ battery)	Utility scale	Residential (w/o battery)	Residential (w/ battery)
2010/11	2640-5000	3070-5800	4000-6000	0.20-0.59	0.25.0.70	0.36-0.71
2014/15	1300-5400	1860-5100	3800-4300	0.08-0.42	0.14-0.47	0.31-0.52
2030	1060-1380	1500-1800				

Source large and small hydro: IRENA RETs (2012): Cost Analysis Series Vol.1 4/5: Solar Photovoltaics and IRENA (2015). LCOE assumes a 10% cost of capital. Efficiency (residential): 14% (2010/11, c-Si PV) and 8-12% (utility; amorphous/thin film) and 17% and 11-17% in 2015 respectively).

Components	**Life (yrs)**	**Cost per kW installed (in USD)**			
		Utility-scale	Roof-top residential	Small (w/o battery)	Small (w/ battery)
PV modules	20-25	660-850	660-850	730-850	730-850
Inverters	5-10	230-750	270-800	270-800	270-800
Wiring; electrical		240	240	240	240
Battery bank					1200-1500
Structure/mount		300	550	300	300
Installation, site preparation, etc.		650	130-220	150-200	200-600
Total cost		2000-2600	1900-2800	1600-2400	2900-4300
LCOE (USD/kWh)		0.10-0.30	0.14-0.46		

Own analysis, based on IRENA (2012), IRENA (2015) and EU Technical Assistance Facility for SE4All). Assumed annual energy production is 800-2000 kWh per m2 per year, depending on latitude. In terms of size installed cost of PV range from USD 0.09-0.16 (> 100 MW), to USD 0.11-0.18 (10-100 MW), USD 0.13-0.20 (1-10 MW), USD 0.15-0.23 (10 kW-1 MW, ground) and USD 0.17-0.25 (1 kW-1 MW, roof). WEC (2013), based on data from China, India, Spain, USA, Australia, Germany and Japan.

Wind power technology

Wind power is the conversion of wind energy into electricity or mechanical energy using wind turbines. The windmill or a wind turbine has blades or rotors which are turned by the wind. As the blades turn, this rotates a piece of equipment called a "speed shaft" in the wind turbine which in turn, drives an electricity generator and as the generator is turned, electricity is generated. The faster the blades turn, the faster the generator is turned and the more electricity is produced.

Table 4 Estimates of investment and levelised cost of wind power

Capital cost breakdown (2010/11 data)	**On-shore**	**Off-shore**
Wind turbines	64-84%	30-50%
Civil works and construction	4-16%	15-25%
Grid connection	9-14%	15-30%
Planning and development	4-10%	8-30%

IRENA (2015) and IRENA (2012), Vol. 5.5 Wind Power. Wind turbines: production, transportation and installation; Civil works: installation, foundation, site preparation and access road. Grid connection: cabling, substations and buildings. Planning and development: engineering, licensing, consultancy, permits

Wind turbine cost	**Installed cost (EUR/kW)**
Wind turbines (> 1 MW)	1500 (1060-2450)
Wind turbines (250 kW-1 MW)	2850 (2300-3400)
Medium (50 kW-500 kW0	3000 (2500-3500)
Small (1.5-50 kW)	5000 (3000-7000)

EU Technical Assistance Facility for SE4All

Wind turbines range from small generators for residential use of a couple of hundred watts to several megawatt machines for wind farms and offshore. The small ones have direct drive generators, direct current output, aeroelastic blades, lifetime bearings and use a vane to point into the wind; while the larger ones generally have geared power trains, alternating current output, flaps and are actively pointed into the wind.

Wind power is used in large scale wind farms for national electrical grids as well as in small individual turbines for providing electricity to rural residences or grid-isolated locations. Large wind turbines are normally grid connected. This category includes diameters of 30-90 m and power outputs 0.5 – 3 MW[12]. By 2020 installation costs for wind farms in the United States and in Europe could fall from currently

[12] See: energypedia.info/wiki/Wind_Energy_-_Introduction#Wind_Electric

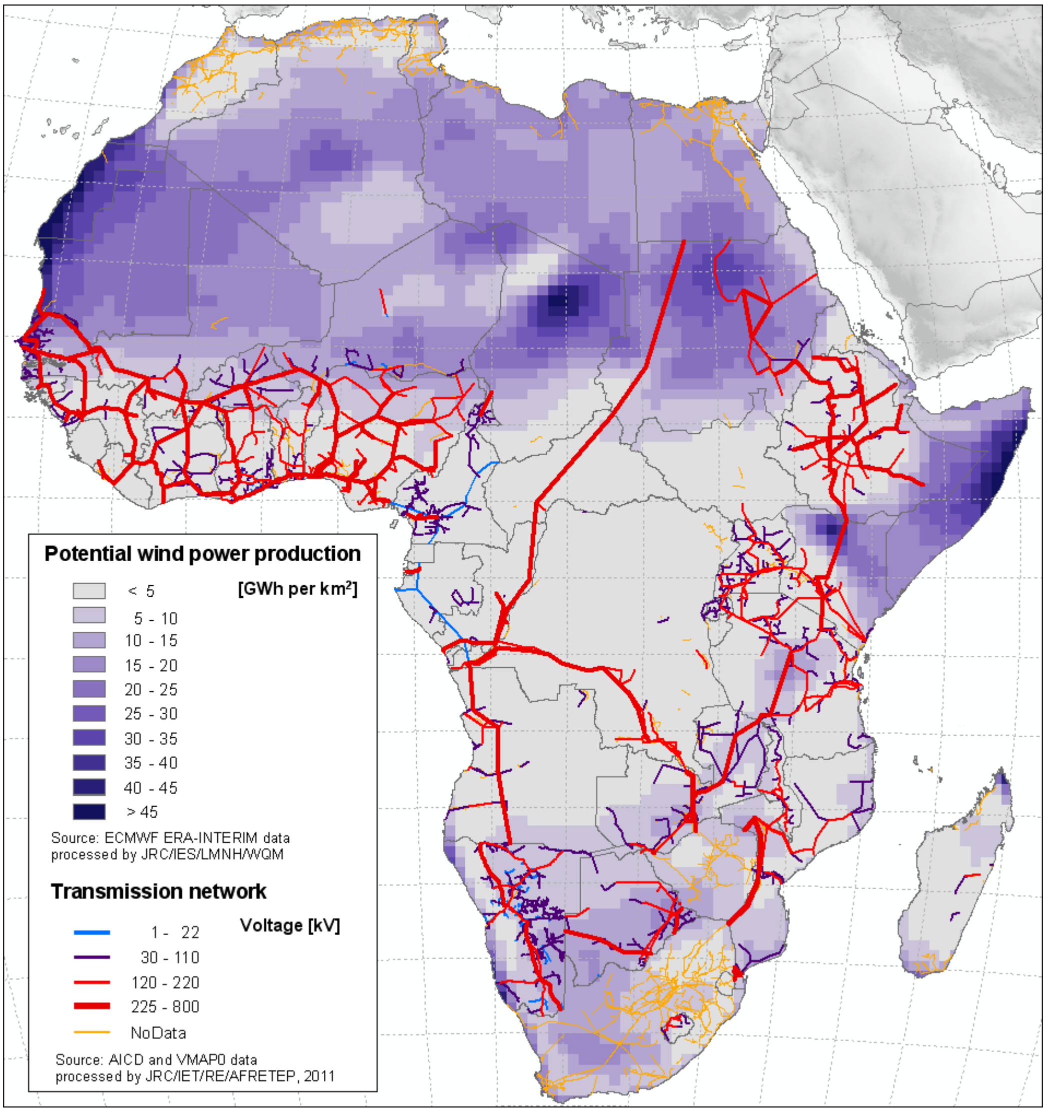
about USD 1,750/kW to between USD 1,300 and USD 1,600/kW. The projection assumes that wind turbine prices stabilise at around $800/kW. This price is still significantly higher than the average prices in China & India (< USD 500/kW). Average capacity factors for new wind farms will continue to rise. But O&M costs for wind turbines will increase and prevent a significant decline of the LCOE.

