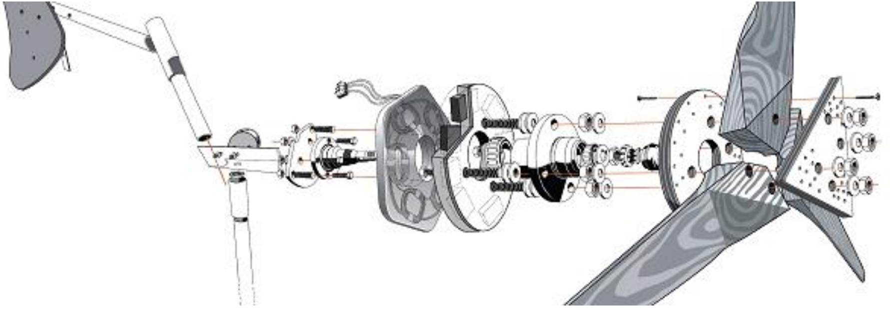

Market Assessment for Locally Manufactured PV-Wind Hybrid Systems in Malawi

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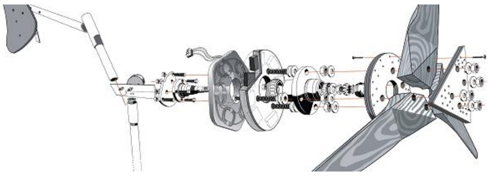
This is an open access study, which means that all of the data is available from WindEmpowerment.org. Additional information or clarifications can be obtained from info@WindEmpowerment.org.



Executive Summary

Malawi is one of the poorest countries in the world, with an economy highly dependent on agriculture. About 83% of Malawi's 16.8 million people are located in rural areas, with approximately 75% of the population living a subsistence farming lifestyle (Trading Economics 2016). Access to the national electricity grid in Malawi is currently just 9.8% and in rural areas, this falls to just 2% (SE4All 2016).

This study evaluates the viability of using locally manufactured PV-wind hybrid systems to offer access to electricity to remote communities in off-grid regions of Malawi. Whilst solar PV panels must be imported, 1kW scale Small Wind Turbines (SWTs) can, and already have been manufactured in Malawi. Although it is not possible to manufacture an entire PV-wind hybrid system in Malawi[1], the ability to construct SWTs locally offers the potential to shift a greater portion of the value chain back into the country. This can create local jobs, feed money back into the local economy and build local capacity for installation, operation and maintenance:

> *"If we can transfer the skills to local technicians and produce everything within the country, then all other things being constant, this is a very powerful economic argument." - Conwell Chisale, Government of Malawi, Department of Energy Affairs, 28th January 2016*

What is more, where the wind and solar resources are complementary, the diversity in power generation sources can offer a much more consistent supply of electricity, significantly increasing the availability of energy to the end-user and/or decrease the size of the required battery bank.

In partnership, Community Energy Malawi (CEM), Wind Empowerment and the University of Strathclyde were commissioned by the Scottish Government to carry out a multidisciplinary analysis designed to evaluate the potential for this technology in Malawi. The methodology for the study involved 3 key stages:

1. ***Learning from existing initiatives***: using a combination of field visits, data logging, interviews with key stakeholders from each project and project report reviews, the locally manufactured SWT, PV-wind hybrid and PV projects that have already been carried out in Malawi were evaluated in order to draw out the key lessons learned. Kamilaza (represented by the Fwasani CBO) in the Mzimba region was selected as a prospective case study of a typical Malawian community in a region predicted to have good wind and solar resources.
2. ***Quantifying the potential market***: a techno-economic spatial analysis was conducted in order to test the scalability of PV-wind hybrid systems across Malawi. An energy systems model designed to meet four different categories of load (mini-grid, maize milling, workshop and egg-incubation) was constructed based on the data obtained with the Fwasani CBO in Kamilaza. A range of sensitivities (diesel price, solar/wind resources, PV panel cost) were used to determine the optimal system architecture (PV-generator, generator, PV-wind-generator or wind-generator) in different locations within Malawi. The results of this modelling were fed into a spatial analysis, which produced a series of maps, indicating which systems are most viable across the country. Within each of these regions that group together locations with common optimal system architecture, the population living without access to grid electricity was used to estimate the size of the market for that particular system architecture.
3. ***Mapping the energy access ecosystem:*** a series of expert interviews was conducted with key Malawian energy access stakeholders[2]. These were designed to identify the key barriers and drivers for PV-wind hybrid systems in Malawi by exploring issues such as local capacity, awareness of renewable energy systems, national policy and logistics.

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[1] Batteries, power electronics and PV panels must still be imported.

[2] Many of whom were also involved in the projects evaluated during the first phase and as a result, the two sets of interviews were conducted as one.

The three stages were carried out in parallel, with the preliminary results from each stage informing the overall direction of the research and guiding data collection, processing and analysis in the other stages.

The **key findings of this research** are that whilst many of the barriers facing the technology could be overcome, the **fundamental lack of wind resources** in most of the country creates an insurmountable barrier. Whilst the potential for job creation, local capacity building and strengthening of the local economy are certainly strong drivers for small wind, the evidence from this study shows that the **wind resource in Malawi is much more variable**, and the **maintenance requirements for SWTs are much higher** than for PV.

Few SWTs have been installed in Malawi to date and the majority of these have been through now discontinued pilot projects. Students for Malawi (SfM) have built 5 SWTs in the South and although they plan to build 3 more, will not continue with further implementation of the technology due to the limited wind resources in the region where they are working. Whilst the capacity building and ownership elements of the projects have seen positive results, to date they have relied exclusively on donor funds and as much of the equipment was imported from the UK, it is unlikely that these systems could ever be financially sustainable. The 6 PV-wind hybrid mini-grids installed by the Government of Malawi (GoM) in 2007/8 under the Solar Villages programme are now scheduled for decommissioning. Whilst the projects functioned successfully in the beginning (IOD PARC 2012), poor quality equipment, a lack of wind resource[3], weak system design, inadequate financial planning, a lack of operator training and a number of other issues have all contributed to the demise of these systems. As a result, there is no track record of successful SWT projects in Malawi.

THE TECHNO-ECONOMIC SPATIAL MODELLING RESULTS SHOW THAT ONLY THE MICRO-GRID LOAD SHOWS ANY POTENTIAL FOR PV-WIND HYBRID SYSTEMS.

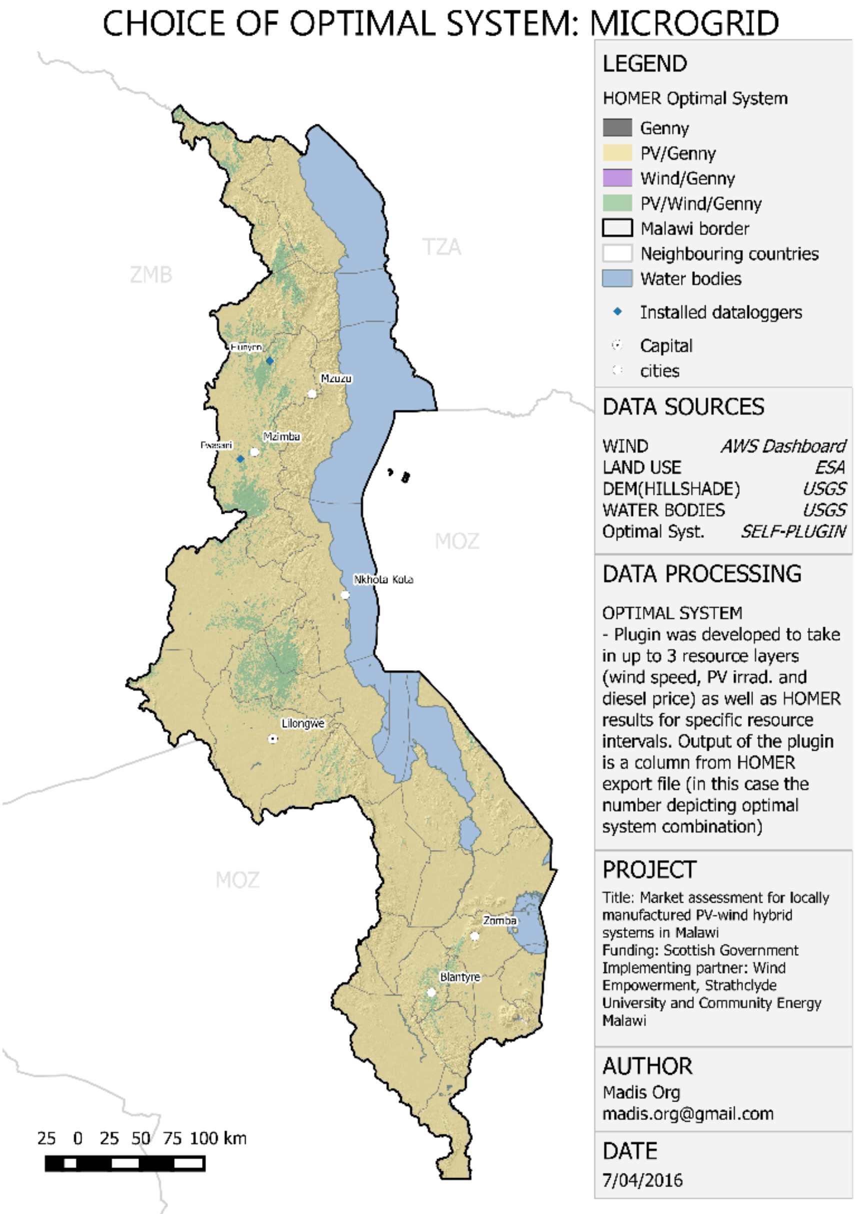
Figure 1 clearly illustrates that whilst the PV-generator system architecture is scalable across the whole country, the PV-wind-generator system architecture is only predicted to be optimal in a few isolated pockets. Even within these pockets, it is a marginal result, indicated by the speckled green patches rather than larger areas of solid colour. This also means that small wind would introduce significant additional risk into off-grid electrification projects, as even if a costly and time consuming full wind resource assessment is properly carried out, then there is no guarantee that the on-site measurements will find sufficient wind resources to justify the installation of a PV-wind hybrid system. This is exemplified by the findings from the dataloggers installed during this research, which despite being located in supposedly high wind regions, found average wind speeds of less than 2m/s at 10m height[4].

> *"Malawi is much better endowed with solar than wind resources, which means that the role for SWTs is much smaller. In almost all areas, solar out competes wind." Conwell Chisale, Government of Malawi, Department of Energy Affairs, 28th January 2016*

[3] On site measurements were not carried out before installation

[4] It should be noted that this is based upon just 2 months of data recorded in the low wind season, however in both locations, this was about half the expected long-term average wind speed for these specific months.

FIGURE 1: OPTIMAL SYSTEM ARCHITECTURE MAP FOR THE MICRO-GRID LOAD CASE.



Of course, such limited data is not by any means representative of the entire country, however, even if the results of any future resource assessment proves the existence of sufficient wind resources to install an SWT, then significant after-sales support with be required to ensure that the specialist tools, spare parts and technical knowledge needed to cater for the additional maintenance requirements of SWTs are all available locally. This will require further capacity building and the development of a service network beyond that which already exists for PV products. The development of this additional social infrastructure can only be justified if there is a significant local market, however the scattered nature of the wind resource in Malawi means that these potential customers are spread all over the country. What is more, even if such a service network did exist, communities themselves who are already struggling to save for the maintenance requirements of PV systems would have to raise even greater amounts in order to maintain an SWT.

However, what this study has highlighted is that solar PV has an extremely high potential for meeting the energy needs of rural Malawians.

Table 1 shows that in three of the four load cases, PV-generator systems are identified as the optimal system architecture. Even for the demanding maize milling load, PV-generator systems offer significant advantages in remote areas, where the cost of hauling diesel makes it prohibitively expensive. What is more, the falling price of PV means that it is likely to soon be viable in all regions of Malawi, especially if diesel prices also increase. These four load profiles offer the potential for the establishment of rural energy based enterprises, however further work is required to match the profitability of each activity with the costs of the energy system in order to determine whether they are viable business opportunities.

Table 1: Estimated market size in off-grid regions as a percentage of the total population of Malawi for each load profile category and each system architecture.

	MINI-GRID	WORKSHOP	MAIZE MILLING	EGG INCUBATION
GENERATOR	0%	0%	71%	0%
PV/GENERATOR	79%	86%	15%	86%
WIND/GENERATOR	0%	0%	0%	0%
PV/WIND/GENERATOR	7%	0%	0%	0%
GRID-PROXIMITY	14%	14%	14%	14%

Despite the vast potential, PV systems have had limited success to date in Malawi. Low ability to pay, market distortion by NGO handouts, lack of ownership, little existing technical capacity and maintenance issues relating to battery storage were found to be the principal barriers holding back further market expansion. Pay-as-you-go business models, community energy committees and Energy Kiosks in remote communities are promising potential solutions to some of these issues, however no truly sustainable model has yet been proven.

In Malawi, the wind and solar resources show limited complementarity. The strongest is the diurnal trend, as the solar resource consistently peaks in the middle of the day, whilst the wind resource is regularly highest in the morning and evening. On a daily basis, there is a randomised complementarity, i.e. windy days are sometimes cloudy days and vice-versa, however on a seasonal basis, the wind and solar resources both peak in the dry season. This means that systems must either be oversized for the rest of the year, rely heavily on diesel backup in the rainy season or be designed with specific applications (e.g. water pumping for irrigation) to make use of the additional power in the dry season.

Predictions for global price trends show that PV is set to continue decreasing in cost significantly in coming years, meaning that the benefit of diversity in power generation sources offered by creating a PV-wind hybrid system could be offset by simply specifying a larger PV array. The simplicity and modularity of PV make it an ideal choice for remote off-grid applications, where capacity for maintenance is low, households are dispersed and energy demand is low.

Although many of the components of a small wind system can be sourced locally, as Malawian industrial capacity is relatively limited, most are likely to have originated from an overseas supplier. Some components (such as the permanent magnets for the generator) are even likely to require the creation of new international supply chains. The local manufacture of SWTs has the potential to increase ownership and create more jobs than for equivalent PV only systems, however the distribution, marketing, installation, operation and maintenance of solar PV systems still offers significant potential. Given the limitations on the scalability of PV-wind hybrid systems and the additional risks that the resource assessment and maintenance challenges present, the potential benefits offered by including 1kW scale LMSWTs as a PV-wind hybrid system are far outweighed. However, PV is a scalable, adaptable and reliable technology that is appropriate for meeting the needs of off-grid communities throughout Malawi, especially in more remote areas where the cost of diesel fuel is highest.

Finally, although this study has ruled out further development of 1kW scale locally manufactured SWTs in Malawi, it should be noted that there may be potential for importing larger wind turbines (>10kW). Although it is not yet possible to manufacture machines of this scale in Malawi, wind turbine power production scales with the square of the rotor diameter, whilst costs increase linearly. This greatly reduces the cost of energy for larger machines, creating a significant economic driver. What is more, the larger the machine, the further away from the demand point it can be located (at the 1kW scale, it is not economically viable to transmit the power more than a few hundred metres). This means that larger scale wind turbines can be located on better wind sites, such as hilltops, and on higher towers (which also increases the wind resource). What is more, the hydro and wind resources show strong seasonal complementarity, meaning that both off-grid and grid-connected wind power may still have a role to play in Malawi.

As a result, the **key recommendations** coming out of this study are:

- Apply CEM's newly acquired expertise in impact evaluation to ensure that proper evaluative studies are conducted on all previous energy access projects, so that the key learning points can be carried forward. The results should be disseminated as widely as possible.
- Leverage CEM's technical experience and community links to develop 1kW scale PV systems.
    - Conduct further HOMER modelling of PV-generator systems for specific projects.
    - Work with local CBOs (Community Based Organisations) to develop business plans for energy based enterprises to ensure they are financially sustainable.
    - Ensure that appropriate financing options are available by partnering with pay-as-you-go service providers or local micro-finance institutions.
    - Focus technical and financial training for communities on battery storage, which has been shown to be the weak point of systems installed to date.
    - Ensure these projects are linked into broader development initiatives.
- Investigate the potential for importing larger wind turbines (>10kW), which may make economic sense for mini-grids in Dowa and Mzimba.
    - Invest in improvement of national wind mapping for larger scale wind power development.
    - Conduct further HOMER modelling of larger scale PV-wind and wind-hydro hybrid mini-grids to determine their economic viability.
    - Ensure that the data logging equipment and expertise of CEM is used to carry out a full wind resource assessment for any future potential wind energy installations, with specific focus on the complementarity of the solar and wind resources.
- Investigate the potential for direct mechanical water pumping with wind energy, as the required wind speeds are lower, the energy demand is well matched with the availability of the wind resource (dry season) and there is no need for battery storage.

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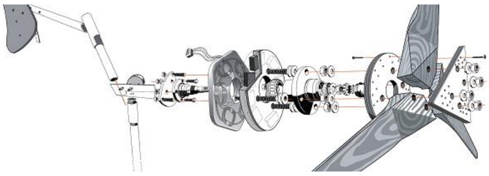

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1 Introduction

1.1 Background and scope of study

In partnership, Wind Empowerment (WE) and Community Energy Malawi (CEM) have been contracted by the Scottish Government and the University of Strathclyde to conduct a market assessment for locally manufactured PV-wind hybrid systems in Malawi. From 20-22nd January 2016, WE delivered a training course for CEM staff and interns, offering an overview of small wind power implementation in developing country contexts, how to install wind resource assessment equipment, and how to conduct a market assessment. From 25-29th January, field visits were conducted and data loggers were installed by representatives of both organisations in order to evaluate previous projects and identify potentially viable sites for the installation of wind/solar systems. In the following months, CEM staff continued with field data collection and WE/CEM collaboratively developed this market assessment, which is designed to determine whether small wind/solar systems are an appropriate technology for Malawi and whether implementing the technology is a viable business opportunity for CEM.

Whilst solar PV technologies undoubtedly have a very high potential for poverty alleviation, the focus of this study is on the potential contribution that wind power could make to these systems. At the utility scale, a wind resource and preliminary market assessment has been undertaken by SgurrEnergy under the WEPP programme. As a result, this study focusses on small scale technologies for off-grid or mini-grid applications, which are also the focus of Community Energy Malawi's bottom up approach to energy access. Preliminary results have shown that the wind resource and solar resources do not show a high level of seasonal complementarity and therefore at the small scale, the key driver for using wind power would be the potential for local manufacture. As a result, this study focusses on systems below 1kW rated power, as larger machines generally require more complex manufacturing processes, therefore limiting the potential for manufacture in Malawi. Hydro power systems are not specifically addressed in this study, as the availability of the resource is extremely site specific. It is assumed that any location that has a suitable watercourse would choose to install a micro-hydro system instead of a PV-wind hybrid system, as it will almost certainly be more cost effective (ESMAP 2007).

The key research questions for this study are:

- How appropriate are locally manufactured wind/solar systems for poverty alleviation in Malawi? If so:
  - How and where should they be employed to ensure maximum impact?
    - What income generating activities could they create or enhance?
  - What should be done to support this transition?
  - Would implementing these systems be a viable business opportunity for CEM?

1.2 Energy access in Malawi

Malawi is a landlocked country in Southern Africa and faces multiple challenges such as low levels of access to electricity and high levels of poverty. Currently, only 9.8% of the population is connected to the national grid (1% in rural areas) and over 90% of the population uses biomass for household energy needs (SE4All 2016; Government of Malawi 2015). Figure 1 shows that access to electricity is closely correlated with quality of life and is one of the essential ingredients for poverty reduction. A series of studies conducted under the Malawi Renewable Energy Acceleration Programme (MREAP) by Community Energy Scotland (CES), Malawi Polytechnic, University of Strathclyde (UoS) and IOD PARC[5], as well as the experiences of the Community Energy Development Programme in the implementation of solar PV and solar lantern projects, has shown that the market for off grid RETs in Malawi is significant (University of Strathclyde 2016).

[5] Trading name for International Organisation Development Ltd.

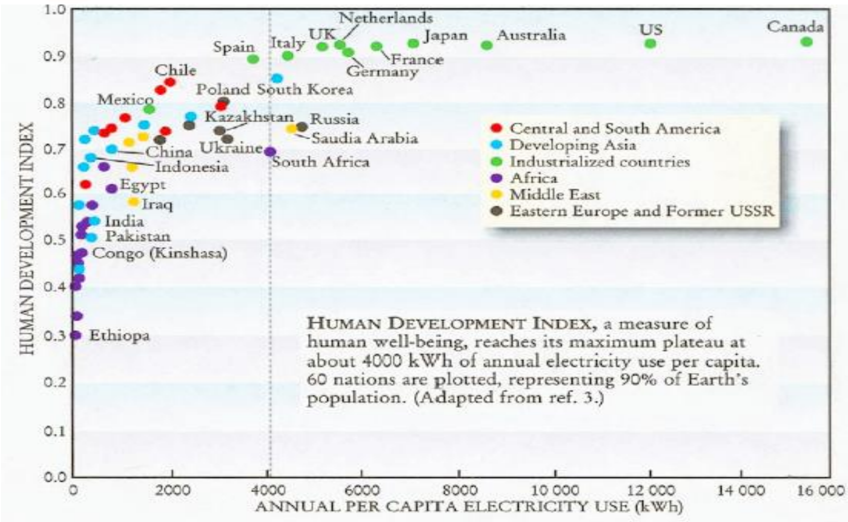


FIGURE 1: THE RELATIONSHIP BETWEEN QUALITY OF LIFE AND ELECTRICITY CONSUMPTION (Energy and Society 2012).

Malawi is one of the poorest countries in the world, ranked 171/181 with gross domestic product (GDP) based on purchasing-power-parity (PPP) per capita GDP (Gross Domestic Product) of about USD 272 in 2010 (Trading Economics 2016). The country has an agro-based economy, which has been growing steadily and has recently seen an increasing contribution from mining sector. Lake Malawi covers much of the East of the country and altitude ranges from just above sea level in the extreme South to over 3,000m in the Mulanje Massif. The population of Malawi is currently about 16.8 million and recently, it has been increasing at a rate of about 2.8% per annum (Trading Economics 2016). About 83% of the population lives in rural areas and about 75% of the population carries out farming as smallholders on fragmented customary land (Government of Malawi 2010). According to the World Bank Sustainable Energy for All (SE4ALL) database (2016), access to the national electricity grid in Malawi is currently just 9.8 %. While electrification has reached 37% of the urban households, rural electrification lies at only 2%.

The draft Energy Policy (Government of Malawi 2015) states that current installed national generating capacity is 350 MW, which is predominantly hydro (>95%), all of which is located on the Shire river. There are plans to significantly expand this in coming years, with a target of 1500 MW by 2020. There is a current supressed demand of 450 MW, which has a significant detrimental effect on national industry, as many companies are failing sustain operations (or even begin in the first place) due to lack of adequate energy. Government of Malawi's Malawi Rural Electrification Programme (MAREP) is devoted entirely to grid extension, however, extending a network that already has a generation shortage instead of focusing on diversification of generation options to include off grid private and community renewable energy systems shows misplaced priorities of government. In fact, a recent DFID report has indicated that mini grids would be the most appropriate was of gaining access to electricity for over 4.5 million Malawians (DFID 2015). Fortunately, the new draft policy (Government of Malawi 2015) proposes to reform MAREP and open up the market for off grid solutions and private actors.

The regulatory framework on energy enterprises was so strict that it favored state owned Electricity Supply Commission of Malawi (ESCOM) and stifled IPPs (Independent Power Producers). However, the government focus is to increase private sector investment towards grid connected systems. Currently there are 17 MOU's signed with Independent Power Producers (IPPs) to generate and feed into the grid. Future plans include diversifying the generation mix to coal, solar (there is a government plan to include 400 MW from solar, but a key challenge is the potential for grid imbalance), wind and geothermal, as well as broadening hydro capacity into the north. There are also discussions for Malawi–Mozambique interconnections; currently there are distribution connections across the borders but no transmission.

However, grid extension is yet to produce significant results in rural areas, consequently, there have been a number of off-grid systems using micro hydro, solar and wind, however the scale of these initiatives is still very limited and many experts interviewed felt there is little government priority given to such systems. A key hope and recent development is the development of new energy policy which will potentially also lead to legislative reforms for energy sector in the country (the first draft was produced in February 2016), as the Scottish Government has sent a secondee to the Department of Energy to support the development of the renewable energy policy and the government has also signed a contract with DFID to promote household solar through policy changes.

In essence, Malawi is struggling to end poverty as a long term goal and as a means of doing so, is addressing energy poverty as well. This gives Malawi a very unique position as far as energy advocacy is concerned. On one hand policy makers have to optimize very limited resources to meet the enormous social needs (education, health care, housing etc.) of a rapidly population and on the other hand to attempt to grow the economy. Locating where energy sits in the overall equation is not easy, as it is both viewed as a sector requiring investment from an already stretched national budget yet it also has the potential to support economic growth.

In principle, energy is a key national priority evidenced by the country's development blue-print, the Malawi Growth and Development Strategy II (2011 to 2016) that states that:

> *"A well-developed and efficient energy system is vital for industrial, mining and tourism development. Government will therefore focus on increasing the generation, transmission and distribution of electricity and promote other energy sources with the aim of improving service delivery and increased output in the economy. To promote industrial development, Government will promote use of modern technology in manufacturing; facilitate accreditation of quality assurance institutions; undertake industrial reforms; promote product and market diversification; and promote value addition in existing and potential products… "pg. 17*

However, energy policies and laws will remain empty promises unless governments allocate adequate resources towards their implementation through their budgets. Tavakoli & Hedger (2009) conducted a historical examination of public expenditure and performance, in relation to measures of poverty and other social indicators in order to explore the extent to which public spending in Malawi has been pro-poor and effective in reducing poverty and accelerating growth. They found that energy had clearly been ignored, with energy sector expenditures actually decreasing over time. As a result, it is not surprising that access levels and private sector investments have been so low. However, some of the experts interviewed suggested that energy did not used to be a key government priority because electricity demand was significantly lower. This has changed drastically in the last decade, affecting economic activities thereby bringing negative political pressure, as there is recognition that energy supply at national level is a key determinant for broader national security and wealth creation.

In fact, for a country like Malawi, it is less about the comparison of energy with other development priorities, because compared to other countries in the world it is far behind across almost all indicators. Rather the focus should be on a holistic development package, for example by incorporating renewable energy into the development of health, education and other infrastructure. Some donors and NGOs have complained that implementing energy projects in Malawi is difficult because there is little or no support from the government. For example, there are no district energy offices (as there are for health and education). In Malawi, if looking at government-led efforts alone, indeed energy would not be seen as a key priority, as most of the investments in the sector are by the foreign actors. For example, DFID has a focus on energy demonstrated through their DISCOVER (Developing Innovative Solutions with Communities to Overcome Vulnerability through Enhanced Resilience) programme, ECRP (Enhanced Climate Resilience Programme) and BIF (Business Innovation Facility) on solar products; UNDP has a Sustainable Energy Management Programme which is a priority focus for renewable energy and energy efficiency; Irish Aid is supporting an improved cook stove programme and pico-solar products (PSPs);

GIZ ENDEV (Energising Development) is running a programme supporting cook stoves and PSPs and the US government through Malawi Challenge Account are supporting Energy Reform plus massive infrastructures upgrade for ESCOM.

In Malawi, according to the draft National Energy Policy (2015) approximately 89% of energy comes from biomass which is largely exploited in a non-sustainable manner. Petroleum which is imported contributes 3.5%, while hydro power accounts for 2.3% of all energy. The new Malawi Energy Policy currently under discussion is set to replace the original Energy Policy developed in 2003 and shows the government's aspiration to supply reliable and modern energy options for its population and it intends to halve biomass use by 50% by 2030 and there have been some efforts to coordinate and regulate the sector. In 2004, four energy laws were created to help operations in the energy sector in Malawi. These are four Energy Acts aimed at addressing various aspects of the energy sector which are: Act 20, the Energy Regulation Act which established Malawi Energy Regulatory Authority (MERA); Act 21, the Rural Electrification Act which laid the foundation for the formation of Rural Electrification Management Committee and Rural Electrification Fund; Act 22, the Electricity Act which deals with electricity issues in terms of licensing, tariffs, generation, transmission, distribution, sales contracts and related issues; Act 23, the Liquid Fuels and Gas (Production and Supply) Act which handles issues related to liquid fuels and gas production in terms of licensing, safety, pricing, taxation, strategic reserves and any other related issues. Some actors are currently advocating for the creation of a fifth act on renewable energy, however this could result in over-regulation of the energy sector and as a result, others favour simplifying the situation by creating a single over-arching energy act, a strategy that has already proved successful in Kenya.

Although the policy framework was in place not much changed in the context of energy poverty in Malawi. Gamula *et al* (2012) observed that the energy sector in Malawi has not been able to meet all the energy requirements across all development sectors and this has been a major challenge for some time and has considerably contributed to the slow development of various other sectors. Lack of financial commitment, lack of favourable conditions for investment in the energy sector, lack of political will and poverty are among the major factors that have contributed to underdevelopment in the energy sector for Malawi.

Civil Society Organisations (CSOs) are central to the energy advocacy agenda in Malawi. The term CSOs refer to non-governmental organisations, community groups, faith-based organisations, trade unions, informal groups (those without constitutions and boards). Governments can either help or hinder CSOs through laws and regulations that they use to establish them, direct their activities, tax them, allow them access to funds (public, private, and foreign), require them to report, audit them, and involve them, or exclude them from government projects and policies. Equally, CSOs can either play their traditional service provision role or can also be pivotal actors in contributing to policy development and in holding government to account for its actions, an advocacy role all relevant and not new to CSOs work in the region.

James (2005) gave a comprehensive account of the evolution of CSOs in Malawi by noting that since independence in 1964, Malawi was a closed society characterised by massive state control in the economic, social and political spheres with little or no citizen participation. In the early 1990s, Malawians made a real challenge to the autocratic rule of Dr Hastings Kamuzu Banda and his one party state. The Catholic Church was instrumental in exposing the ills of Dr Banda's regime through a pastoral letter in 1992. This was a landmark in Malawian political history and the beginning of politics of inclusion. Malawi went through a participatory process of developing a new Constitution, which guaranteed the basic rights to all Malawians, and which also facilitated multi-party elections in 1994. The elections resulted in the change of government from the Malawi Congress Party to the United Democratic Front Party. These developments resulted in the opening up of Malawian society and for the first time, Malawians had the chance to elect political leaders. With a new Constitution, which guaranteed people's rights and freedoms, Malawi has seen an emergence of civil society that has demanded involvement in issues of governance and holding government to account for its actions. Civil society Organisations (CSOs) have been active in human rights, political and economic governance issues, and HIV/AIDS among other areas. In the last five years CSOs have begun to mobilise and come together around sectoral thematic groups forming CSO networks, coalitions, and alliances. The network, CONREMA, the Cooperation Network for Renewable Energy in Malawi has recently been launched to coordinate the various CSOs active in the energy access sector in Malawi.

Some efforts to aid the deployment of renewable energy and increasing energy access are being driven by the Sustainable Energy for All (SE4ALL) initiative which is linked into the recently agreed Sustainable Development Goals (SDGs). Through these developments there is hope for a more defined focus and commitment towards increasing energy access, investment in renewable forms of energy and energy efficiency. The overall objective of the initiative is to end energy poverty by 2030 by addressing three specific global objectives:

- To achieve universal access to modern energy services by 2030
- To double the rate of improvement of energy efficiency by 2030
- To double renewable energy in the global energy mix by 2030

Malawi is participating in the envisaged SE4ALL country action processes and recent discussion of the draft energy policy and Growth and Development Strategy provided an opportunity to address issues of energy access for rural communities in a more proactive and innovative manner. It commenced with a partnership declaration ("opt-in") within Rio+ 20 in 2012 which was followed by a an energy rapid assessments or gap analysis. The Department of Energy has been supported by the African Development Bank (AfDB) through the United Nations Development Programme (UNDP) to provide technical and financial assistance for the development of an Action Agenda and Investment Prospectus that will guide the country towards achieving targets set under the SE4All. So far Malawi has officially launched the SE4ALL initiative, and created a road map towards the SE4All Action Agenda and Investment Prospectus processes. Currently, Malawi's specific targets with regard to SE4All are:

- To improve access to electricity to 15% by 2015, 20% by 2020 and 30% by 2030
- To improve the use of energy efficient end-use devices by 1% by 2015, 5% by 2020 and 10% by 2030
- To increase the contribution of RES in the mix by 1% by 2015, 3% by 2020 and 6% by 2030

The summary of the kick-off stakeholder meeting for the SE4All initiative (Deloitter & Econoler 2015) indicates that the Malawi SE4All Country Action Plan is still under development, following this, an Investment Plan will be drawn up that will clarify the funding priorities. With regards to small wind turbines, the in the kick-off stakeholder workshop listed the following initial:

- Promotion of solar mini-grids in off-grid areas and reviving the existing 6 solar-wind hybrid systems.
- Promotion of wind technology in feasible areas for electricity generation and water pumping.
- Promotion of small wind turbine technology under RE priorities in section 7 of the report.

1.3 Benefits of small wind power

Figure 2 illustrates that at smaller capacities, renewables can offer a much more cost effective solution than fossil fuels when taking into account the cost of each kWh produced over the lifetime of the system (see Figure 3). On a site with a good wind resource, wind has the potential to supply energy at a much lower cost than solar PV. Weisser (2007) and Evans et al. (2009) found the GHG emissions of wind to be similar to those of hydro, but around a third those of PV.

FIGURE 2: LEVELISED GENERATING COST OF DIFFERENT ENERGY TECHNOLOGIES (LEARY ET AL. 2012).

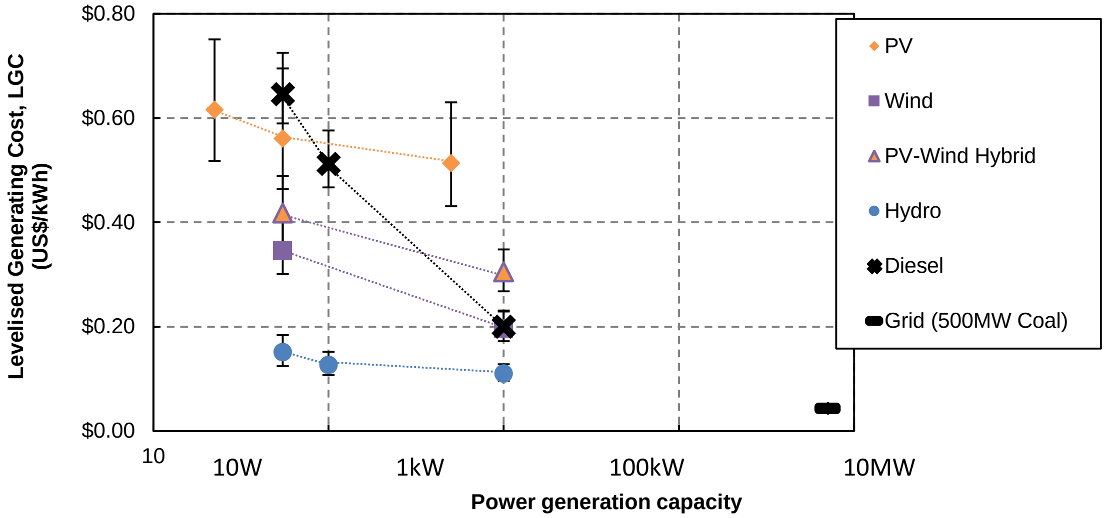
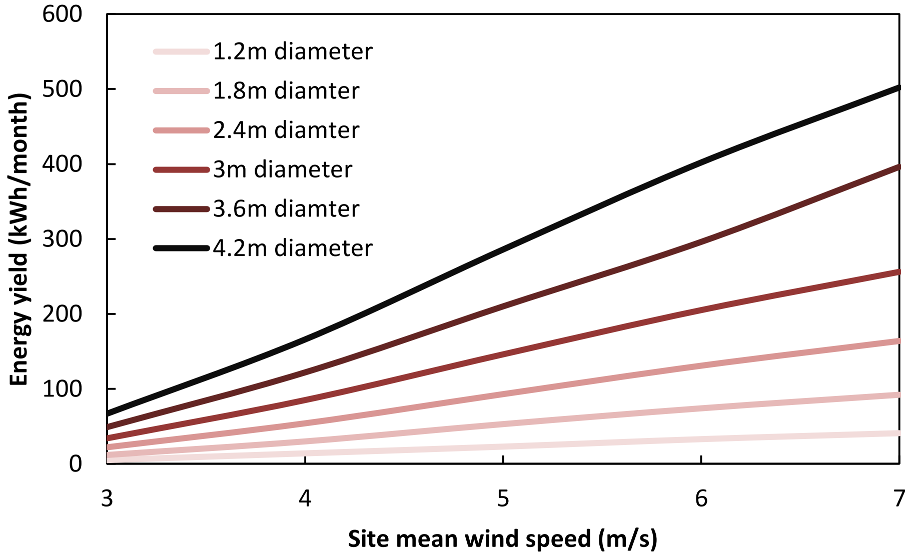


FIGURE 3: ESTIMATED MONTHLY ENERGY YIELDS FOR SWTS (PIGGOTT DESIGN) OF UP TO 5M ROTOR DIAMETER IN VARYING WIND CONDITIONS (Sumanik-Leary et al. 2013).



1.3.1 Locally Manufactured Small Wind Turbines (LMSWT)

Locally manufactured SWTs have already been successfully employed in rural electrification initiatives, the most notable of which being that of the Inner Mongolia Science and Technology Commission (IMS&TC), who facilitated the dissemination of over 100,000 household wind generators to local herdsmen in one of China's windiest provinces (Batchelor et al. 1999). The emphasis on local manufacture, rather than importing from abroad gave flexibility to adapt the technology to the local context, fed money back into the local economy and increased local capacity. To address the reliability issue, service centres were established in each county to give users access to the tools, parts and knowledge required to perform repairs and the successful redesign of the product meant that the most unreliable parts could be replaced by the user.

Hugh Piggott publishes an open-source design for a wind turbine that can be locally manufactured using basic shop tools and widely available reclaimed and low-cost materials (Piggott 2013). This design was developed over 30 years as a means to provide electricity to Piggott's home community of Scoraig, a remote settlement on the northwest coast of Scotland. With proper maintenance the wind turbine can operate reliably for over 15 years, even in hard, remote environments. Piggott has over 30 years of experience with locally manufactured micro-wind turbines and is rightly recognized as a "trusted independent expert" by the commercial small wind industry. The potential of Piggott's design is greatly increased by its open-source nature, which enables it to draw on the global pool of expertise from hobbyists to non-governmental organizations to universities. Currently there are over 35 organizations and hundreds of individuals around the world using variants of Piggott's proven design for rural electrification. These practitioners are organized through the association, Wind Empowerment (see below).

Figure 4: Manufacture of a SWT using simple tools and techniques in Mozambique. Photo courtesy of The Clean Energy Initiative.