Since wind speed is not constant, the annual energy production of a wind converter is dependent on the capacity factor. A well-sited wind generator will have a capacity factor of about 35%. As a general rule, wind generators are practical where the average wind speed is 4.5 m/s or greater. Usually, sites are pre-selected on the basis of a wind atlas, and validated with on-site wind measurements. Medium-sized turbines are used in small independent grids in a hybrid configuration with a diesel or PV generator. These turbines have diameters of between 5-30 m and a power output of 10- 250 kW. For small turbines, the electricity generated can be used to charge batteries or used directly for battery charging and have a turbine diameter of between 0.5 –5 m and a power output of 0.5 – 2 kW. Installed costs vary between US$ 4 – 10 per watt.

Benefits	Challenges
• Wind power can be used in almost every location if there is enough wind • It is relatively clean as opposed to using fossil fuel powered systems for electrical application.	• Often systems are installed without any wind assessment due to lack of accurate wind data • Most wind systems will need a large number of batteries in series and most batteries used have a short lifespan.

Wind resources and potential

Figure 9 Potential wind power production in Africa, overlaid on the existing power transmission grids



Source: EU-JRC (2011)

Solar and wind in Malawi

The project *Renewable Energy Resource Mapping for the Republic of Malawi* focuses on solar resource mapping and measurement services as a part of a technical assistance in the renewable energy development funded by the Energy Sector Management Assistance Program (ESMAP) of the World Bank in Malawi, in close coordination with the Department of Energy Affairs (DEA). The project has produced meteorological data (global horizontal irradiation, GHI, and global normal irradiation, GNI). These data are validated with ground measurements at seven sites, representing different geographic regions in Malawi, for which site-specific time typical data are produced (as well as air temperature, wind speed, wind direction, and relative humidity data. Geospatial data are delivered in a format suitable for Geographical Information Systems (GIS), and also as digital maps. The project has produced estimates of electricity production from PV that are given in Figure 10.