Establishing an SWT local manufacturing hub can have a much broader range of developmental impacts than simply importing pre-fabricated equipment from abroad, such as local capacity building and local economic development. It creates skills, jobs and micro enterprise development within a community, thereby strengthening the local economy. SWTs require more maintenance than Solar Home Systems (SHS) (Marandin et al. 2013) however the local availability of skills to perform maintenance increases the communities resilience and creates further local employment throughout the lifetime of the installation. The turbine design incorporates predominantly locally sourced materials, furthering support for the local economy and the fact that it can be manufactured using basic hand tools means that it has a lower cost and lower fuel to build (important in areas already energy poor).

Figure 5: Example Electrical system for a LMSWT (Sumanik-Leary, 2012)

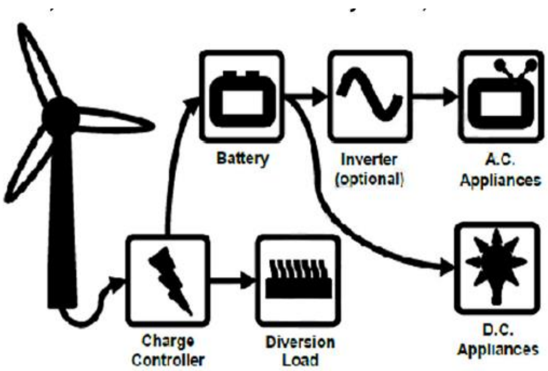
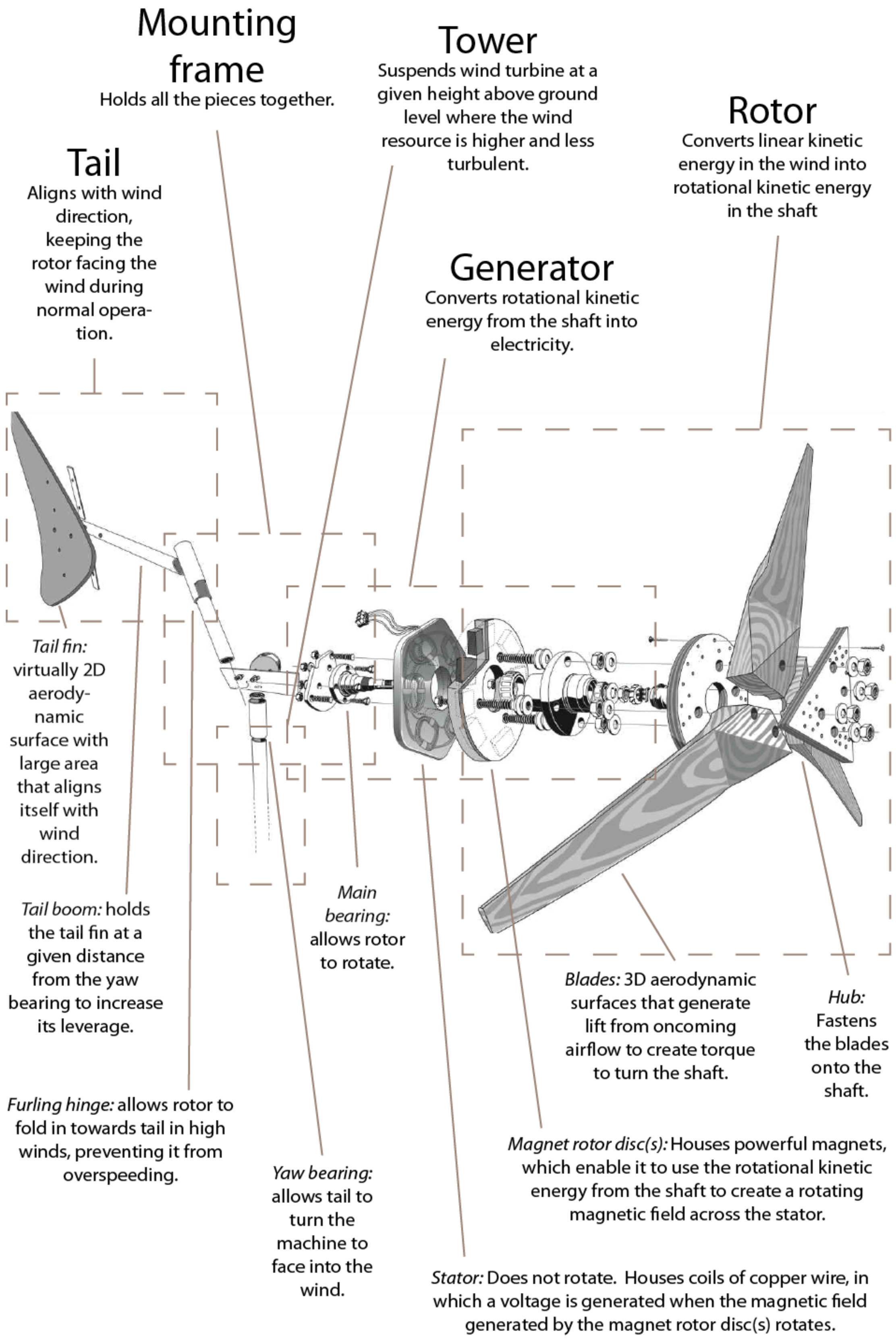


FIGURE 6: EXPLODED CAD ILLUSTRATION OF AN LMSWT IDENTIFYING AND CLASSIFYING THE KEY COMPONENTS AND THE INTERACTIONS BETWEEN THEM. IMAGE ADAPTED FROM ROLAND BEILE/TRIPALIUM BY SUMANIK-LEARY, WHILE, ET AL. (2013).



1.3.1.1 Local capacity building

Participation in the construction of an SWT is an incredibly powerful educational experience. What is more, this practical method of knowledge transfer is much more likely to be effective than conventional theoretical training for people with lower levels of formal education. Consequently, it offers a valuable educational tool for building local capacity, not only for manufacturing in urban centres, but also for operation and maintenance in rural areas. Marandin et al.'s (2013) findings in Nicaragua indicate that it is a highly successful method for transferring technical skills and building a sense of ownership, both of which contribute to both the ability and motivation that will inevitably be required to overcome the maintenance challenges that lie ahead. The Students for Malawi group have trialled such participatory construction techniques in the South of Malawi, the findings from which are discussed later in this report.

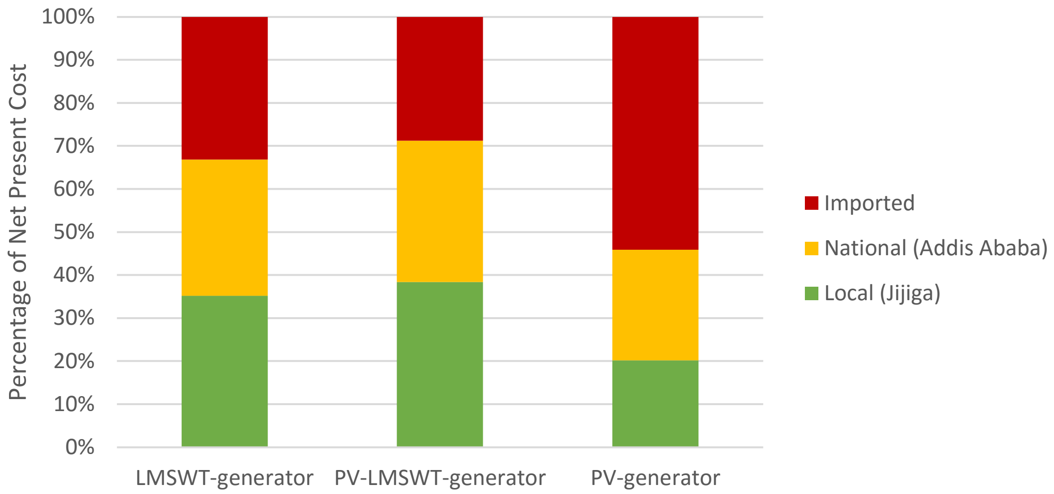
1.3.1.2 Local economic development

The requirement for foreign exchange places a huge burden on developing economies, which may have few products or services with which to generate such credits. Sending significant portions of a poor country's GDP overseas is clearly not desirable, especially if a suitable locally manufactured alternative is available. What is more, the establishment of new international supply chains is a significant barrier, as the bureaucracies involved in the importation process (import taxes, additional time awaiting approval etc.) and shipping charges should not be underestimated. Although many of the materials and components required to manufacture an SWT locally can be obtained in urban centres around the world, in most developing countries, a significant portion may only be available in bigger cities and some will still need to be imported.

Figure 7 presents a value chain analysis of the three most viable system configurations modelled during the market assessment for SWTs carried out by Wind Empowerment in Ethiopia (Eales 2015). It categorises the costs associated with the manufacture/purchase, installation and maintenance of each of the three technologies, according to where these expenditures occurred. Money spent locally (Jijiga) is shown in green, whilst that spent nationally (within Ethiopia) is in yellow and finally, money that is sent overseas is in red. Interestingly, despite the fact that PV modules are imported, the PV-LMSWT-generator hybrid system was found to have the most locally embedded value chain. This is due to the fact that Ethiopia has no domestic oil production and the generator is run significantly more when using the wind resource alone, as the solar resource offers significant diversification in power generation sources, meaning that the battery bank reaches the low point at which the generator is tripped on less frequently. The key finding of this analysis is that in such a PV-LMSWT-generator hybrid system, over two thirds of the capital required over the system's 20 year lifetime is spent within Ethiopia and one third is spent in the Somali region itself. In contrast, over half goes overseas for a comparable PV-generator system.

In addition to keeping a greater proportion of money within the local economy, the local manufacture of SWTs also directly creates additional jobs. Based upon the experience of Wind Empowerment member organisations who operate similar business models in other countries, running a micro-enterprise that manufactures, installs and maintains 10 LMSWTs per year would require 3 full time members of staff. The establishment of a service network to offer after-sales services in rural areas would require the creation of further jobs in places where such employment is likely to be even more highly valued.

FIGURE 7: VALUE CHAIN ANALYSIS OF OFF-GRID LMSWT, PV AND GENERATOR SYSTEMS (Eales 2015).



1.4 Challenges with small wind power

The two most significant challenges with using small wind for development are the high variability in the resource and the high maintenance requirements. The wind resource is extremely variable in both time and spatial, which makes it one of the most difficult renewable resources to assess. In the time domain, there are gusts acting over seconds, calm periods lasting for days, seasonal patterns across the year and climatic influences leading to inter-annual variation. In the spatial domain, trees cause very localised shelter effects, gentle hills can funnel the wind smoothly around them and continental land masses slow down the winds that whip across the ocean. Consequently, assessing the wind resource is not easy, but is of vital importance as the power available is proportional to the cube of the wind speed, meaning that a doubling of the wind speed yields an eight-fold increase in power:

$$P = {}^{1}\!/_{2}\,\rho A V^{3} \qquad (1)$$

P = wind power (W)
ρ = density of air (kg/m^3)
A = swept area of wind energy conversion device (m^2)
V = wind velocity (m/s)

SWTs require a high level of maintenance, which therefore requires a high level of support. Piggott (2013) warns builders of his machines to expect two problems in the first year and one per year thereafter. Maintenance can be divided into two key categories, preventative and corrective, both of which are detailed in *Appendix A – Preventative and corrective maintenance requirements for Piggott turbines*. Financially, this fits best with a business model (as opposed to a donor model, where upfront costs are donated), where the energy produced is used to generate revenue that can pay for the on-going costs of O&M. Local capacity to perform maintenance must also be created by training community technicians and establishing a service network to bridge the gap between the manufacturer/supplier and the community itself, which offers the opportunity to create jobs and build capacity in rural areas. Areas with high levels of environmental hazards (lightning, corrosion, hurricanes etc.) should be avoided unless a strong support network can be put in place for maintenance.

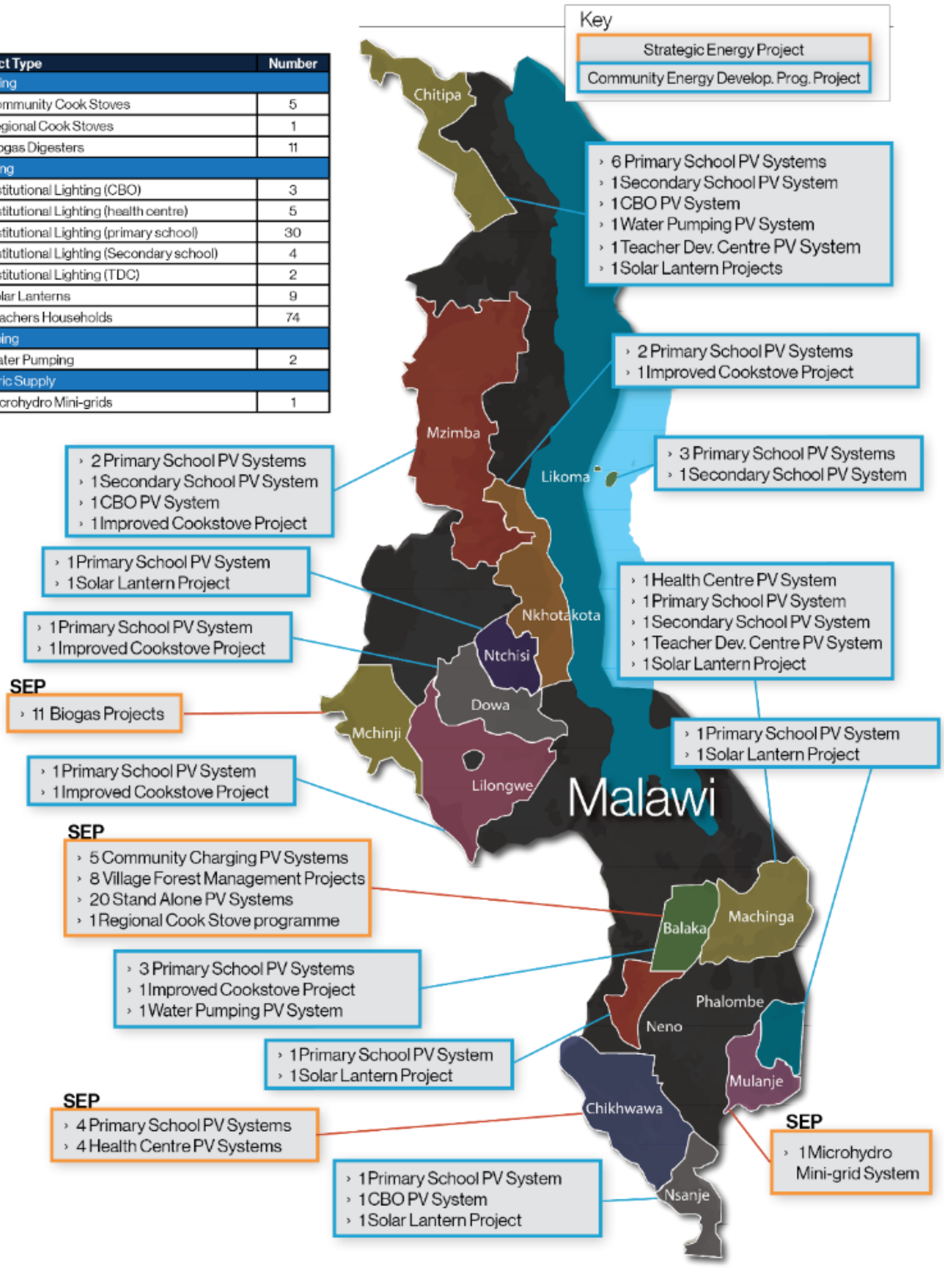
1.5 Partner organisations

1.5.1 Community Energy Malawi (CEM)

CEM is a membership based organisation which aims *"to enable communities in Malawi to create sustainable renewable energy solutions to meet their energy needs."* This is achieved through the creation and facilitation of a mutually supportive network of community group members and by representing members in making the case for the creation of a supportive government policy and regulatory framework. CEM is a national organisation and the link to local communities is made through the Community Based Organisations (CBOs) that comprise the membership. Figure 8 shows the districts in which CEM is currently active and the energy access projects implemented in partnership with the CBOs to date.

FIGURE 8: THE DISTRICTS WHERE CEM IS ACTIVELY WORKING AND THE PROJECTS IMPLEMENTED TO DATE (UNIVERSITY OF STRATHCLYDE 2016).

Project Type	Number
Cooking	
Community Cook Stoves	5
Regional Cook Stoves	1
Biogas Digesters	11
Lighting	
Institutional Lighting (CBO)	3
Institutional Lighting (health centre)	5
Institutional Lighting (primary school)	30
Institutional Lighting (Secondary school)	4
Institutional Lighting (TDC)	2
Solar Lanterns	9
Teachers Households	74
Pumping	
Water Pumping	2
Electric Supply	
Microhydro Mini-grids	1



1.5.2 Wind Empowerment

Wind Empowerment aims to support the development of locally manufactured small wind turbines for sustainable rural electrification by strengthening the capacity of its members through collaboration and knowledge exchange. Wind Empowerment is a global association of over 40 member organizations in over 25 different countries (see Figure 9), consisting of universities (e.g. National Technical University of Athens), research institutions (The Wuppertal Institute), NGOs - Non-Governmental Organisations (e.g. COMET-ME), social enterprises (e.g. WindAid), co-operatives (e.g. V3 Power) and more, as well as over 1,000 individual participants[6]. A complete list of current Wind Empowerment members and contact details can be found in *Appendix F – Survey Results*

Overview

Surveys were conducted with households and businesses to determine current energy use, income levels and ability to pay for energy services. The purpose of the research is to determine the energy demand in the CBOs that CEM are active with, and whether the systems investigated in this study are feasible in terms of the social-economic factors present on the ground.

1.5.2.1 Data Collection Platform: Kobo Collect

KoBoToolbox is a suite of tools for field data collection for use in challenging environments, and was used as the data collection source for this study. The software, developed by the Harvard Humanitarian Initiative, is an open source suite of tools for data collection and analysis. Smart Phones were used to conduct surveys with the information being stored digitally, and then uploaded to a server which can then be accessed anywhere in the world through a web portal.

4 surveys were designed and conducted in the 12 CBOs visited by CEM staff during January and February 2016. A summary of the surveys is outlined below and the results of the surveys are presented following the table.

Name of Survey	**Target Participant**	**Purpose**	**No. of Surveys**
Household	Householders	Household social-economic and energy use	94
Business	Owners or Employees of rural businesses	Business social-economic and energy used day	62
Productive Use of Energy	Householders and businesses	Willingness to pay for productive uses of energy	115
Willingness to Pay	Householders	Willingness to pay for solar system	60

1.5.3 Household Survey

94 household surveys were conducted asking questions relating to energy use. The first questions relate to their income and what type of job. The above graph shows the maximum, minimum and average annual income.

FIGURE 61: MONTHLY HOUSEHOLD INCOME

[6] Individuals with an interest in locally manufactured small wind turbines and/or rural electrification.

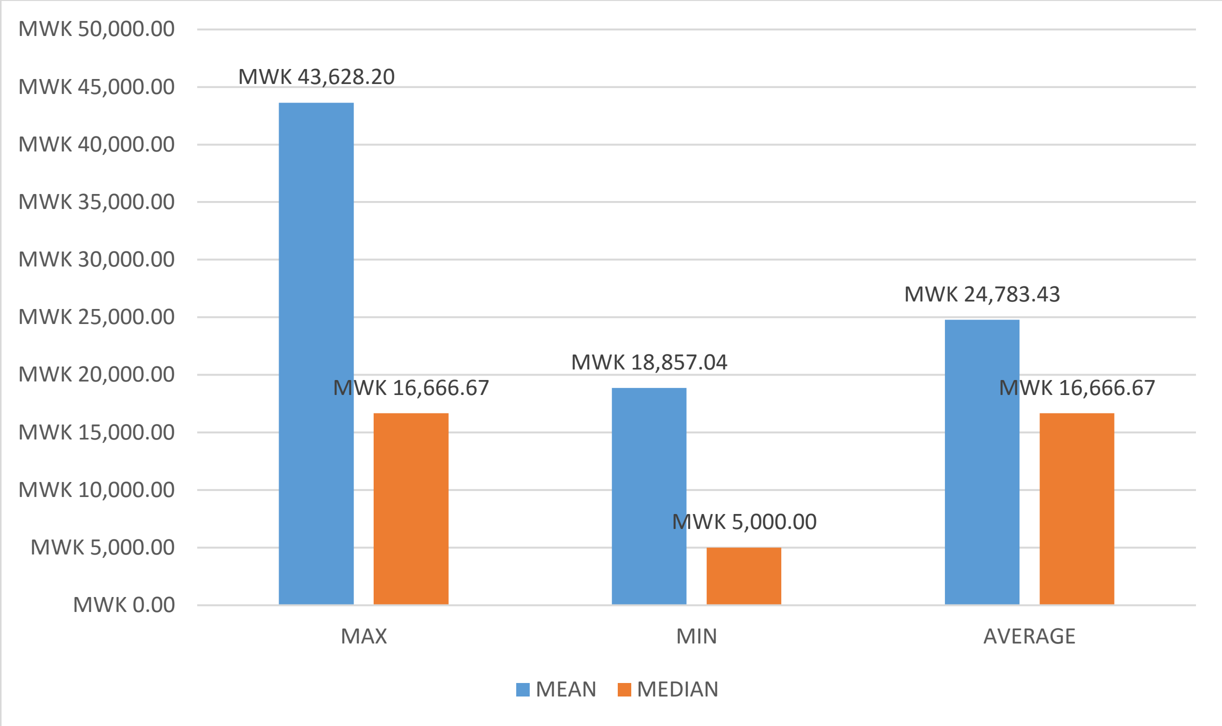


FIGURE 62: INCOME BY JOB CATEGORY

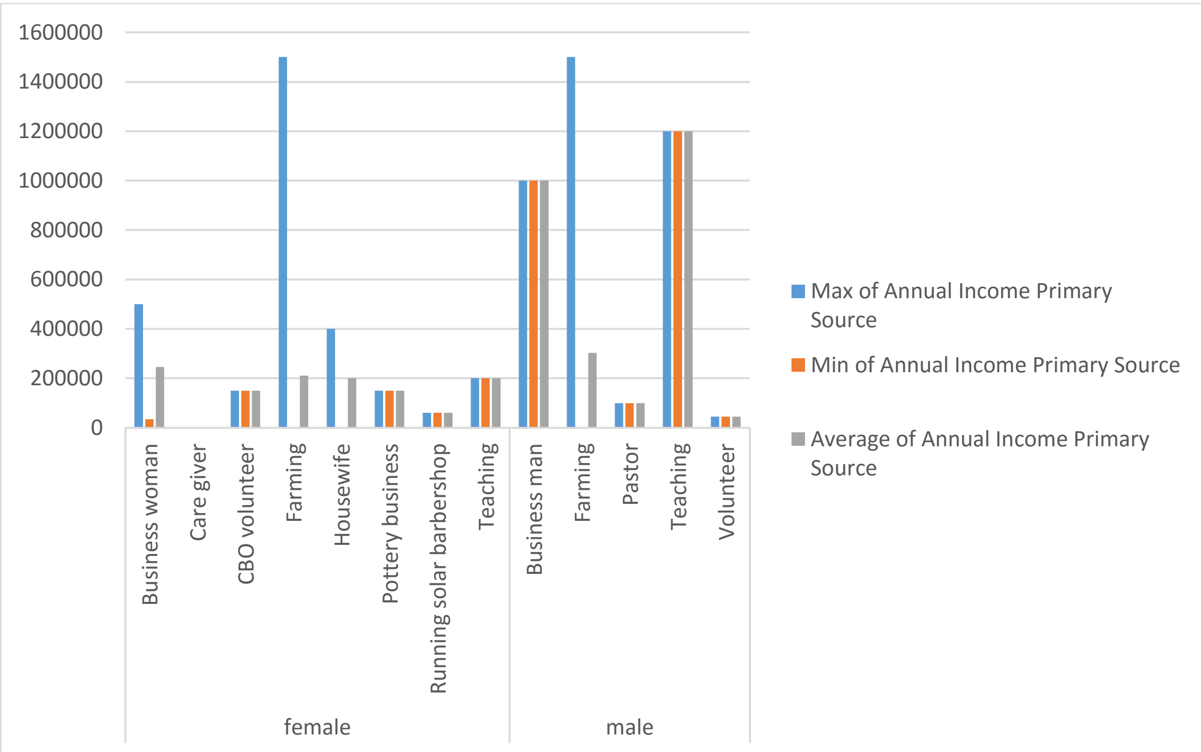
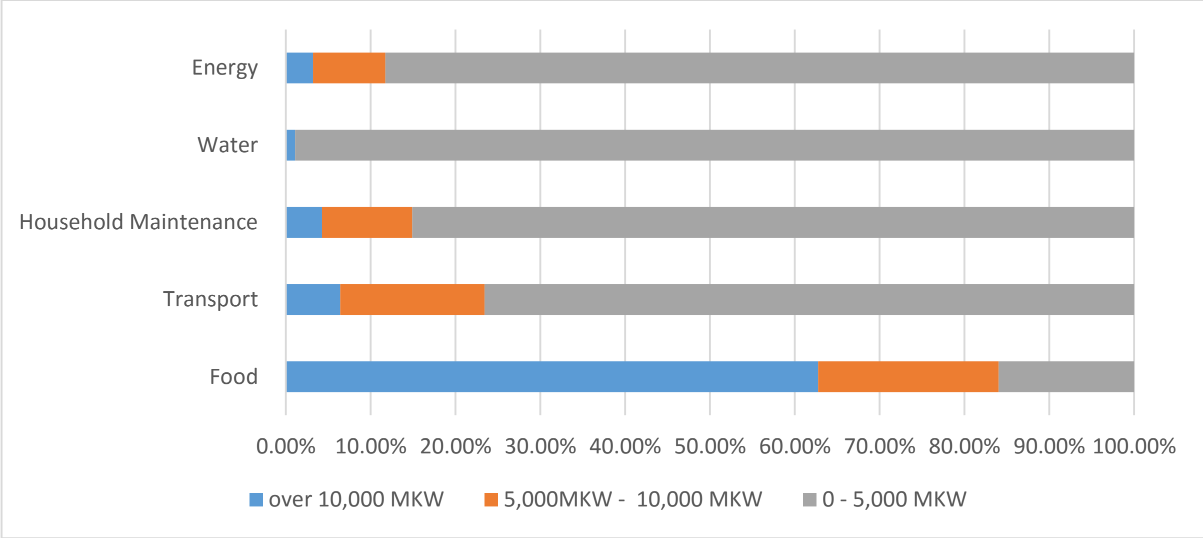


FIGURE 63: PERCENTAGE OF RESPONDENTS MONTHLY SPENDING CATEGORIES

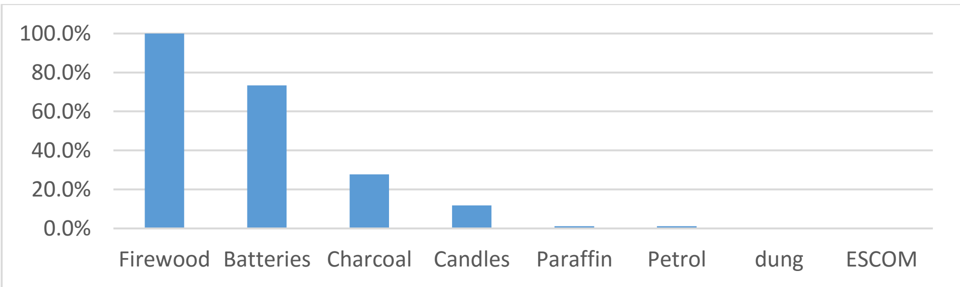


It can be seen that the majority of respondents spend 0 – 5000 MKW on energy, water, household maintenance and transport. Food is the only noticeable difference with the others, which is that over 60% of respondents spend over 10,000 MKW on food. The graph ultimately shows that food is the highest expense for the respondents interviewed.

1.5.3.1 Energy Use

It can be seen that all the respondents use firewood, and a large majority (over 70% use dry cell batteries. Charcoal is the next highest, followed by candles. Paraffin and petrol use were used by very few of the respondents. No respondents use dung and none are connected to the ESCOM grid.

Figure 64: Percentage of Respondents using a particular type of energy



1.5.3.2 Batteries

Although data on cost and collection time for firewood and charcoal was collected, it is not presented here as it has less relevance for energy provided by wind and solar power. The following graphs show the frequency of purchasing, the monthly spend, and the travel time to collect batteries. The costs give a good indication of how much people would be willing to spend on a renewable energy service to provide lighting to replace the current costs of batteries.

Figure 65: Frequency of Buying Batteries

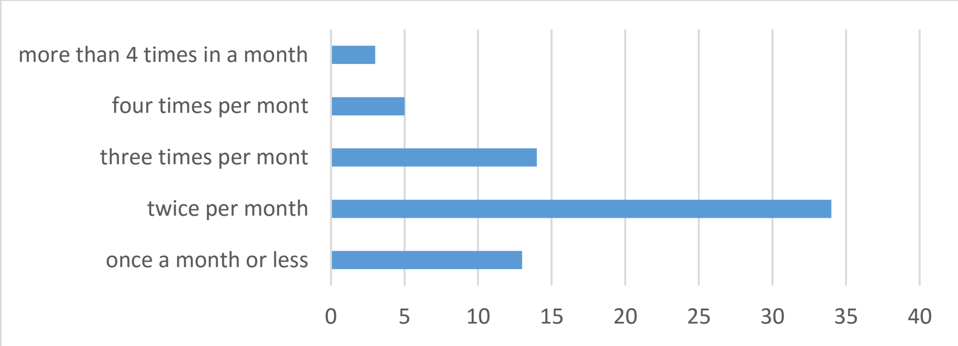


FIGURE 66: MONTHLY SPEND ON BATTERIES (MKW)

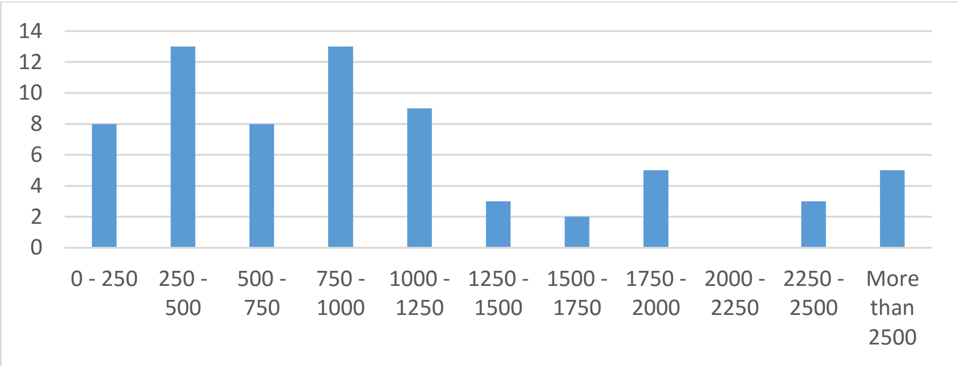


FIGURE 67: MONTHLY COST OF BATTERIES (MKW)

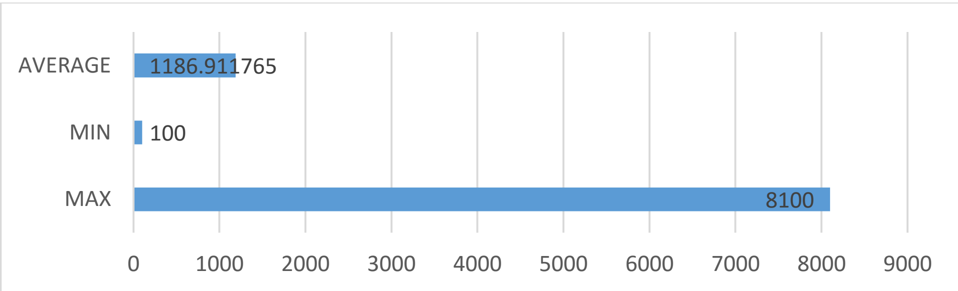
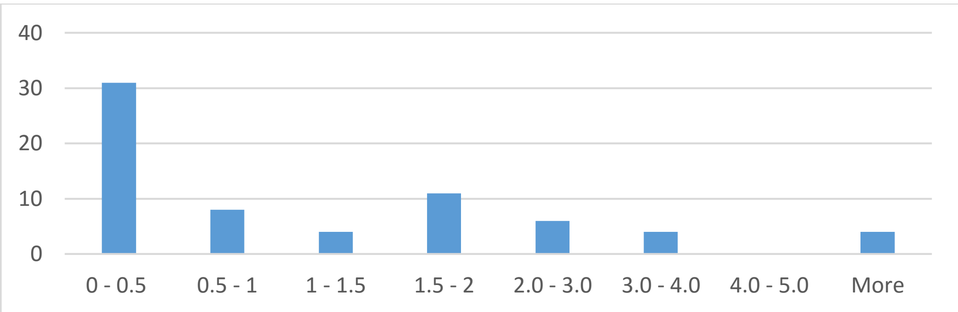


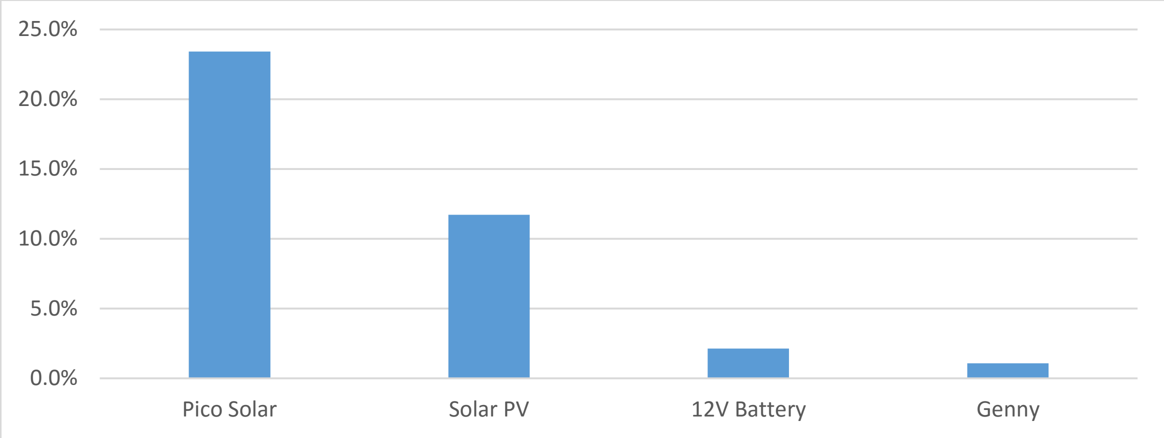
FIGURE 68: ROUND TRIP TRAVEL TIME (HOURS) TO COLLECT BATTERIES



1.5.3.3 Ownership of Energy Generators

Respondents were asked if they own energy generators. Most did not, for the respondents that did own, it was mostly pico solar products, (22%) followed by Solar Home Systems (12%), with few respondents owning 12V batteries and generators

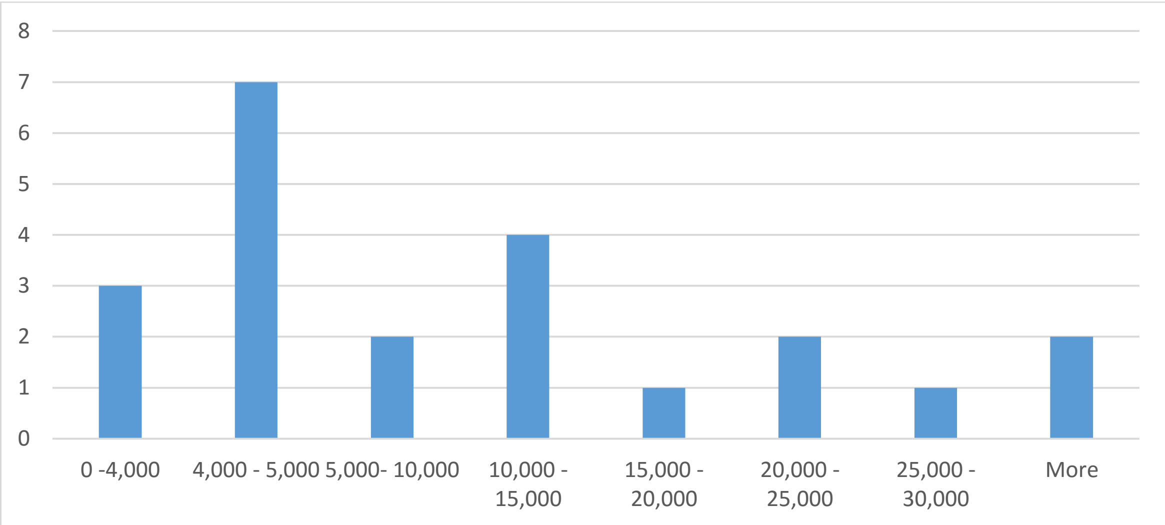
FIGURE 69:: % OF RESPONDENTS OWNING A PARTICULAR ENERGY GENERATOR



1.5.3.4 Pico Solar Cost

A Histogram of the costs of the pico solar products is shown below. Most are in the region of 4,000 – 5,000 MWK. The most expensive system cost 36,000 MWK, the cheapest was 3,500 MKW and the average cost of all the systems was 11,985 MWK.

Figure 70: Cost of Pico Solar Systems



1.5.3.5 Comments about Pico Solar

Respondents were asked about their opinions of pico solar products, which are outlined below in categories with the number of repeated comments in brackets. Most respondents were positive about the technology.

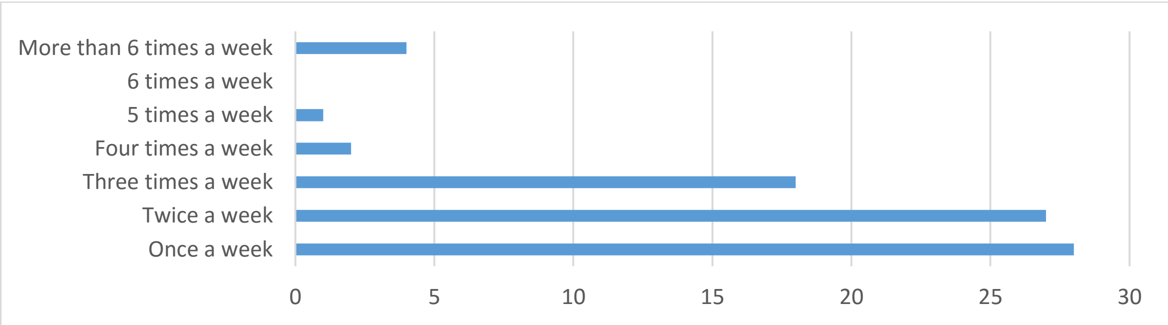
Good	Bad
• Performs better than battery torches (4) • Very reliable (4) • it is cheap to use/more cost effective than buying batteries (6) • High performance (4) • easy to charge • generally these products are good (4) • durable (2) • has made life simple (2)	• not reliable • It is also expensive to buy (3) • It is not functioning anymore (3)

1.5.3.6 Mobile Phone Use

Respondents were asked how many phones were in their household, what the cost of charging it was, and what the travel time was to charge their phones. Also asked was how often a phone is charged in their household. The results are shown below:

	Max	Min	Average
Number of Phones in household	4	0	1.5
Cost of charging (MKW)	300	0	43
Distance to travel (hours)	12	0	2

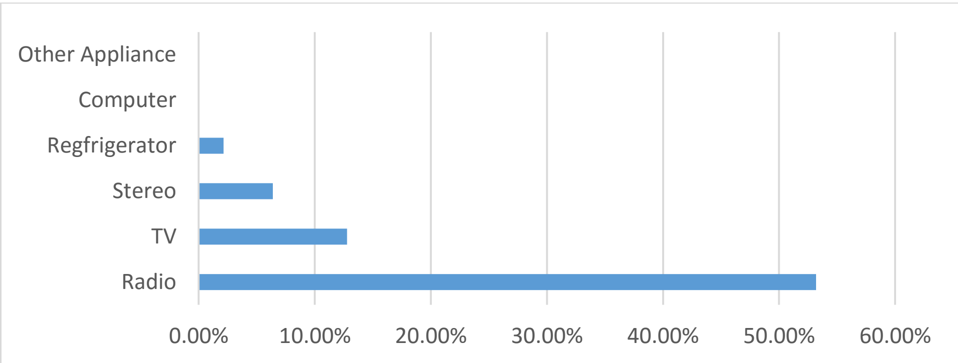
FIGURE 71: HOUSEHOLD PHONE CHARGE FREQUENCY



1.5.3.7 Appliances

Respondents were asked what appliances they own, and what the source of power is for these appliances. Just over half of the respondents owned a radio. 13% owned a TV, whereas 6% owned a stereo. Results are shown below

FIGURE 72: OWNERSHIP OF APPLIANCES



1.5.3.8 Source of Power for Appliances

Most people (63%) are using dry cells for the radio with the remaining using solar power. The majority of respondents do not use their TV because they don't have a power source for it, although 34% use solar.