Figure 10 Global solar irradiation (GHI) data, Malawi

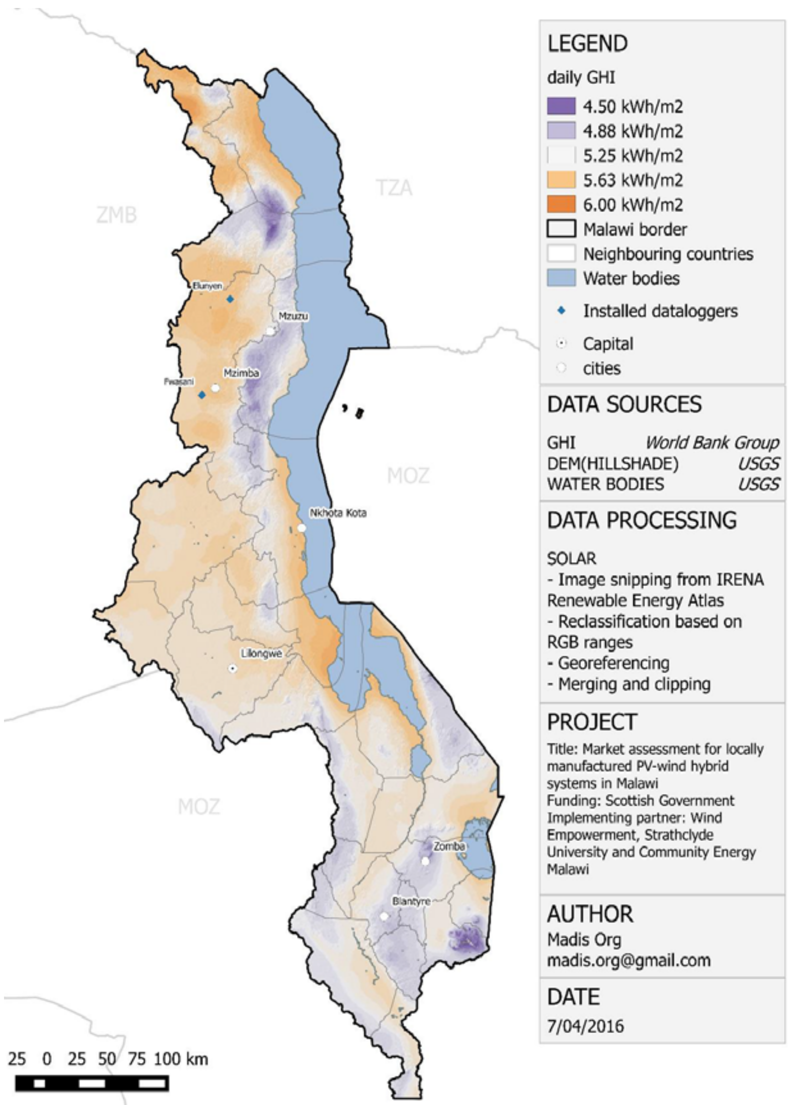


Figure 11 Electricity output from a 1 kW PV system

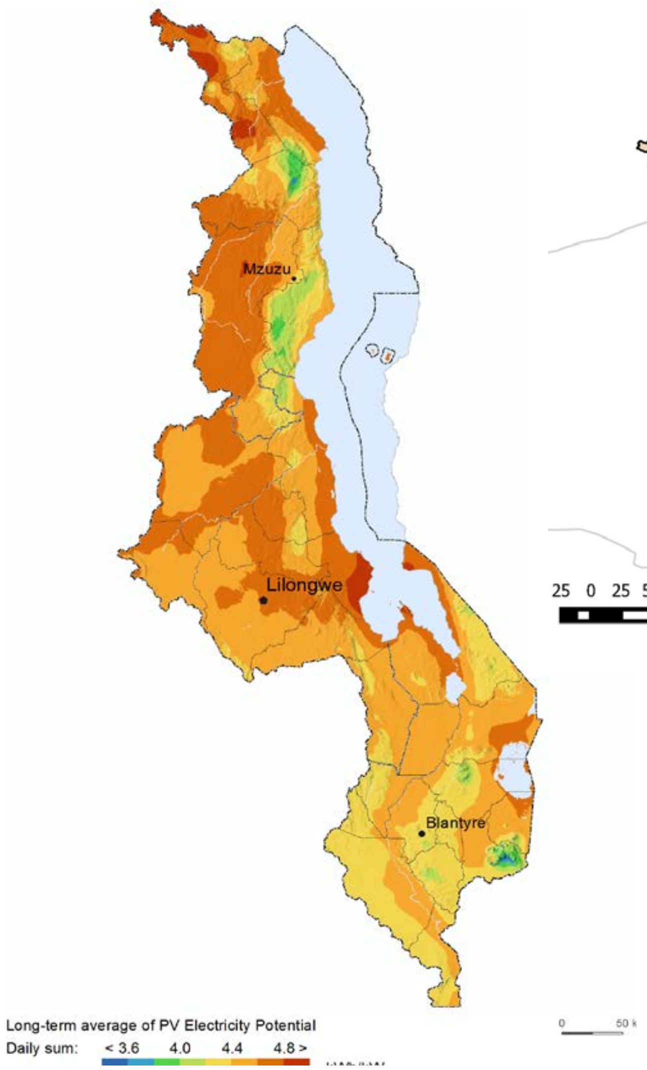


Table 5 Solar irradiation data and PV electricity production information for 7 sites

Source: World Bank-ESMAP (2015)

Month	Global Horizontal Irradiation [kWh/m²]													
	Karonga		Mzuzu		Mzimba		Chitedze		Mangochi		Blantyre		Nsanje	
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max
January	5.58	4.48 6.37	5.16	4.51 5.59	5.25	4.76 5.71	5.26	4.56 6.12	5.57	4.85 6.38	5.44	4.76 6.11	5.85	4.81 6.86
February	5.60	4.57 6.42	5.07	4.30 5.83	5.20	4.58 5.98	5.41	4.21 6.72	5.82	4.37 7.16	5.73	4.17 6.77	5.90	4.05 6.97
March	5.82	4.97 6.38	5.24	4.30 5.82	5.30	4.27 6.11	5.56	4.86 6.46	6.01	5.20 7.18	5.57	4.99 6.61	5.86	4.77 6.36
April	5.65	5.14 6.27	4.79	4.04 5.28	5.50	5.01 6.00	5.51	4.70 6.08	5.76	4.83 6.33	5.22	4.28 5.79	5.32	4.67 5.88
May	5.50	5.16 5.91	4.77	3.99 5.50	5.45	4.48 5.87	5.27	4.16 5.83	5.37	4.43 5.78	4.84	3.71 5.30	4.75	4.24 5.17
June	5.31	4.91 5.55	4.47	4.00 5.11	5.17	4.83 5.55	4.81	4.11 5.28	4.78	4.32 5.07	4.24	3.67 4.62	4.21	3.77 4.69
July	5.51	5.01 5.85	4.55	3.97 5.35	5.28	4.83 5.81	4.80	3.92 5.45	4.83	4.38 5.26	4.24	3.46 4.92	4.27	3.70 4.92
August	6.20	5.72 6.55	5.51	4.61 6.23	5.95	5.30 6.56	5.56	4.63 6.10	5.56	4.85 6.09	5.13	4.40 5.60	5.22	4.67 5.58
September	6.93	6.41 7.15	6.60	5.81 7.13	6.90	6.48 7.27	6.56	6.02 6.99	6.41	5.82 6.91	6.16	5.42 6.62	6.07	5.37 6.33
October	7.36	6.88 7.68	7.01	6.16 7.65	7.22	6.44 7.62	6.81	6.06 7.49	6.79	6.19 7.38	6.41	5.64 7.10	6.55	5.61 7.08
November	7.08	5.59 7.81	6.83	4.94 7.89	6.80	5.01 7.94	6.50	5.00 7.55	6.74	5.24 7.36	6.35	5.16 6.80	6.62	5.57 7.07
December	6.20	5.28 7.12	5.71	4.76 6.83	5.78	4.91 6.77	5.67	4.53 6.59	6.18	4.91 6.92	5.91	4.86 6.66	6.17	5.63 6.81
YEAR	6.06	5.93 [illegible]	5.48	5.17 [illegible]	5.82	5.65 [illegible]	5.64	5.27 [illegible]	5.82	5.32 [illegible]	5.43	5.00 [illegible]	5.56	5.21 [illegible]

Month	Direct Normal Irradiation [kWh/m²]													
	Karonga		Mzuzu		Mzimba		Chitedze		Mangochi		Blantyre		Nsanje	
	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max	Average	Min Max
January	3.69	1.96 5.09	3.14	2.22 4.04	3.27	2.49 4.22	3.14	2.07 4.31	3.68	2.62 4.90	3.53	2.45 4.83	4.19	2.93 5.68
February	3.66	2.21 5.01	3.03	1.85 4.08	3.24	2.24 4.58	3.47	1.79 5.91	4.30	2.18 6.31	4.16	1.79 5.95	4.52	2.07 6.05
March	4.36	2.97 5.27	3.59	2.29 4.51	3.83	2.22 5.03	4.16	2.87 6.16	5.03	3.65 7.71	4.44	3.27 6.42	4.97	3.16 6.03
April	4.98	4.22 6.11	3.76	2.70 4.67	5.15	4.29 5.99	5.29	3.80 6.41	5.92	4.20 7.22	5.02	3.32 6.46	5.16	4.09 6.51
May	5.55	4.83 6.33	4.64	3.08 6.08	6.18	4.31 6.99	6.09	3.83 7.46	6.38	4.44 7.30	5.45	3.14 6.47	5.25	4.02 6.29
June	5.72	4.87 6.58	4.59	3.46 6.21	6.25	5.38 7.22	5.79	4.43 7.13	5.68	4.48 6.50	4.80	3.56 5.71	4.68	3.46 5.87
July	5.69	4.86 6.45	4.51	3.41 5.80	6.03	5.01 7.14	5.30	3.46 6.67	5.26	4.19 6.17	4.41	2.94 5.71	4.37	3.28 5.63
August	5.85	5.07 6.51	5.17	3.66 6.32	6.07	4.75 7.18	5.47	3.58 6.65	5.34	3.90 6.59	4.88	3.47 5.86	4.89	3.80 5.58
September	6.06	5.32 6.81	5.85	4.72 7.17	6.40	5.27 7.36	5.79	4.95 6.73	5.46	4.41 6.53	5.25	4.11 6.25	4.86	4.07 5.59
October	6.57	5.49 7.40	6.25	4.73 7.31	6.66	5.44 7.40	5.70	4.40 6.82	5.60	4.44 6.59	5.16	3.89 6.17	5.25	3.64 6.55
November	6.36	3.89 7.46	6.15	2.86 7.84	6.16	3.16 7.98	5.26	2.90 6.84	5.51	3.19 6.47	5.03	3.12 5.86	5.41	3.60 6.39
December	4.92	3.24 6.39	4.26	2.63 6.02	4.38	2.63 6.14	3.88	2.24 5.46	4.63	2.53 6.06	4.30	2.74 5.82	4.65	3.52 5.76
YEAR	5.29	4.98 5.84	4.59	4.01 5.14	5.31	4.96 5.87	4.95	4.26 5.69	5.23	4.39 5.98	4.70	3.97 5.34	4.85	4.33 5.31