FIGURE 73: SOURCE OF POWER FOR RADIO

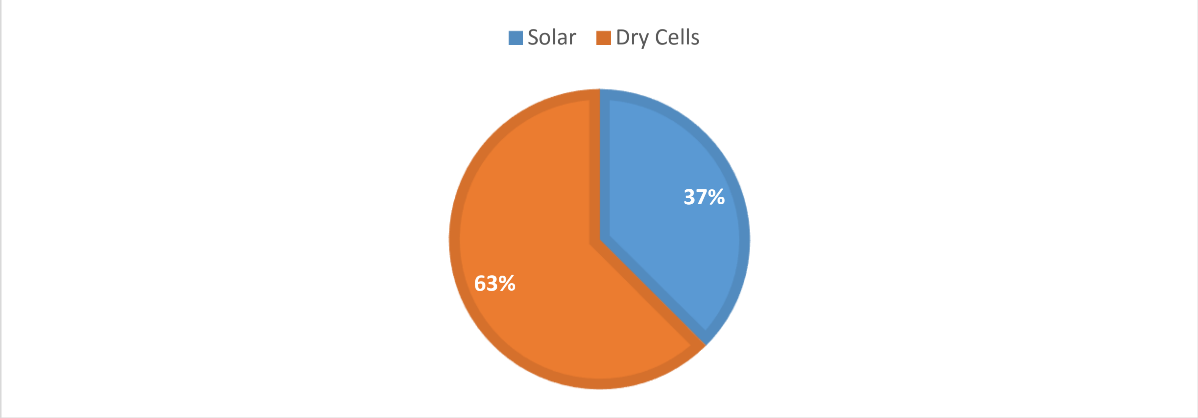


FIGURE 74: SOURCE OF POWER FOR TV

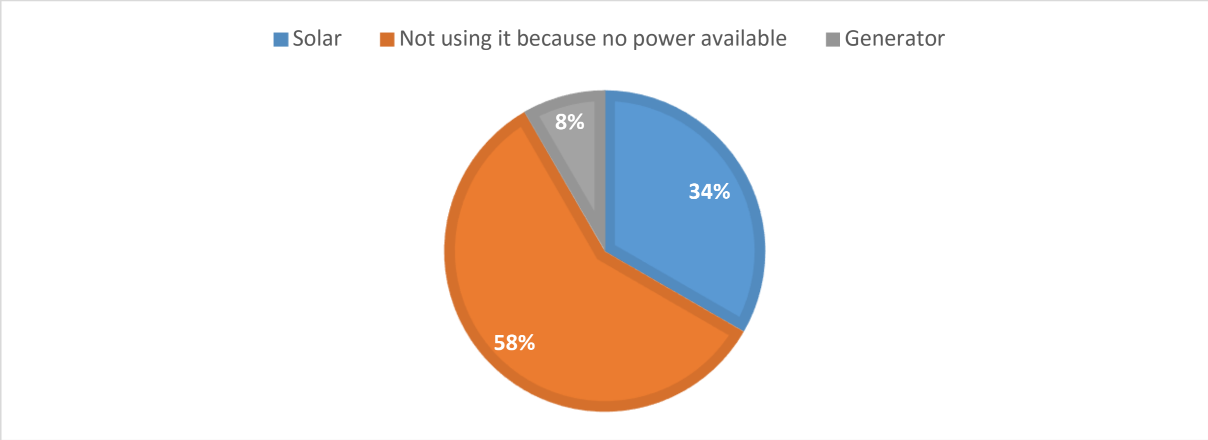
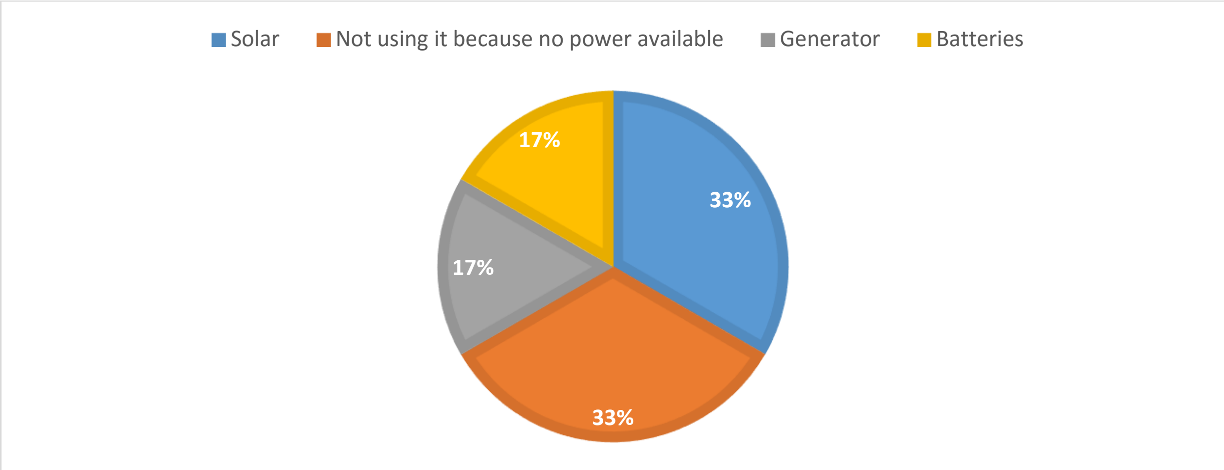


FIGURE 75: SOURCE OF POWER FOR STEREO

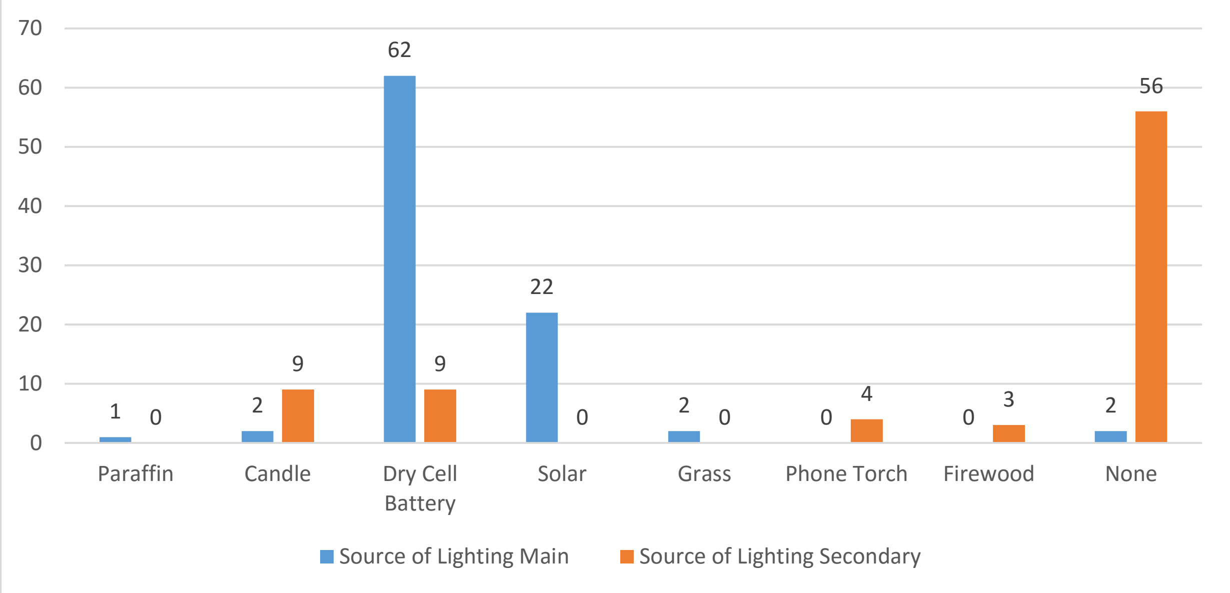


The two respondents that owned a refrigerator did not have a power source for it. It is interesting to see that many respondents own appliances but do not have a power source for them.

1.5.3.9 Lighting

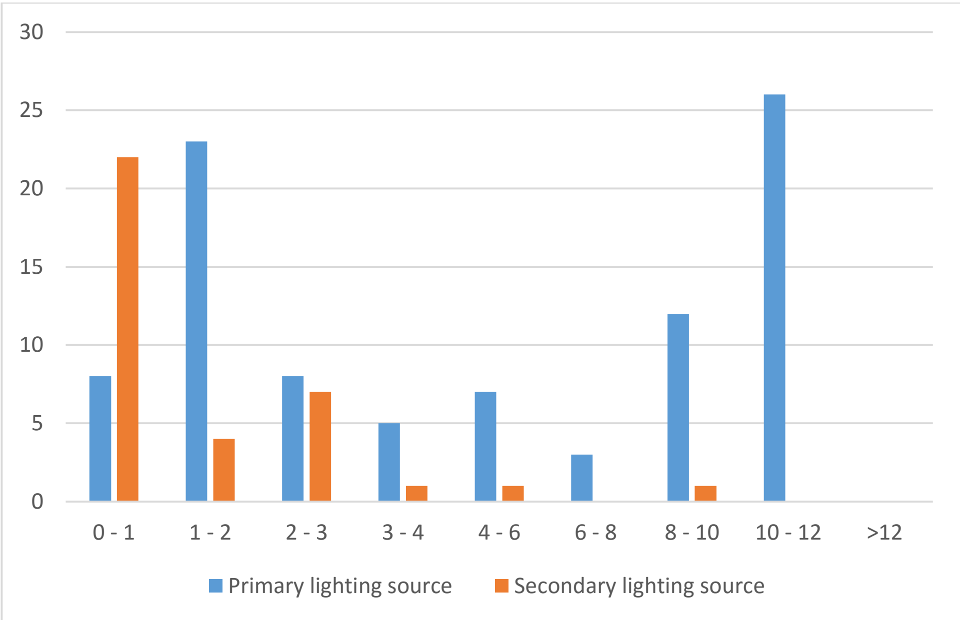
Respondents were asked what their primary and secondary lighting source is, and results are shown below

FIGURE 76: SOURCE OF LIGHTING FOR HOUSEHOLDS



It can be seen that the most popular primary source of lighting is dry cell batteries, followed by solar, with a few respondents using elephant grass or candles. 2 respondents had no source of lighting. The majority of the respondents had no source of secondary lighting, however the ones that did mostly used dry cell batteries and candles, which some using the torch on their phone or firewood.

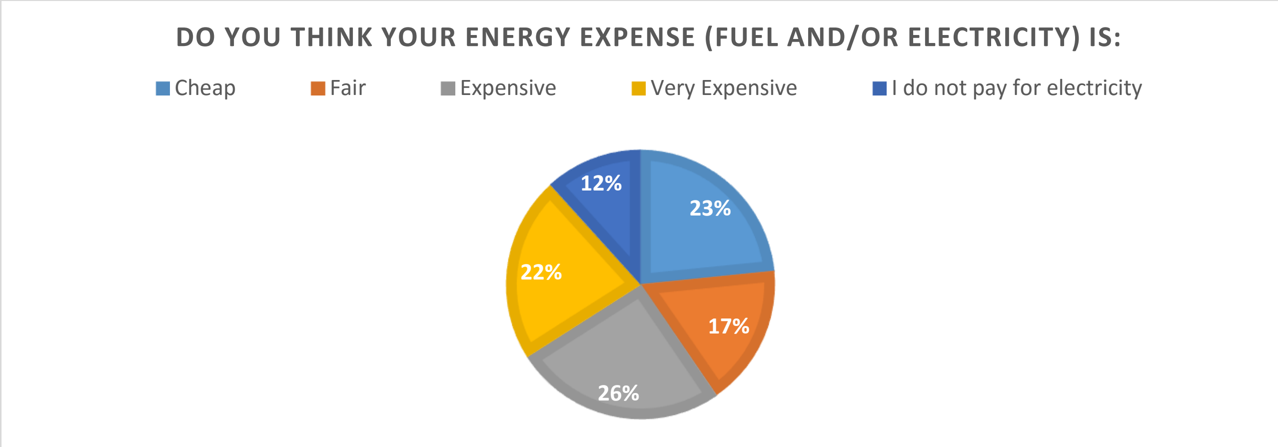
FIGURE 77: HOW MANY HOURS PER NIGHT EACH SOURCE OF LIGHTING IS USED

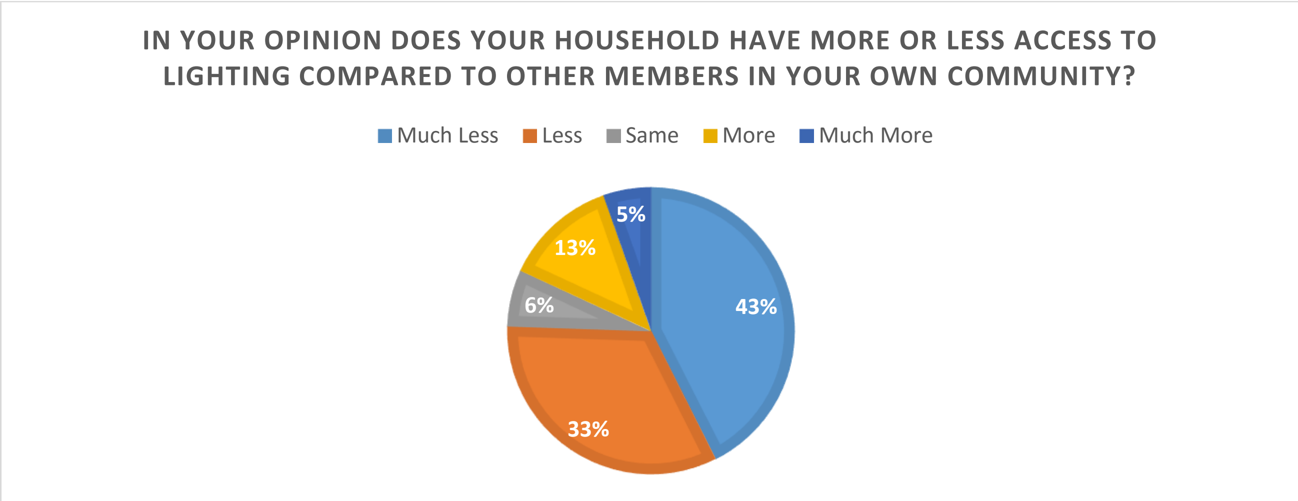


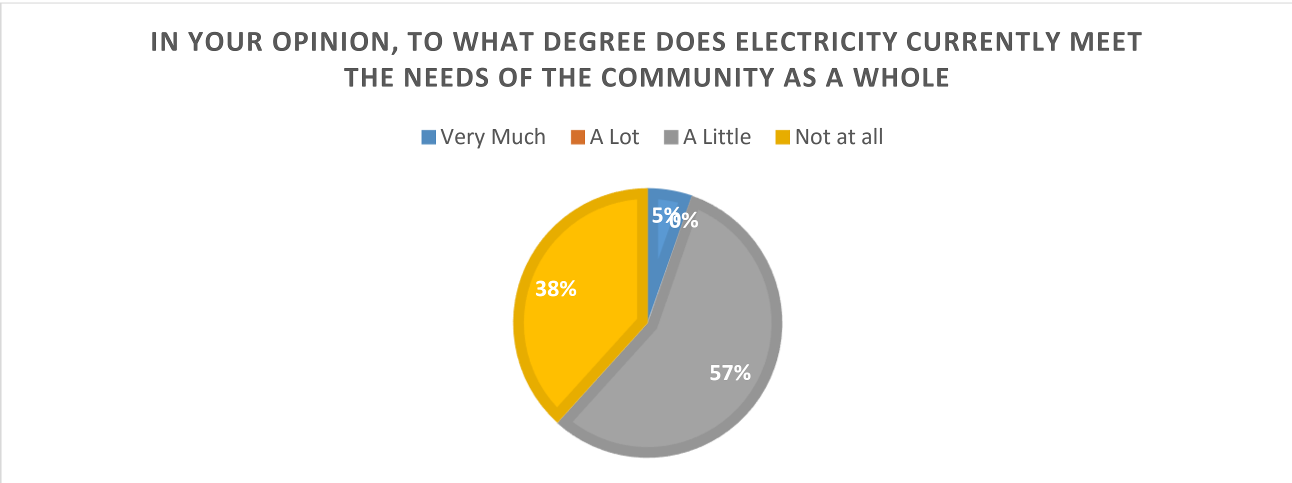
In terms of length of time used for each source of lighting, most respondents stated that they used the light for 10 – 12 hours. As the most used source of lighting is dry cells, it may be that they meant that the light was available for a longer time. The next most common length of time is 1 – 2 hours which is more believable. The secondary source of lighting is mostly used very briefly (0-1hours) with respondents saying for example that firewood or elephant grass is only used while cooking.

1.5.4 Energy Use Options

Respondents were asked various questions regarding their energy use, responses are shown below for each question.







Most of the respondents indicated that they thought their energy is expensive or very expensive (48% in total), whereas 40% thought their energy is cheap or fair. A clearer response is found in the next question, where 76% of respondents stated that their household has less or much less access to lighting than other households. The clearest response is in the final question, where 95% of respondents indicated that electricity meets the needs of the community a little or not at all.

1.5.5 Willingness to pay for energy services

Respondents were shown a variety of pico solar products, a picture of a solar home system, and a picture of a minigrid. Each product or system was described to them, including the main features and how it worked. Respondent were then asked to state what a fair price would be for rental for once month of the product, and then a fair price to purchase the product.

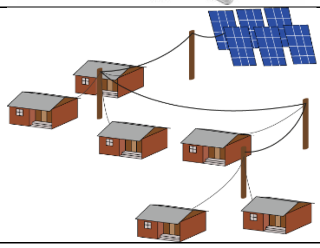
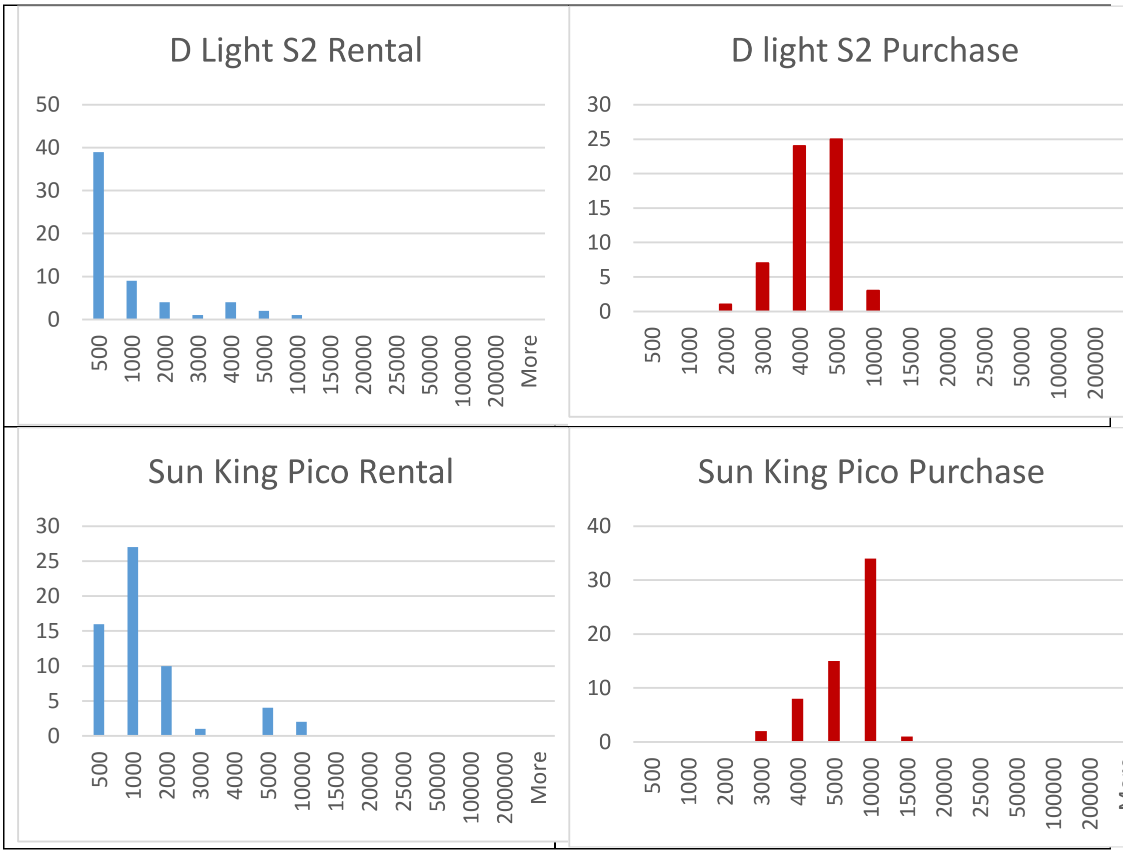
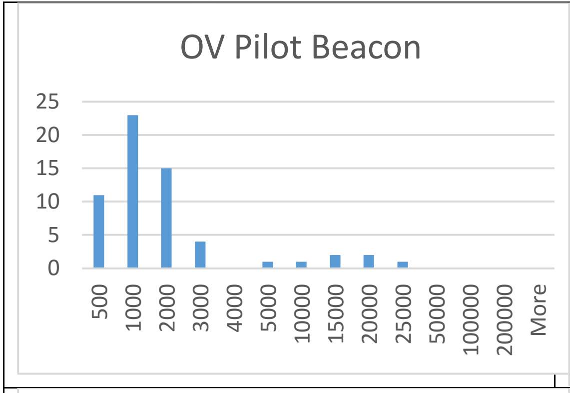
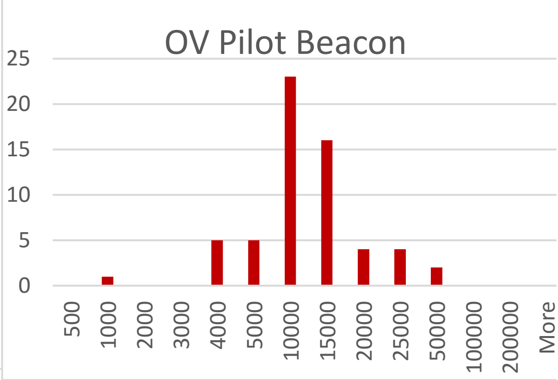
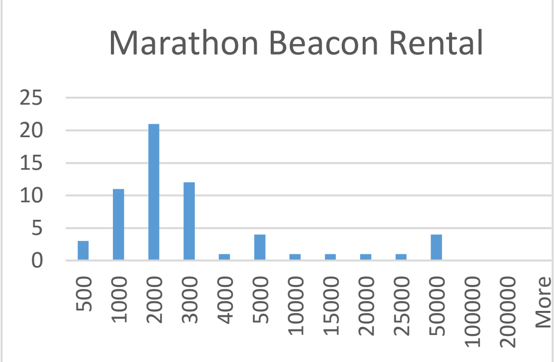
Dlight S2	only lights, no phone charging
Sunking pico	Only lights
OV Pilot	Light stand, phone charging 1.8
Marathon beacon 380	3 lamps, phone charger, 5.5Wp panel, remote control
Solar Home System	
Minigrid	

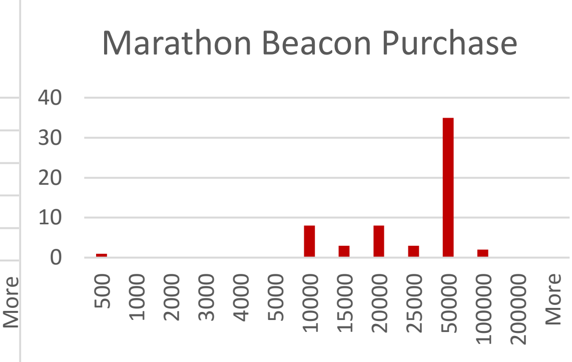
FIGURE 78: WILLINGNESS TO PAY FOR ENERGY SERVICES

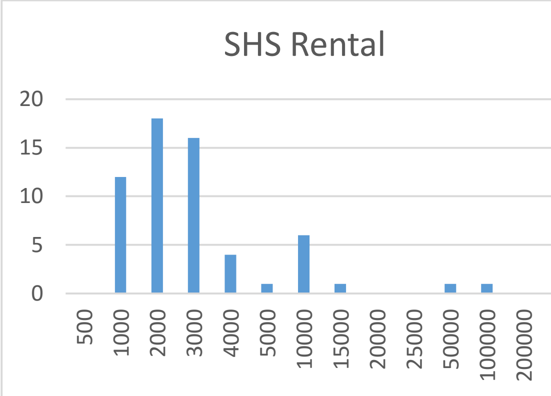


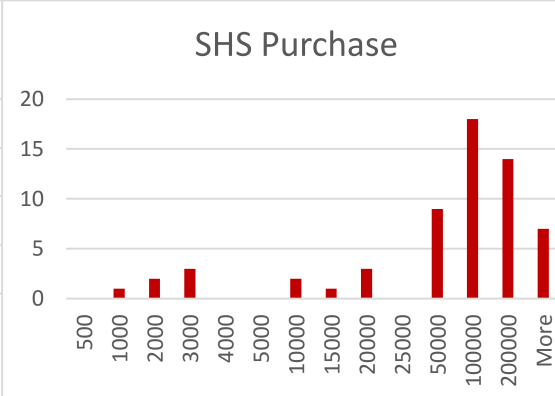


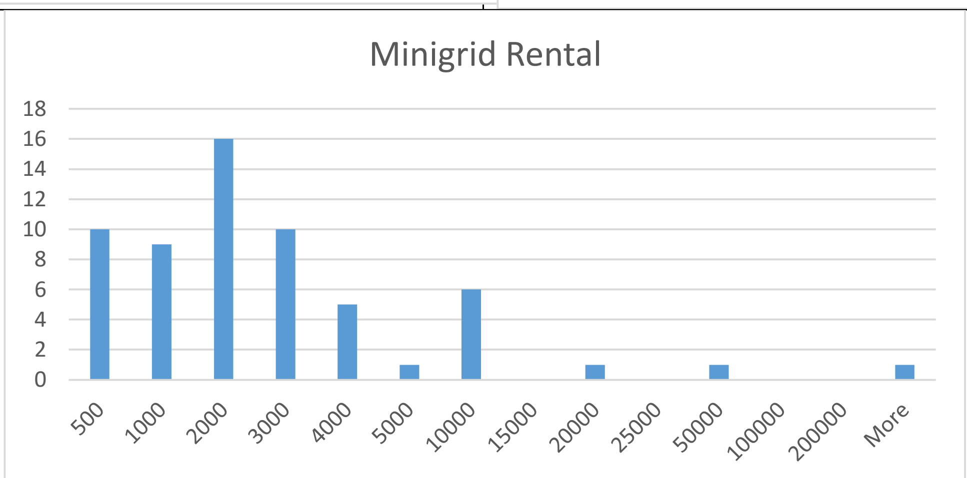












Appendix G – Full list of Wind Empowerment members.

FIGURE 9: WIND EMPOWERMENT MEMBER ORGANISATIONS.

1.5.6 University of Strathclyde

The University of Strathclyde have a historical link with Malawi and have been working on projects relating to Health, education, water and sanitation, and energy in Malawi for over 10 years. Related to rural electrification, previous UoS projects in Malawi include Community Rural Electrification and Development (CRED) and the Malawi Renewable Energy Acceleration Programme (MREAP) (University of Strathclyde 2016). CRED saw 6 solar systems installed to provide power for rural primary schools, while MREAP was a large programme focussing on institutional support at government and district levels, capacity building in Universities, and a community energy programme installing 70 different renewable energy projects in 12 districts. Currently UoS are supporting Community Energy Malawi (CEM), the successor of the MREAP programme, in its role to provide community energy access across 12 districts, and coordinating the Sustainable Off Grid Electrification of Rural Villages (SOGERV) project installing solar systems in the South of Malawi and looking in depth at how they perform technically, financially, socially and organisationally.

2 Methodology

Table 2 outlines the multidisciplinary methodology used to collect, process and analyse data for this market assessment. In theory, the market assessment methodology can be neatly subdivided, as Table 2 suggests, however in practice, all three key stages were carried out in parallel, with the data collection, processing and analysis often taking place simultaneously. Both quantitative and qualitative data were interweaved, for example by using qualitative data collected from interviews, questionnaires and observation on energy livelihoods relevant to the Malawian context to inform the load profiles modelled using the techno-economic energy systems modelling. The preliminary results of one stage inform the data subsequently collected in another and vice-versa. A socio-technical approach was adopted throughout this study, in which people are seen as equally important as technology. This approach reflects that fact that what may be optimal in one particular local context may be far from it in another. For example, does carving blades from wood make sense in locations where there are no trees, such as the plains of Inner Mongolia or the high peaks of the Peruvian Andes? If there are no trees, there is also likely to be a lack of carpentry skills with which to carve any wood that may be brought in from elsewhere. The appropriateness of wood as a construction material and consequently the optimisation of a set of blades can therefore be said to be governed by the interaction of the social and the technical. Separating the two is impossible and as a result, in order to understand one, the other must also be understood.

TABLE 2: COMPARISON OF THE THREE PRINCIPAL STAGES CARRIED OUT DURING THIS MARKET ASSESSMENT.

STAGE	KEY RESEARCH QUESTIONS	DATA COLLECTION TECHNIQUES	DATA PROCESSING TECHNIQUES	DATA ANALYSIS FRAMEWORKS	KEY OUTPUTS
STAGE I: LEARNING FROM EXISTING INITIATIVES	What are the critical success factors? Which solutions could be scalable?	Expert interviews Local case studies - Interviews - Questionnaires - Observation - Project report review - Datalogging	Transcription/note taking & summary according to specific themes Energy systems modelling Basic statistical analysis	Socio-technical approach	Identification of scalable delivery models & critical success factors
STAGE II: QUANTIFYING THE POTENTIAL MARKET	How scalable are these solutions?	Primary data (from local case studies & RE suppliers): - System configuration - Economic data Secondary data: - national statistics - GIS layers	- Energy systems modelling (HOMER) - Geographic Information System (QGIS) - Python script to link HOMER with QGIS	2 stage HOMER/QGIS filter	Market size and location
STAGE III: MAPPING THE ENERGY ACCESS ECOSYSTEM	What are the key barriers preventing these solutions from reaching scale? What can be done to overcome them?	Expert interviews[7] Literature review	Transcription/note taking & summary according to specific themes	Energy access ecosystem framework	Recommendations for targeted interventions

[7] As the interviewees and topics discussed overlapped significantly, the expert interviews conducted in Stages I and III were conducted together.

2.1 STAGE I: Learning from existing initiatives

2.1.1 Global experiences with locally manufactured SWTs

Learning from past experiences through case study research can offer valuable insight into both the generic and contextual factors that contribute to the success or failure of a particular technology. Sumanik-Leary et al. (2013) combined case study work conducted in Peru, Nicaragua and Scotland with the collective experience of the Wind Empowerment association[8] to derive the check-list of factors shown in Table 3 that depict the ideal context for SWTs. These factors are assessed throughout this market assessment to determine how closely Malawi matches this ideal context, and therefore how viable locally manufactured SWTs are likely to be. Figure 10 shows the way in which many of these factors interact, highlighting the key actors and the roles that they must carry out in order to facilitate sustainable rural electrification with locally manufactured SWTs.

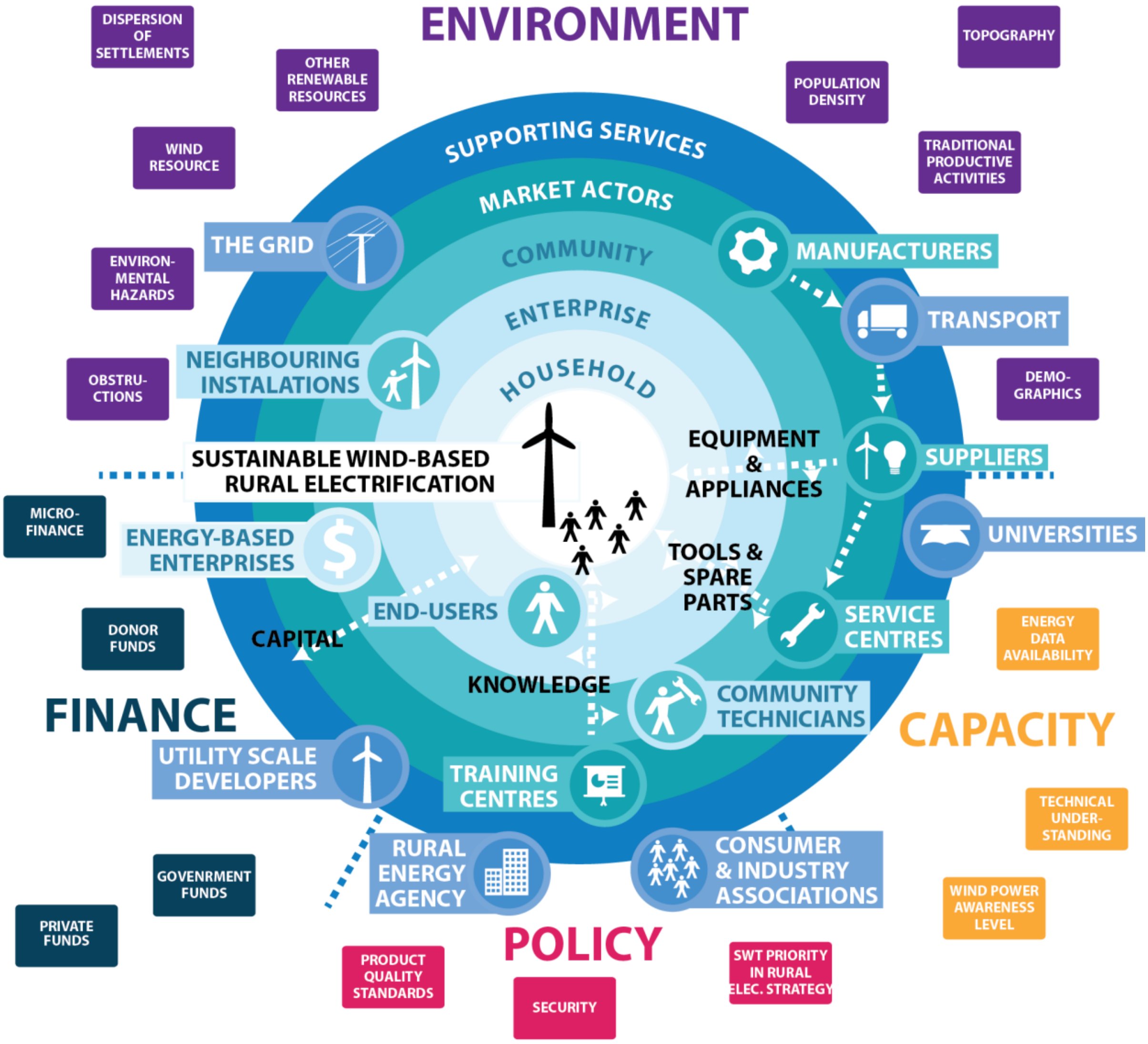
TABLE 3: IDEAL CONDITIONS FOR LOCALLY MANUFACTURED SWTS - THE MOST CRITICAL FACTORS ARE SHOWN IN BOLD/ITALIC (Sumanik-Leary et al. 2013).

Enabling environment	Environment	∗ High wind resource (>4m/s monthly average throughout the year) in the regions where most people lack access to electricity. ∗ Lack of environmental hazards (low frequency of dangerously high winds and lightning strikes and cool, inert environment to prevent corrosion, overheating or contamination with dust/sand). ∗ Solar or hydro resources that peak in the opposite season to the wind resource and cannot provide sufficient power generation throughout the year. ∗ Flat plains with no trees or other obstructions (to cause turbulence, reduce wind speeds and necessitate individual site assessment). • Wind resource that peaks in the same season as traditional productive activities, e.g. dry season for farmers in need of irrigation. • High air density (cold, low altitude) for maximum power extraction and cooling of the generator.
	Finance	∗ If there is insufficient access to capital, the potential for establishing energy based enterprises should be high and/or innovative financing models such as pay-as-you-go energy metering should be available. ∗ Targeted subsidies for providing maintenance services or wind resource assessment can be effective
	Capacity	∗ High level of awareness of SWTs and understanding of the technical advantages and disadvantages. ∗ Freely available high quality wind maps (validated with anemometry in the areas where SWTs are most viable, of high resolution and relevant to low hub heights).
	Policy	∗ A realistic evaluation of the national potential for SWTs and a plan for how to achieve this potential, which forms part of national rural electrification strategy. ∗ In complex terrain, individual wind studies should be supported for each new location. ∗ Strong and consistent institutional support to foster the development of a strong SWT ecosystem, in particular the social infrastructure required for maintenance. • Product quality standards that ensure consumer confidence, but don't unnecessarily hinder manufacturers. • Government endorsement to build trust in SWTs. • Tax exemptions for imported SWTs, wind pumps, power electronics and batteries. • Favourable feed-in tariff to encourage grid-tied SWTs.
Supporting services		∗ Good transportation infrastructure that facilitates easy access to installation sites. ∗ Consumer and industry associations that share knowledge between SWT market actors and give them a voice in the policy arena. • Universities that are willing to collaborate with SWT market actors in specific research projects, as well as offering wind power related training. • Utility-scale wind farm developers willing to support SWT market actors with funds and experience. • Grid electricity available in a nearby town/city (if manufacturing centrally).
Market actors		∗ A variety of training and demonstration centres that can raise awareness of SWTs and empower community technicians/end-users. ∗ A network of service centres capable of bridging the gap between the supplier/manufacturer and the community by offering technical support for SWTs at a local level. • A variety of construction material suppliers offering products relevant to SWTs (if manufacturing locally). • A variety of SWT manufacturers offering a range of products that are well matched to local needs. • A variety of SWT suppliers with regional branches in all areas where SWTs are viable, offering support for site selection and system design, as well as installation.