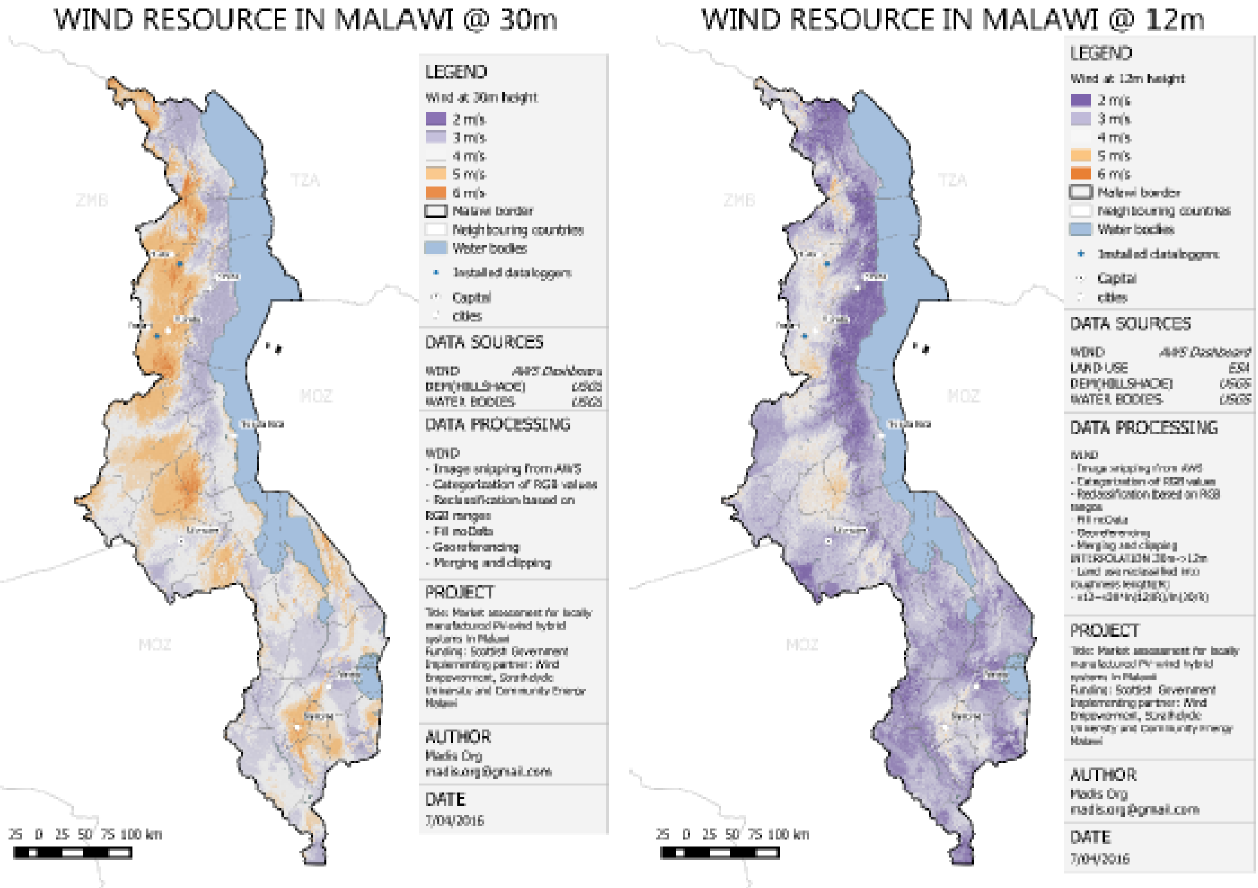
Site	Average daily sum of electricity production [kWh/kWp]												Year
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	
Karonga	3.99	4.09	4.48	4.63	4.75	4.74	4.87	5.23	5.46	5.45	4.99	4.33	4.75
Mzuzu	3.80	3.81	4.17	4.04	4.26	4.12	4.16	4.80	5.37	5.34	4.95	4.10	4.41
Mzimba	3.82	3.88	4.21	4.70	4.98	4.89	4.92	5.22	5.59	5.44	4.83	4.07	4.72
Chitedze	3.84	4.05	4.45	4.75	4.87	4.62	4.51	4.91	5.33	5.14	4.64	4.03	4.60
Mangochi	3.96	4.26	4.75	4.93	4.95	4.56	4.51	4.86	5.14	5.03	4.72	4.28	4.66
Blantyre	3.89	4.23	4.46	4.53	4.53	4.11	4.03	4.56	5.00	4.82	4.49	4.12	4.40
Nsanje	4.11	4.31	4.61	4.52	4.34	3.99	3.96	4.55	4.82	4.81	4.57	4.20	4.40

Table 6 Review of wind data available for Malawi

Data Source	Website	Ref. height (m)	Spatial resolution	Notes	50m wind speed (m/s) @ Rhumpi-West Mast site	50m wind speed (m/s) @ Mzimba Mast site
SgurrEnergy/ WEPP 2014	http://strath-e4d.com/2014/12/05/malawi-wind-wepp-data-preview/	70	POINT	Datalogging systems installed by SgurrEnergy at Rhumpi-west and Mzimba. These are real logged figures. Anemometers at 30/50/70m	6.45	7.0
AWS TruePower	https://www.awstruepower.com/	10	200m	Simulated time-series data. Created using a proprietary method tool that combines meso-scale and micro-scale wind flow modeling (AWS Truepower 2012).	5.96	6.65
		20	200m		5.72	6.07
		40	200m		5.63	5.98
		100	200m		5.71	6.22
		140	200m		5.74	6.31
DTU Global Atlas	http://globalwindatlas.com/	50	1km	Simulated. Created using a combination of meso-scale and WAsP modelling.	4.55	3.59
		100	1km		4.42	3.45
		200	1km		4.82	3.59
Sanders+Partner	http://www.sander-partner.com/	50	Appx.30km		4.5	4.5
3TIER	http://www.3tier.com/	80	3km	Simulated: Created using statistical models and physics-based weather models Compared to 4000 met stations around the world	5.88	6.55
CENER	www.cener.com	10	10km	Simulated using SKIRON model	5.77	8.15
NASA	https://eosweb.larc.nasa.gov/sse/	80m	1deg Lat/ Long	Real results taken at 80m from satellites. Extrapolated for lower hub heights. 1985-2012 measured data	4.77	4.77

Source: *Market Assessment for Locally Manufactured PV-Wind Hybrid Systems in Malawi,* Community Energy Malawi (2016)
The right-hand columns show data normalised at 50 m height to compare the various data sets.