[8] Currently over 40 member organisations in over 25 countries and still growing.

Community	* High level of technical knowledge available at a local level. * Highly motivated individuals to take on the role of community technician. * End-users with sufficient capital to pay for O&M costs or a willingness to use the electricity to generate sufficient revenue. • End-users that are willing to adapt their behaviour around the availability of the wind resource.

FIGURE 10: GRAPHICAL REPRESENTATION OF THE MANY ELEMENTS THAT MAKE UP THE SOCIO-TECHNICAL SYSTEM IN WHICH SWTS EXIST AND THE VARIOUS COMPLEX INTERACTIONS BETWEEN THEM. ADAPTED FROM (PRACTICAL ACTION 2012) BY (Sumanik-Leary et al. 2013).



2.1.2 Community case studies

The aim of the community case studies was to determine the contextual factors specific to Malawian communities that could influence the viability of PV-wind hybrid systems. For example, typical livelihoods, energy resources and existing technical capacity. The findings from the community case studies were used to inform the techno-economic spatial analysis described in *STAGE II: Quantifying the potential market*, for example by guiding the selection of which energy services to model, what ranges of renewable resources to include and what delivery model to employ. Primary data was collected during field work in two specific communities, Kamilaza (Fwasani CBO) and Elunyeni. Key stakeholders in these two energy access initiatives were interviewed and relevant project reports were reviewed. In addition, further interviews were conducted with stakeholders from other previous initiatives (e.g. Solar Kiosks), the methodology for which is described in *STAGE III: Mapping the energy access ecosystem.*

An initial review of wind speed data showed that although the wind resource in most of the country is poor, a few small pockets of reasonable wind exist, mainly in the central and northern areas of Malawi. The two largest such pockets are located in the regions of Dowa and Mzimba:

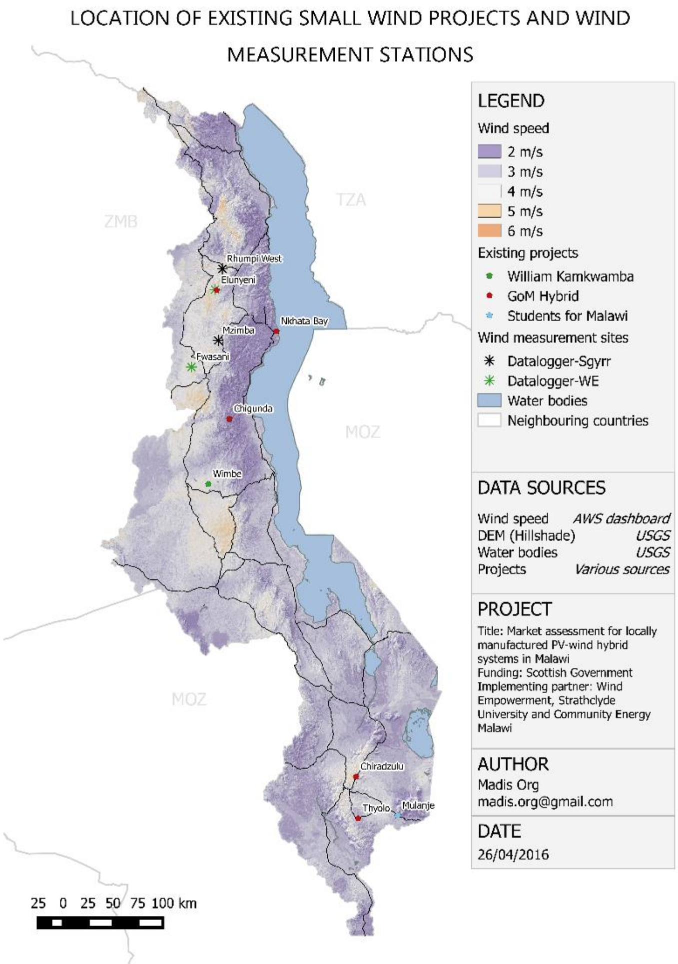
- Dowa has a high population density and is within reasonable distance of the capital city, Lilongwe. As a result, it is expected to be connected to the national grid infrastructure within a relatively short timescale, as the Malawi Rural Electrification Program (MAREP) is looking to connect large population centres.
- Mzimba is further from major population centres and as a result, there are a significant number of remote, rural communities with a low probability of grid connection in the short to medium term.

Consequently, although the analysis in this market assessment covers the whole country, the focus is on the Mzimba region, as this is expected to be the most viable region for PV-wind hybrid systems. Within the Mzimba region, two specific communities were selected as case studies:

- Fwasani – one of the twelve CBOs supported by Community Energy Malawi. A prospective analysis was conducted to determine the viability of a PV-wind hybrid system in the Kamilaza community that it serves.
- Elunyeni – one of six PV-wind hybrid mini-grid systems installed by the Government of Malawi under the Solar Villages initiative. A retrospective analysis was conducted in order to evaluate the impact of this project and draw out the key lessons learned.

Data was collected from these two communities using interviews, focus groups, questionnaires, dataloggers and observation during field visits to Kamilaza (Fwasani CBO) and Elunyeni on the 25th and 26th January 2016, respectively. Basic statistical analysis was carried out on the questionnaire data in order to pick out the key trends, such as the most desirable energy services. Figure 11 shows where these two communities are located within the context of the wind resources available in Malawi and the other small wind projects and wind measurement stations discussed in this report. It shows that Kamilaza (Fwasani CBO) has a slightly higher wind potential, and as a result, this community was selected as the default case for the energy systems modelling during the in depth techno-economic analysis described in *STAGE II: Quantifying the potential market*.

FIGURE 11: LOCATION OF COMMUNITY CASE STUDIES, OTHER SMALL WIND PROJECTS AND WIND MEASUREMENT STATIONS.



2.1.2.1 Interviews, focus groups and questionnaires

In Kamilaza (Fwasani CBO), a focus group was held with 20-30 community members in order to discuss how they were currently using energy, how they perceived different energy technologies and how they saw their energy futures. The focus group was facilitated by Fwasani CBO and CEM staff. The session was recorded and summarised to draw out the key issues. Questionnaires were administered to 10 households and 4 businesses in order to determine their energy consumption and expenditure, willingness to pay for specific energy services and awareness of particular energy technologies. Responses were collected using the KoboCollect smart phone application (see Figure 12) and processed using KoboToolbox[9], which offers basic statistical analyses. Observations were recorded throughout the visit by photograph and field diary.

FIGURE 12: COLLECTING DATA ON HOUSEHOLD ENERGY USE USING KOBOCOLLECT SMART PHONE APPLICATION IN ELUNYENI.

[9] http://www.kobotoolbox.org/

In Elunyeni, a focus group was conducted with community leaders and technicians in order to learn about the delivery model for the PV-wind hybrid mini-grid, the impact of the system on the people living in the community and any other relevant issues (see Figure 13). Participatory methods were used to determine what had happened to the PV-wind hybrid system since it had been installed by collaboratively producing a timeline of each system component, detailing the failures that had occurred, the time spent out of service and the procedure for making a repair. The community technicians took the research team on an observational tour of the community energy system, and data was collected using both photographs and field diaries.

FIGURE 13: FOCUS GROUP FACILITATED BY CEM/WE WITH COMMUNITY LEADERS AND TECHNICIANS IN THE PV-WIND HYBRID SYSTEM POWER HOUSE AT ELUNYENI.

2.1.2.2 In-situ wind and solar resource measurements

Malawi has 22 weather monitoring stations that have been recording wind speeds for many years, however the vast majority are measuring at 2m height, which is too low for wind energy applications (see *Appendix B – Input data for techno-economic spatial modelling in Stage II* for more details). As a result, a data-logging system was installed in each community during the field visits in January 2016 to obtain in-situ measurements of the wind resource that could verify the predictions made by the AWS TruePower database. Table 4 describes the technical specifications of the datalogging systems and Figure 14, Figure 15, Figure 16 and Figure 17 show where they were installed. This measured data was used as part of the validation for the simulated data used in the techno-economic spatial modelling, however, due to the short length of time available for data recording, it was considered insufficient for direct use in the modelling. The data from the data loggers is in human-readable .csv files, with one file created per day. Analysing this data can be done using Excel, however some open-source python analysis scripts have been written to make this process easier and available for download[10]. It should be noted that these analysis tools are a work in progress due to the developmental nature of these low cost data logger units. It is hoped to provide better tools and simpler work flow in the future.

TABLE 4: TECHNICAL SPECIFICATIONS OF DATALOGGING SYSTEMS INSTALLED IN THE TWO CASE STUDY COMMUNITIES.

	Kamilaza (Fwasani CBO)	Elunyeni
Installation date	25th January 2016	26th January 2016
GPS Coordinate	Lat: -11.95099164 Long: 33.49602745	Lat: -11.22919796 Long: 33.70477519
Altitude	1280m	1200m
Anemometer height	10m	10m
Tower	Purpose built wooden mast with boom	Purpose built wooden boom on tower of one of the three existing SWTs
Solar irradiation	PV panel	PV panel
Wind speed	Inspeed vortex & unbranded weather station spare part	Inspeed vortex & unbranded weather station spare part
Wind direction	Unbranded weather station spare part.	Unbranded weather station spare part
Sampling rate	1 second	1 second
Averaging interval	1 minute	1 minute
Manufacturer	RE-Innovation.co.uk	RE-Innovation.co.uk
Data storage	SD card	SD card
Power supply	Disposable battery	Disposable battery

FIGURE 14: THE PHOTO WAS TAKEN DURING THE INSTALLATION OF THE WIND DATA LOGGER. THE 10 M TALL MAST HOLDS AN ANEMOMETER AND A WIND VANE. THE MAST WAS LOCATED IN THE VICINITY OF THE VILLAGE CENTRE, ON A RELATIVELY OPEN FIELD.

[10] https://github.com/matthewg42/winda - installation will require Python 3.4 or higher.

FIGURE 15: AERIAL PHOTOGRAPH (GOOGLE MAPS) OF THE VILLAGE OF KAMILAZA (FWASANI CBO) WITH SOME OF THE MAIN FACILITIES IDENTIFIED. THE RED DOT INDICATES THE SITE WHERE THE WIND DATA LOGGER WAS INSTALLED DURING THE FIELD VISIT IN JANUARY 2016.

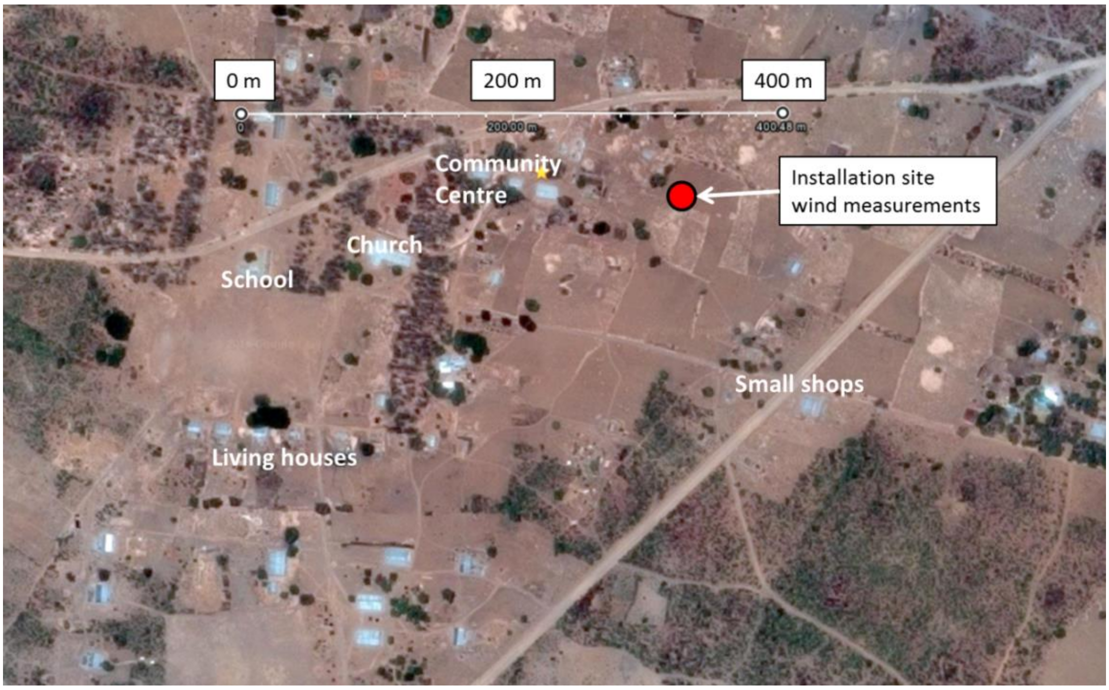


FIGURE 16: DATALOGGER INSTALLATION ON EXISTING SWT TOWER AT ELUNYENI.

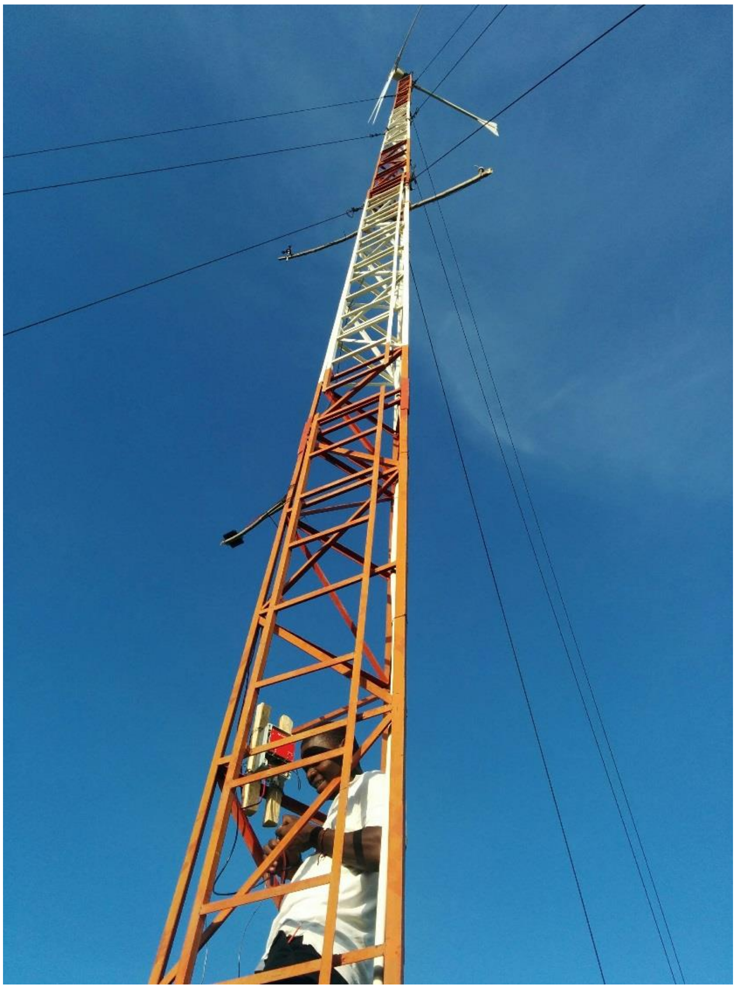
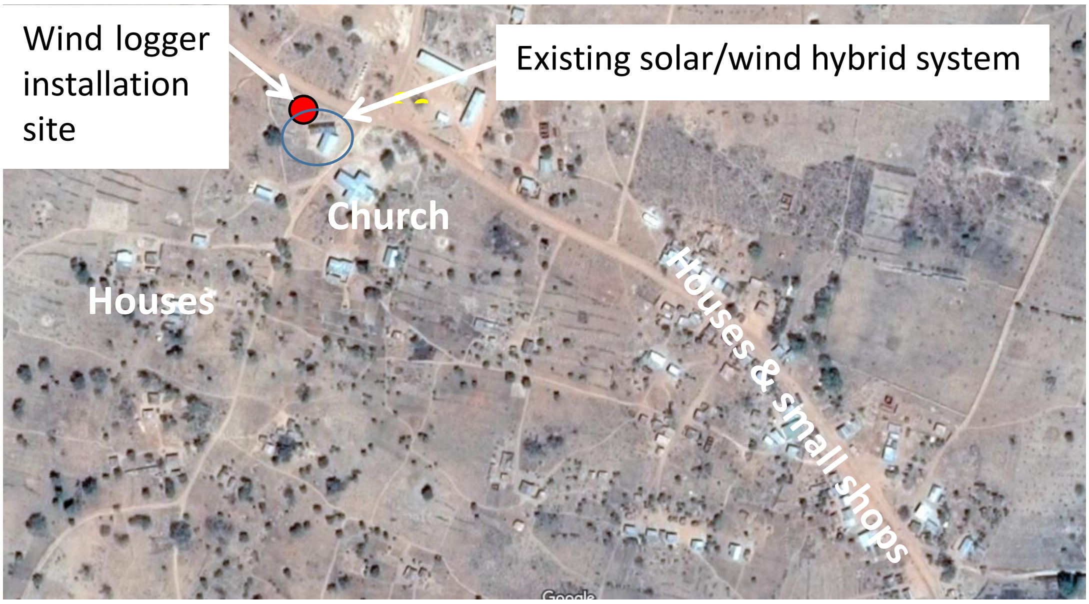


FIGURE 17: AERIAL PHOTOGRAPH (GOOGLE MAPS) OF THE VILLAGE OF ELUNYENI WITH SOME OF THE MAIN FACILITIES IDENTIFIED. THE RED DOT INDICATES THE SITE WHERE THE WIND DATA LOGGER WAS INSTALLED DURING THE FIELD VISIT IN JANUARY 2016.