Figure 12 Wind resource maps (30m and 12m)

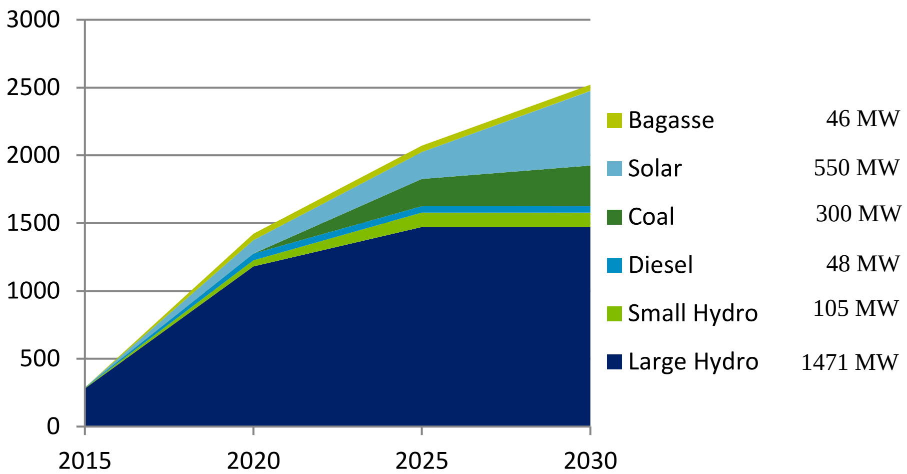


Malawi's present network of meteorological (met) stations comprises 22 full meteorological stations and 21 subsidiary agro-meteorological stations (CEM, 2016). Wind data is recorded, but at 2-10 m height, which is too low to extrapolate up for wind power generation. There are various annual average wind maps for Malawi at public display, however, often no spatial wind data of sufficient resolution could be found for wind power potential evaluation or these are not freely available for direct download. An overview is given in CEM (2016). The report also presents wind resource maps, based on data provided by AWS Truepower (see Figure 12).

The conclusion is that Malawi is also well-endowed with solar and wind energy resources. Malawi has great solar potential with an average of 3,000 sunshine hours per year and solar irradiation potential is estimated at around 5.8 kWh/m^2/day, which is adequate for photovoltaic applications, and wind speeds averaging 2–7 m/s for electricity generation[13]. IPPs have applied for power purchase agreements for their large-scale, on-grid, solar PV project. An 850 kW solar demonstration plant was installed at the Kamuzu International airport in Lilongwe.

Box 1 The role of renewable energy in Malawi's energy planning

A recent study on grid capacity indicates that renewables development of solar and wind of 15 to 17 MW (dependent on location) could be accommodated across the network up to a maximum total capacity of 70MW (MottMcDonald, *Grid Capacity Study,* 2016).



Installed capacity in 2030 as in National Energy Policy (NEP) and SE4All targets

The draft Updated National Energy Policy paper (2016) include projections for a major expansion of large-scale hydro. There is indeed a great potential for such expansion. However, given the low water levels at the existing Shire River and the uncertain impact of climate change on future water flows, a diversification of generation resources is a more prudent path. There is also good potential for development of coal, solar and wind power resources. The draft SE4All Action Agenda (Ecoloner/Deloitte, 2016) foresee that most of the 2,620 MW of generation capacity is provided by renewable energy by 2030.

These expansion figures seem to assume that a grid can accommodate only 6% of its total capacity from intermittent sources like solar and wind. The draft SE4Action Agenda (Ecoloner/Deloitte, 2016) mentions that such a rule of thumb needs revision. Depending on grid characteristics, this can be up to 30% as evidenced in countries like Denmark, 24% wind, or Germany, 30% from renewables. Also, in Malawi the share of intermittent sources of power (variable solar and wind) could be much higher depending on the quality of the grid system (aided by interconnection with the SAPP and the use of new smart grid technology; as well as demand-side management). The solar target could even be higher if including on-site distributed energy (grid-connected), such as roof-top PV installations on buildings.

Source : draft SE4Action Agenda (Ecoloner/Deloitte, 2016)

[13] Kaunda (2013) and HIVOS *Malawi Energy Profile*

5. Hybrid systems

Solar or wind energy rarely appears as a single-source of energy for mini-grids given their intermittences and unpredictable fluctuations. Battery storage can solve availability problems of renewable sources but their economic and environmental impacts become the main barrier to solar/wind mini-grid applications.

The benefits and advantages of each technology complement each other. Since renewables operate "fuel free," they are not subject to fuel price or supply volatility. However, renewable systems are non-dispatchable, which means that they depend on the availability of the resource at a specified time. Diesel gensets, in contrast, are dispatchable and can deliver electricity when scheduled. By combining these two sources, a variety of shifting load profiles can be covered.

Hybrid power systems typically rely on renewable energy to generate 75-99% of total supply. The large share of renewables makes these systems almost independent and lowers the energy prices over the long term, and the diesel genset is used as a backup to assist in periods of high loads or low renewable power availability. The battery backup size can be lower and suffers less stress than in a 100% renewable power system, prolonging battery lifespan significantly and reducing replacement costs. Hybrid systems often are the least-cost long-term energy solution, capable of delivering the best services of the three alternatives.

Solar-diesel or wind-diesel hybrid systems try to find an optimal solution of combining solar and/or wind with a genset and a battery system to meet the load demand. For example, the following four configurations PV-diesel-batteries are possible:

- **PV with battery**

Traditionally, solar power plants for mini-grids were designed at high costs with oversized PV modules and oversized batteries and these solutions were often more expensive than traditional diesel-generator supply and mainly attractive for infrastructure facilities (hospitals, schools) as stand-alone systems), and not as a power source for mini-grids. The high upfront cost was perceived as a barrier against diesel-based gensets.

- **PV – Diesel hybrid with battery**

Today a backup diesel genset is common to avoid the over-sizing of the battery and provide a more flexible service to customers without excessive additional cost, but the system is more complex to design, to install and to operate than the above systems. The optimised design should minimise the size of the battery (to compensate day-time fluctuations of PV output) and the fuel consumption (evening operation). The challenge is to maximize the share of renewable generation to the total energy mix (also called 'penetration rate') to reduce the burden of the fuel price. Hybrid solutions with batteries can still be an expensive solution when considering the replacements over the lifecycle.

- **PV – Diesel hybrid without battery**

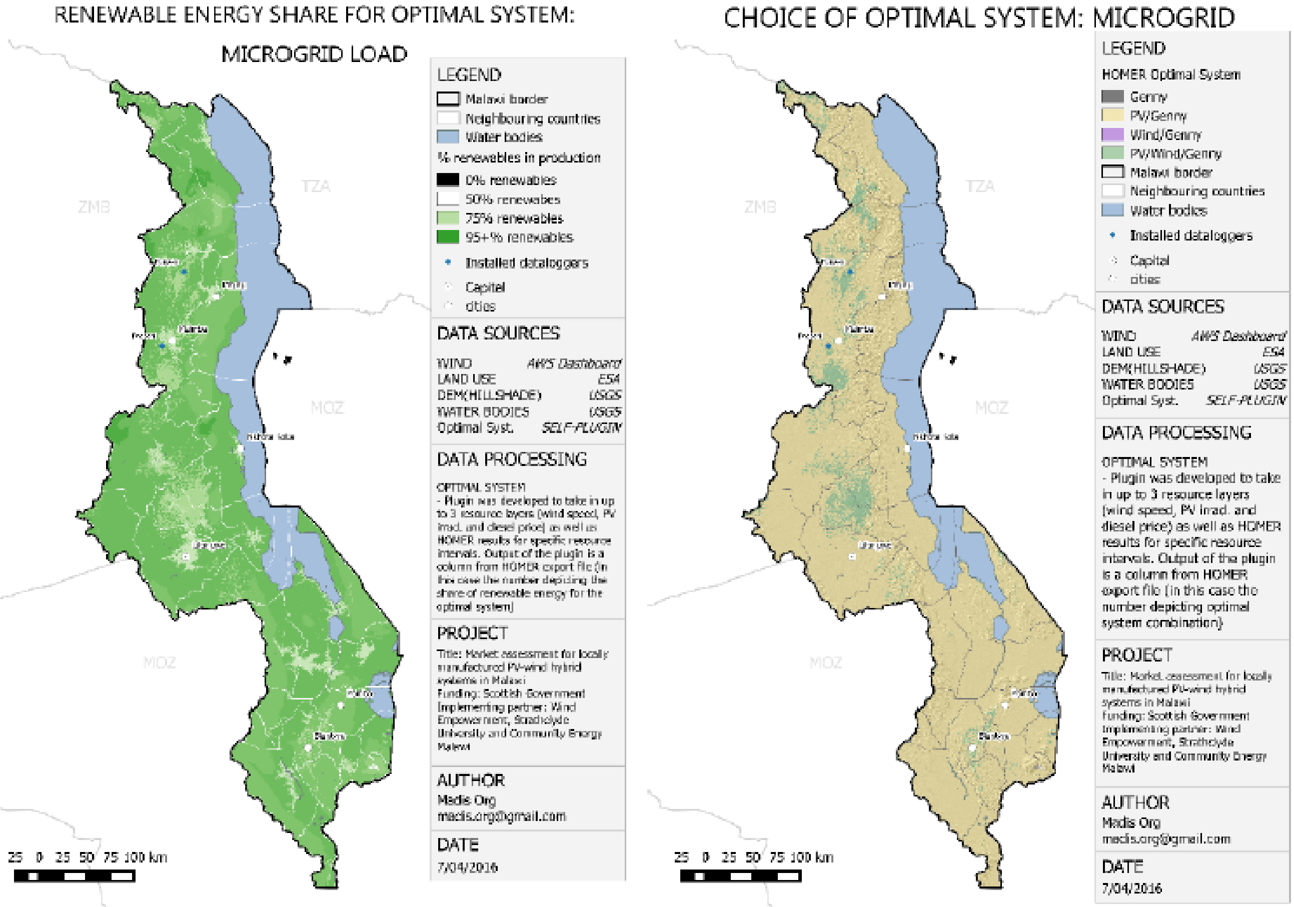
In these systems, the PV share in this type of hybrid is limited to about 30% of the load peak power during daytime to avoid affecting genset operation. Consequently, fuel savings and benefits are limited.

Similar configurations can be analysed with **wind with/without battery and wind with/without diesel genset.** The unpredictability of the wind reinforces the need for storage and increases the system cost. The wind-diesel hybrid systems are apparently more technically demanding. Another configuration for mini-grids is **solar-wind-battery,** which can be designed in some specific case when solar radiation is well complementary with wind speeds. Another configuration is with a genset (**solar-wind-diesel**). Larger fuel savings should balance the higher investment cost, but the design and the operation become more complex by increasing the number of sources. Optimised hybrid design attempts to reduce as far as possible the use of batteries or fuel consumption, for which various software design tools are available (see Information Sheet No.4).

To date, Malawi has had some experience with mini-grids in various models and approaches using different technologies i.e. hydro, solar and wind. Mini-grids present a significant opportunity to both enhance energy access and promote private sector participation in energy delivery. However, there has been no clear evidence that mini-grid systems have been sustainable. For example, the Government (Department of Energy Affairs) installed six wind/solar mini-grids but due to design issues, and the resulting lack of maintenance, all but one of the systems have ceased operating. This is discussed further in one of the Case Studies "*Powering mini-grids by solar-wind-diesel hybrid systems",* which also describes the option of having a solar PV-diesel hybrid system in Likoma Island in Lake Malawi as a least-cost power supply option. Making a clear case regarding the sustainability of mini-grids in Malawi is a focus of the GEF-UNDP-Government Project *Increasing Access to Clean and Affordable Decentralised Energy Services in Selected Vulnerable Areas of Malawi* that, among other issues, will look at issues related to barriers for scaling up mini-grids.

The study *Market Assessment for Locally Manufactured PV-Wind Hybrid Systems in Malawi, Community Energy Malawi (*2016) presents an analysis of optimal mini-grid load configurations for mini-grids.

Figure 13 Maps for renewable energy fraction in micro-grid hybrid systems



Source: CEM (2016).
Notes: The optimal system type has wind within the mix, even with lower PV module prices. The 'hill' where the optimal system type is PV/generator, rather than Wind/PV/Generator, is due to the high incremental cost of adding a wind turbine. Adding more PV makes sense up to a point, as it is more modular so smaller quantities can be added. At a certain point, then adding another wind turbine becomes most sensible within certain locations.

6. Micro-grids, solar kiosks, and battery charging

There are new technologies appearing that attempt to bridge a gap between mini-grids that serve the households in a village with a central source of power and individual solutions, such as pico-hydro, pico-solar and solar home systems. Challenges faced by mini-grids are high initial capital cost, inflexible installed capacity and high risks associated for the investor or developer, while individual solar PV solutions can serve only basic power needs, excess energy generation is dumped and productive uses are limited.

A **solar kiosk** can be defined as a self-functioning system that not only produces its own energy but also additional energy to charge other product. The charged products are then rented out or sold to the customers. Solar kiosks offer a variety of services ranging from simple charging stations (for lamps, lanterns and mobile phones) to other services such as cooling of drinks, running the television, internet services, selling retail products and in many cases offering a haircut using an electronic razor. It can be both mobile and stationary depending on the kiosk operator's capacity and the customer's demand. It usually consists of PV panels that power the kiosk and may include additional batteries for storage as well as the the round-the-clock functioning of the kiosk. In some instances, the PV panels may be complemented with diesel generators for backup. If operated on a commercial basis, one issue is that solar kiosks have a high upfront cost (apart from expenses such as the cost of the land, construction cost, and products cost) and also high recurring cost (such as replacing the battery every 2-3 years), while often the revenues can be quite low.

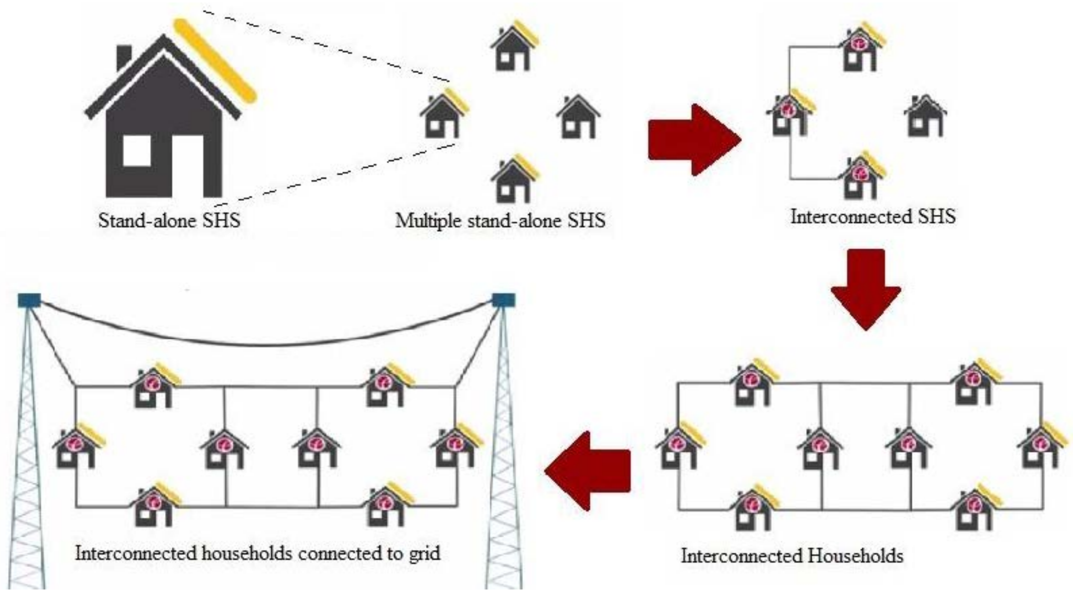
In Malawi, the SOGERV project is experimenting with the solar kiosk concept. This is described in the Case Study *Solar photovoltaic (PV) mini-grid solutions,* which discusses [14] the experience with solar kiosks in Chikwawa and Nsanje Districts.

Battery charging stations can be a viable option to provide electricity in unelectrified areas and where incomes are insufficient to pay for solutions like solar home systems (SHS) and mini-grid solutions are not available. In comparison with pico-solutions (pico-PV, pico-hydro; see Information Sheet No. 2). Charged (car) batteries, in fact, can provide services comparable to the upper end of the pico-PV range at lower investment costs, though running costs eventually are higher. A little electricity, like from car batteries, can considerably improve living conditions of its users, such as lighting and phone-charging, radio and TV, while to a small extent, electricity from charged (car) batteries can also contribute to raising incomes of small businesses and handicraft

Often some villagers already have rechargeable batteries to provide light and some other services which they, however, have to carry a long way - e.g. to the next town and back - in order to get them recharged. Battery charging stations, installed at central points, in rural areas have the potential to considerably reduce time and expenses for recharging such batteries. Battery charging stations can either be fed from electricity generated by renewable energy technologies (RETs) such as solar battery charging stations, hydro battery charging station, wind or diesel generators. In some cases, the stations can be fed directly from (the end of) the (mini-)grid to provide electricity to customers in the area that are unable (or unwilling) to be connected to the grid.

In **swarm electrification** the individual households (that have a solar PV or generator and battery storage capacity are connected to make a swarm grid, enabling by smart grid technology. The swarm grid could be connected to another swarm grid in a neighbouring village and the swarm grid could be connected to a (mini-)grid. The concept is being pioneered in countries such as Bangladesh, Tanzania, and Philippines (see MES, 2013, see figure below, or Hollberg, KTH)[15]. A swarm system can grow with the customers' electricity demand. A household can start with an SHS, then be part of swarm grid that when an appropriate demand level has been reached, can get connected to a larger configuration (see Figure 14).

Figure 14 Swarm electrification



Source: Forschungsschwerpunkt Mikroenergie-Systeme (MES), Technische Universität Berlin (2013)

[14] Sustainable Energy for Rural Communities (SE4RC) is a European Union Sponsored project being implemented in Zimbabwe and Malawi by a consortium of organisations, viz: Hivos, Environment Africa, Dabani Trust, Practical Action and Churches in Action Relief and Development (CARD). The feasibility study conducted in 2014 defined the plans to construct 6 Energy kiosks and 4 solar mini grids in Nsanje and Chikwawa. The primary consumers of the power from the four solar PV mini-grids (at Nyamvuu, Chimombo, Mwalija and Oleole) will be the productive end-users irrigation schemes), social services (schools and health clinics). In the two Districts will be 6 solar kiosks (at Oleole, Mwalija, Mmelo, Ngeluwe, Nyamvuu and Nyanthana). See Practical Action-HIVOS (2017)

[15] More information on micro-energy.com or energypedia.info

6. Bibliography

Renewable energies

African Development Bank	2017	GMG Market Assessment Methodology; Part 1 Evaluation of Methodologies and Best Practices Available to assess GMG Potential
Alliance for Rural Electrification	2009	Green light for renewable energy in developing countries
International Renewable Energy Agency (IRENA)	2012, 2014 2012 2013 2013 2015 2015 2016 2016	Renewable Power Generation Costs Prospects for the African Power Sector Biomass Potential in Africa Southern African Power Pool: Planning and Prospects for Renewable Energy Africa Power Sector: Planning and Prospects for Renewable Energy Off-Grid Renewable Energy Systems: Status and Methodological issues International Off-grid Renewable Energy Conference and Exhibition (IOREC), 2016 Renewable Energy Statistics
EU-Joint Research Centre (JRC)	2011 2013 --	Renewable Energies in Africa: Current knowledge The availability of renewable energies in a changing Africa Online interactive map (http://re.jrc.ec.europa.eu/re2naf.html)
Intergovernmental Panel on Climate Change (IPCC)	2011	Renewable Energy Sources and Climate Change Mitigation
REN21	2015 2016, 2017	SADC Renewable Energy and Energy Efficiency Status Report Renewables Global Status Report
Van den Akker, J.H.A. (ASCENDIS)	2017	Overview of costs of sustainable energy technologies. Energy production: on-grid, mini-grid and off-grid power generation and supply and heat applications
World Energy Council	2013	World Energy Perspective: Cost of Energy Technologies
World Bank (ESMAP)	2009 2016 2007	Study of Equipment Prices in the Power Sector Assessing and Mapping Renewable Energy Resources Technical and Economic Assessment of Off-grid, Mini-grid and Grid Electrification Technologies (Summary, Main Report, Annexes)

Hydropower and biomass

Alliance for Rural Electrification	2014	The Potential of Small Hydro for Rural Electrification, Latin America
International Hydropower Association (IHA)	2016	Hydropower Status Report
IRENA	2012	Renewable Energy Technologies; Cost Analysis Series, Vol.1 Power Sector, Issue 3/5: Hydropower
IRENA – International Energy Agency (IAE)-ETSAP)	2015	Hydropower, Technology brief
OpenEI		Bioenergy assessment toolkit https://openei.org/wiki/Bioenergy_Assessment_Toolkit#tab=Introduction_E2_86_92
Practical Action	1999 2013 2015	Environmental impact Assessment of Micro-Hydro Sites Low-cost civil Works for Micro-Hydro Schemes Operation & Maintenance of Community Based Micro-Hydro Village Electrification Schemes

Water for Agriculture and Energy in Africa (2008 (Ministerial Conference)	2008	Hydropower Resource Assessment of Africa
World Bank – ESMAP	2000 2002 2005 2011 2015	Best Practices for Sustainable Development of Micro Hydro Power in Developing Countries Tanzania – Mini Hydropower Development Case Studies Stimulating the Pico-Hydropower Market for Low-Income Households in Ecuador Peru Opportunities and Challenges of Small Hydropower Development Mini and Micro Hydropower Applications. Nepal: Scaling Up Electricity Access

Solar and wind energy

Alliance for Rural Electrification	2012	The Potential of Small and Medium Wind Energy in Developing Countries: A Guide for Energy Sector Decision-makers
Clean Energy Solutions Center	2015	Solar Power, Policy Overview and Good Practices
GIZ – A.T.Kearney	2014	Investment and Finance Study for Off-Grid Lighting
International Energy Agency	2013 2014	Technology Roadmap, Wind Energy Technology Roadmap, Solar Photovoltaic Energy
IRENA	2012 2014 2015 2016	IRENA 2012 Renewable Energy Technologies; Cost Analysis Series, Vol.1 Power Sector, Issue 4/5: Solar Photovoltaics, Issue 5/5 Wind Power Global Atlas for Renewable Energy: Overview of Solar and Wind Maps Quality Infrastructure for Renewable Energy Technologies, Small Wind Turbines Solar PV in Africa: Costs and Markets
IRENA – International Energy Agency (IAE)-ETSAP)	2013 2016	Solar photovoltaics, Technology Brief Wind Energy, Technology Brief
Lighting Global	2015	Procurement of Off-grid Lighting Products – Guidance for Aid Organizations and Governments
Practical Action	- 2008 2008 2011 2016	Rural Lighting (Technical brief) Energy from the Wind Wind for Electricity Generation Solar Photovoltaic Energy (Technical brief) Accelerating Access to Electricity in Africa with Off-grid Solar
UN Development Programme	2004 2008	Solar Photovoltaics in Africa: Experiences with Financing and Delivery Models Promotion of Wind Energy: Lessons Learned for International Experience and UNDP-GEF Projects
World Bank – Bloomberg	2016	Off-Grid Solar Market Trends 2016
World Wind Energy Association	2014	World Wind Resource Assessment Report

Hybrid systems, microgrids, swarms

Developing Energy Enterprises Project East Africa (DEEP EA)		Technology Factsheet, Solar Charging PV stations
ENDEVA		The Energy Kiosk Model, Current Challenges and Future Strategies
GIZ	2013	Hybrid (Solar PV-Diesel) Mini Grids in Philippines

International Energy Agency (IEA)	2015	A user guide to simple monitoring and sustainable operation of PV-diesel hybrid systems
KTH (Hollberg, P.)	2016	Swarm Grids – Innovation in Rural Electrification
MES (Forschungs-schwerpunkt Mikroenergie Systeme – TU Berlin	2013	The Swarm Electrification Concept
National Renewable Energy Laboratory	1998 1999 2001	Modeling, Testing and Economic Analysis of a Wind-Electric Battery Charging Station Renewable Energy for Sustainable Rural Village Power Field Performance of Hybrid Power Systems
Practical Action	2011	Small wind energy systems for battery charging
SNV – Practical Axction	2017	SE4RC Business Models for Energy Delivery
UN Environment – Frankfurt School Collaborating Centre	2015	Renewable Energy Hybrid Mini-Grids and Isolated Grids: Economic Benefits and Business Cases
World Bank – ESMAP	2001 2007	The Kenya Portable Battery Pack Experience Solar-diesel Hybrid Options for the Peruvian Amazon

Malawi

African Development Fund	2013	Kholombidzo Hydro Electric Power Plant Feasibility Study Malawi
Business Innovation Facility (BIF)	2014 2014 2016	A Survey of the Pico Solar Product Grey Market in Malawi Facilitating Systemic Change in the Malawi Pico Solar Products Market Off-grid Lighting and Phone Charging Survey
Community Energy Scotland-MuREA	2014	Community Renewable Energy Toolkit for Malawi
Gamula, G., et.al.	2013	An Overview of the Energy Sector in Malawi, in: Energy and Power Engineering, 2013, 5, 8-17
Hurford, A., et.al.	2014	Malawi Case Study: Harnessing Hydropower (Department for International Development)
JICA (Japan) and Ministry of Agriculture, Irrigation and Water Development	2014	Project for National Water Resources Master Plan, Final Report, Vol.II: Main Report
Kaunda, C.S.	2013	Energy situation, potential and application status of small-scale hydropower system sin Malawi, in: Renewable and Sustainable Resources Review 26 (2013) 1-19
Ministry of Irrigation and Water Development	2007	Integrated Water Resources Management Plan / Water Efficiency Plan
HIVOS-Practical Action-CARD (SE4RC)	2017	Business Models for Sustainable Energy of Rural Communities Project in Chikwawa and Nsanje Districts, Malawi
REEEP	2012	Energy Profile Malawi
Salima, G. and Chavula, G.	2012	Determining Angstrom Constants for Estimating Solar Radiation in Malawi, in: International Journal of Geosciences, 2012, 3, 391-397
University of Glasgow, P.G. Kumbala	2010	Sustainability of water resources development for Malawi with particular emphasis on North and Central Malawi. PhD thesis.
UNIDO-ICSHP	2013	World Small Hydropower Development report, Malawi
World Bank (ESMAP)	2015	Solar Resource Mapping in Malawi - Solar Modelling report - Model Validation Report

The Toolkit Information Sheets were drafted by Jan van den Akker with support from Diliza Nyasulu as part of the UNDP project, “Increasing Access to Clean and Affordable Decentralised Energy Services in Selected Vulnerable Areas of Malawi” with co-financing support from the Global Environment Facility (GEF) and in coordination with Malawi’s Department of Energy Affairs