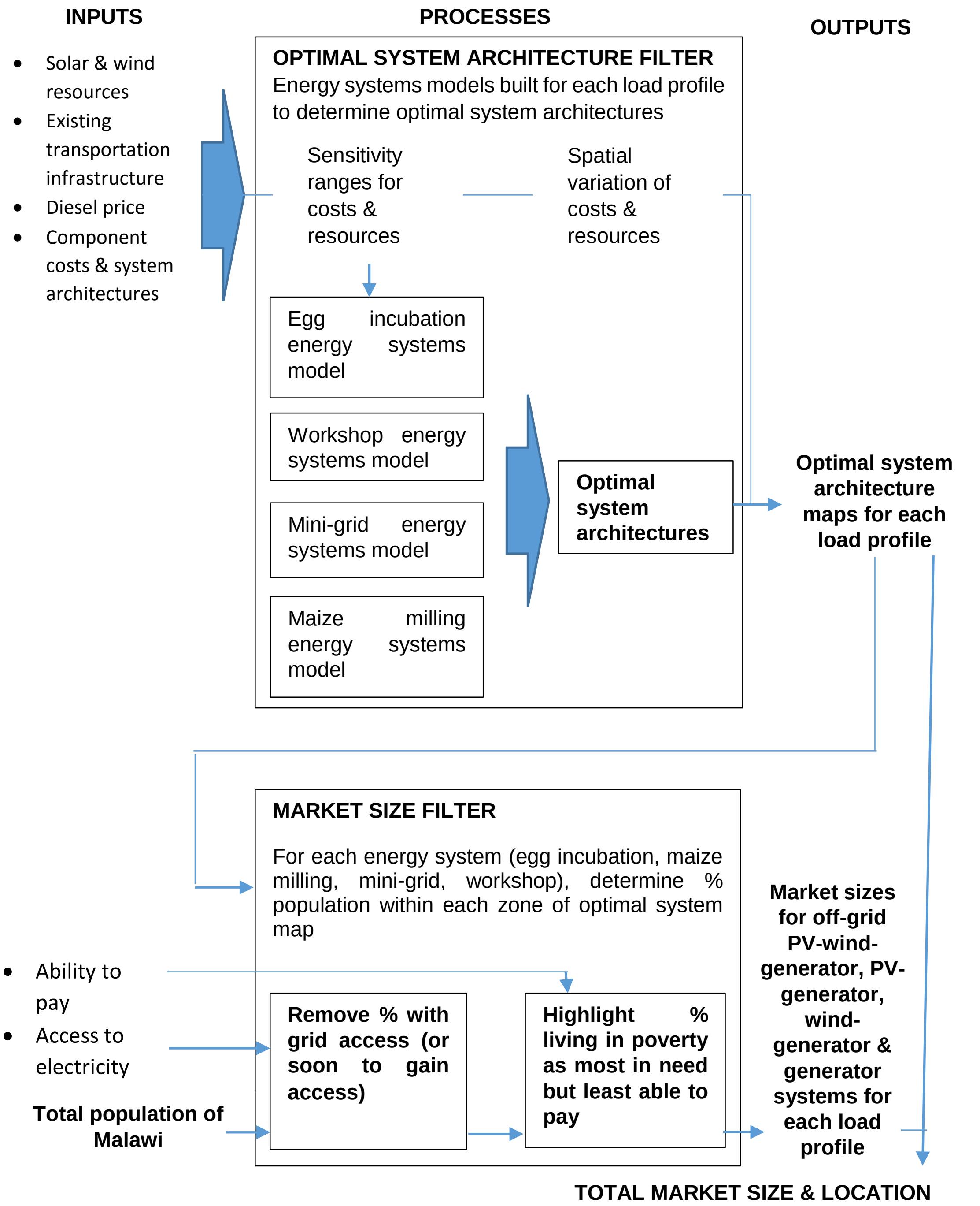
2.2 STAGE II: Quantifying the potential market

2.2.1 Methodology overview

This stage of the market assessment takes the locally appropriate energy systems identified in the previous stage and tests their scalability across the country. The prospective case study conducted in Kamilaza (Fwasani CBO) was chosen as a location representative of Malawian communities with good wind and solar resources and as a result, the energy systems prioritised by people in Kamilaza were modelled during this stage of the market assessment.

Figure 18 offers an overview of the methodology employed to locate and quantify the market for 1kW scale locally manufactured PV-wind hybrid systems. The evaluation was conducted using computer simulations primarily conducted in the techno-economic and spatial modelling packages, HOMER and QGIS.

FIGURE 18: SCHEMATIC OF THE METHODOLOGY EMPLOYED TO LOCATE AND QUANTIFY THE MARKET FOR PV-WIND HYBRID OFF-GRID SYSTEMS IN MALAWI.



A user-focussed approach was employed to match energy services in demand by rural people in Malawi with the energy resources available in their local area and appropriate system architectures that are capable of harnessing them cost-effectively. As described in the previous section, demand for a variety of energy services was estimated using the results of the questionnaires carried out in Kamilaza (see *Appendix B – Input data for techno-economic spatial modelling* for details). As a result, the four representative load profiles described in Table 5 were selected for further analysis. The ability of the following hybrid system architectures to meet these load profiles was investigated:

- Generator only
- PV-generator
- PV-wind-generator
- Wind-generator

TABLE 5: DETAILS OF THE FOUR REPRESENTATIVE LOAD PROFILES SELECTED FOR THIS ANALYSIS.

Representative load profile	Description	Similar load profiles
Maize milling	Very popular with almost all households. Maize is a staple crop grown and eaten in Malawi and the main ingredient of Nsima. 96% of maize consumed in Malawi is grown in Malawi.	Agricultural processing
Egg incubation	From initial data this was a popular household load, although it is less popular as a business proposition.	Small but consistent 24 hour loads, e.g. mobile phone charging
Small workshop	Small workshops offering metal and woodworking services offer local people the opportunity to fabricate and repair products locally.	Daytime loads with a range of appliances, e.g. barber shop, beauty parlour, convenience store
Mini-grid (inc. water pumping)	A mini-grid could provide refrigeration, lighting, mobile phone charging and entertainment to a small community. Excess energy could be used to pump water, which is very popular for irrigation and potable water extraction.	Variety of appliances with peak demand in the evening.

Figure 18 shows that the output data from each of the four HOMER models was matched with the GIS layers describing the spatial variation in diesel price, renewable resources and existing transportation infrastructure in order to produce four output layers displaying the optimal system architecture to meet that particular load throughout Malawi. Finally,

Figure 18 shows that a further spatial analysis was conducted in order to determine the size of the market in each of these regions. Each optimal system architecture layer was overlaid on the population distribution layer to calculate the fraction of the population living in each region. The national grid infrastructure layer was used to subtract those people living close to the grid, as they would either already have access to grid electricity and if not, then grid extension is assumed to be the most viable means of meeting these loads. Finally, the poverty index layer was used to highlight those living on under $2 (USD) per day, as these people would be most in need of access to electricity, but would be least able to pay for it. Full details of this methodology are given in Appendix B – Input data for techno-economic spatial modelling.

2.2.2 Input data

Table 3 shows that there are a huge number of factors that must be taken into account in order to properly assess the market for off-grid PV-wind hybrid systems. Some of these factors are quantifiable and those for which suitable supporting data could be obtained were included in the techno-economic spatial analysis. Table 6 describes the data collected for each of these factors and the methodology used to integrate this data into the overall analysis.

TABLE 6: THE DATA COLLECTED AND THE TECHNIQUES USED TO PROCESS IT FOR EACH FACTOR TAKEN INTO ACCOUNT IN THIS MARKET ANALYSIS.

Factor	Data collected	Data sources	Software
Component costs & system architectures	System architectures taken from previous projects & component costs calculated for each configuration. Road network used to estimate transport costs for installation & maintenance.		
	Cost breakdowns for LMSWT materials, energy system components, installation & O&M.	Actual costs from Students for Malawi project reports Quotes from Malawian RE suppliers Malawi Bureau of Land (2016) Field visits Expert interviews	Excel, HOMER
Diesel price	Local diesel price calculated by adding cost to transport fuel to remote communities.		

	National fuel price, land use, topography & road network GIS layers	Field visits Expert interviews European Space Agency (2010) Radar Topography Mission (SRTM) Malawi Bureau of Land (2016)	HOMER, QGIS
Energy demand	Actual energy demand in Kamilaza (Fwasani CBO) estimated using questionnaires. Traditional productive activities matched with appropriate energy services. Population distribution used to calculate market size.		
	Load profiles, population distribution	Site visit Literature review Expert interviews	Excel, HOMER, QGIS, KoboToolbox
Electricity access	Population with access or soon to gain access to national grid excluded from market size for off-grid systems.		
	Map of existing national grid infrastructure	National Roads Authority (high voltage) Dept. Rural Affairs (Low voltage)	QGIS
Solar & wind resources	Spatial variation of solar & wind resources (18m height) from mesoscale modelling fed into optimal system map using HOMER modelling results. Land use & topography used to assess difficulty of making local resource assessments. Surface roughness from land use used to convert wind resource different heights. Python scripts used to investigate complementarity on different timescales. Site specific data used to validate mesoscale modelling.		
	Land use, topography & solar/wind resource GIS layers. Site specific wind resource measurements.	(Meteonorm 2016) World Bank European Space Agency (2010) Radar Topography Mission (SRTM) (AWS Truepower 2016) SgurrEnergy (2013) Datalogging	QGIS, HOMER, Python, Excel
Ability & willingness to pay	Questionnaires used to assess current energy expenditures, willingness to pay for energy services. Spatial analysis of poverty levels used as indicator of ability to pay.		
	Poverty levels, household/business questionnaires	Global dataset WorldPop (2015) Household & business surveys	QGIS, KoboToolbox

2.2.3 Techno-economic energy systems modelling

2.2.3.1 Modelling in HOMER

An energy system links the energy resources available in any particular place with energy demand. In this study, HOMER (Hybrid Optimization Model for Electric Renewables) software was used to model and optimize the performance of different energy system architectures. HOMER (http://www.homerenergy.com) is a modelling and simulation package designed specifically for modelling hybrid renewable energy systems. HOMER Legacy edition was used for this analysis.

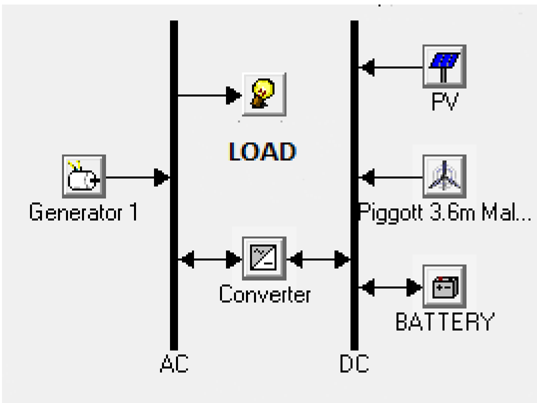
HOMER simulates the system operation by calculating the energy balance on an hourly basis over the entire year across all possible system configurations. The output allows the user to analyse the techno-economic operation of an overall system configuration in terms of both energy and cash flows. The optimization that HOMER performs ranks the system configurations that meet (or exceed) the specified energy demand in terms of energy production according to Net Present Cost (NPC). The NPC takes into account all expected costs related to the implementation and operation of the energy system over its life-time, adjusted for discount rates and inflation.

The energy system designs set up within the HOMER software follow a generalised architecture illustrated in

Figure 19. The technical system allows electricity production from a combination of SWTs, solar PV panels and/or a diesel generator. Energy storage is inevitably necessary to allow a system involving renewable resources with variable availability to provide electricity access at all times. All system configurations assume standard lead-acid battery storage. Further, a bi-directional inverter converts electricity between Alternating- and Direct Current (AC/DC). The technical system operates within an economic environment which is parameterized in HOMER to a set of input values entered by the user in order to represent the economic, social and technical constraints in which the system must operate. The input data for the HOMER simulations is summarised in Table 6 and presented in detail in *Appendix*

B – Input data for techno-economic spatial modelling. To run the HOMER model, we needed time-series data for both the solar resource and wind speed.

FIGURE 19: SYSTEM COMPONENTS MODELLED IN HOMER FOR THIS MARKET ASSESSMENT.



2.2.3.2 Key assumptions and sensitivities

The investment cost of equipment required to define the energy system was collected directly from suppliers in the main urban areas of Lilongwe and Blantyre, gathered during the field visit in January 2016 or extracted from implementation reports of SWTs conducted by "Students for Malawi" in 2015 (Maclean & Friese 2015). There is an intrinsic uncertainty when it comes to cost estimates due to the highly variable national inflation rate, as well as a range of qualities to choose from. Where is was not possible to obtain particular items in Malawi, UK prices were used and where it was not possible to obtain full quotations for the complete range of sizes of particular components, a linear extrapolation was used (for example, generators are priced at $336/kW). In a similar way, operation and maintenance costs are set as rough figures based on experiences from similar projects or with reference to similar activities in Malawi. The cost estimates have been verified by comparing to costs presented for similar systems in nearby countries.

To test the impact of the component cost increase and decrease on the final optimal system design, the HOMER model included sensitivity parameters that scale the various cost inputs with a multiplier factor. The practise helps to evaluate the stability of the simulated result, but can also serve to better understand where it makes sense to put efforts to cut expenses, or for example what impact a future higher diesel price would have.

Labour and business costs that would be required to manufacture SWTs locally were not included in this analysis, as local job creation is seen as a positive outcome. However, it should be noted that the results of the analysis must therefore show very strong potential for SWTs in order to justify any decision to promote them in a specific area, else it is unlikely that such an initiative could ever be economically sustainable.

For renewable resources, the community study in Kamilaza (Fwasani CBO) was used as the default case for the HOMER simulations. The solar and wind resources were then varied as a sensitivity to investigate how other areas with different resources may compare. As shown in *Appendix B – Input data for techno-economic spatial modelling*, the solar and wind resources have a very similar seasonal profile throughout Malawi, making this a valid strategy. Table 7 shows each of the sensitivities investigated by the HOMER modelling. The main factors affecting the system design are the cost of diesel (the actual cost of diesel varies depending upon location, due to haulage costs), renewable resource availability, load variations and the falling price of PV. Although both 12m and 18m towers were originally modelled, the subsequent wind resource analysis was conducted at 18m, due to the generally low levels of wind resources available in Malawi.

TABLE 7: MODELLED SENSITIVITIES FOR EACH LOAD PROFILE.

Parameter	Range of values	Step size	Units

Wind resource sensitivity	4-6	1.0	m/s
Solar resource sensitivity	4-7	0.5	kWh/m2
Reduction of PV cost	50-100		%
Increase of diesel cost	1.12-2.5	0.25	$/l
Increase in load	-20 to +20		%
Increase in tower height	12, 18		m

2.2.4 Spatial modelling

The open-source GIS software, QGIS, was used to process the spatial data obtained. The GIS layers used as inputs for this analysis are listed in Table 6 and the techniques used to process each one are described in *Appendix B – Input data for techno-economic spatial modelling*. Table 8 lists the custom GIS layers created during the course of this analysis, which are described in detail in the following sub-sections.

TABLE 8: CUSTOM GIS LAYERS CREATED FOR THIS STUDY AND THE KEY INPUT DATA USED TO CREATE THEM.

Filter	Custom GIS layer name	Key input data
Optimal system architecture filter	4x 'Optimal system architecture layers'	• Output file from HOMER simulations of 4 load profiles • Solar resource GIS layer • Wind resource GIS layer • Diesel price GIS layer
	'Diesel price layer'	• Petrol station location GIS layer • Road network GIS layer • Land cover GIS layer
Market size filter	'Grid proximity layer'	• PDFs of existing and planned power lines
	4x 'Off-grid market size layers'	• Population distribution GIS layer • 'Grid proximity layer' • 4x 'Optimal system architecture layers'
	'Ability to pay layer'	• Poverty distribution GIS layer • Population distribution GIS layer • 'Grid proximity layer' • 4x 'Optimal system architecture layers'

2.2.4.1 Optimal system architecture filter

Maps of Malawi depicting which system architectures are most viable for meeting each of the four load profiles described above were developed using the output from the four independent HOMER simulations. Sensitivity analyses were run in HOMER in order to model the effect of the three most spatially varying parameters (diesel cost, solar irradiation and wind speed). A HOMER output file indicating the optimal system architecture for all possible combinations of these resource parameters was used as an input for QGIS, so that each point within Malawi could be matched with a corresponding optimal system architecture. No existing tool could be identified to carry out the task of efficiently creating a single raster image out of the roughly 200 range combinations, so a custom Python script was developed. The HOMER results file also indicates the share of renewable energy for each of the optimal systems, so the Python script was extended to also map out the proportion of renewable energy within each optimal system architecture, for each pixel on the map.

2.2.4.2 Market size filter

A further spatial analysis was performed to calculate the number of people without access to the national grid in each optimal system areas for each various load cases. Firstly, a spatial estimation of the people connected to the grid was needed. Unfortunately no spatial layer of the ESCOM grid could be obtained. Instead, both the existing and planned power lines (400kV, 22kV, 132kV, 66kV and 33kV) from two separate PDF maps (Merz and McLellan Consulting Engineers 2010; National Roads Authority 2006) were traced and georeferenced in QGIS.

There are two main ambiguities associated with the map developed. Firstly, the smaller power cables are not drawn on the map and hence it is not possible to know exactly which areas are electrified and which areas are off-grid. Also, even though an overhead powerline exists, it does not necessarily mean that the area below it is electrified (the line could be just passing over the area without being transformed to low voltage for household consumption). To account for these ambiguities, the following methodology was developed. Firstly, a 3 kilometre buffer zone on both sides of the power line was assumed to cover the populated areas adjacent to the grid. This buffer layer was then merged with urban areas (mainly Lilongwe and Blantyre), that did not fall within 3km from the grid in order to create a *'grid proximity layer'*. Of course, not everyone living within this grid proximity layer is grid-connected, so using the zonal statistics functionality in QGIS, the people living within the areas covered by the grid proximity layer amounts to 39.2% of the overall population. Given the World Bank's (2016) estimate for the electrification rate in Malawi of 9.8%, it was possible to deduce an estimate for the fraction of people that are connected to the grid within this proximity layer (9.8/39.2=25%). Hence, 75% of the population within the grid proximity zone is still to be considered off-grid.

Based on this information, an *'off-grid market size layer'* was developed from the population map of Malawi, which reduced the population in the grid proximity zones by 25%. To generate this buffer zone, the planned grid extensions were also taken into account, even though no reliable estimate for the predicted increase in grid connected households could be found. For each of the four load profiles, the *'off-grid market size layer'* was then utilized to assess the potential market size for each of the optimal system configurations by calculating the number of people without access to electricity for each optimal system area.

According to the WorldPop dataset on poverty (Worldpop 2015), approximately 78% of the population of Malawi lives under 2USD/day. Using this dataset it is possible to estimate the average poverty level in each of the optimal system architecture areas defined above (separating out the areas defined as within the *'grid proximity zone'*). These poverty levels were used as an indicator of ability to pay, as whilst people living in poverty would be most in need of access to energy services, they would be the least able to pay for them, which would make the availability of innovative financing models more critical.

2.3 STAGE III: Mapping the energy access ecosystem

The final stage of this market assessment draws together the findings from the previous two stages, triangulating and supplementing the findings with the perspectives of a range of experts and a literature review. The key output of this section is a series of recommendations designed to facilitate the transition to the technological solutions recommended by the previous section by identifying the barriers preventing them from reaching scale and proposing targeted interventions to overcome them. Semi-structured interviews were employed to collect data from these experts. This approach allowed the interviews to capture respondents knowledge on energy access, SWTs, mini-grids and productive uses of energy, whilst at the same time leaving space to learn more about any specific projects that each interviewee may have been involved with or any other relevant experience they may have been willing to share. The standard questions asked to all respondents can be found in *Appendix C – Expert interview questions*.

Notes taken during the interviews were sent back to each respondent in order to verify that the information had been correctly recorded. The analysis of these interview notes grouped responses according to specific themes, assessing both conflicting and complementary viewpoints. The interviews were conducted in parallel with the techno-economic spatial modelling, which allowed the triangulation of findings between these two methodologies. A cross section of key experts were selected for interview across the rural development and renewable energy sectors in Malawi, as indicated in Table 9.

TABLE 9: EXPERTS INTERVIEWED FOR THIS MARKET ASSESSMENT.

Name	Organisation	Position	Reason for interview
Frederick Munthali	National Commission for Sensor Technologies	Chief Research Officer	Involved with SgurrEnergy wind measurements & PV-wind feasibility study
Joseph Kalowekamo	GoM Department of Energy Affairs	Deputy Director	Ministry of Energy representatives

& Conwell Chisale			
David Waller	DFW Consulting	Economic Consultant	Background in development economics
Drew Corbyn	Practical Action	Energy Consultant	Managing MEGA project in Mulanje
Martina Kunert	RENAMA/Renew'N'Able	Director	Involved with Students for Malawi projects & networking of Malawian energy access stakeholders
Laura MacLean & Ryan Cassidy	Students for Malawi	Project Officer & Director	5 SWT projects in Malawi
Edgar Bayani	CEM	Director	CEM Director
Peter Dauenhauer	Strathclyde University	Research Associate	Managed previous RE projects in Malawi and oversaw the formation of CEM
Collen Zalengera	Mzuzu University	Head of Energy Studies	Involved with SgurrEnergy wind measurements & very experienced with RE4D projects
Mjimapemba	UNDP	Energy Project Manager	Managing UN Energy Programmes
Cenard Mwale	DfID	Climate change Adviser	Managing DFID Climate and Energy Funding
Margriet Sacrani	Green Malata Project	Founder & Director	Contact recommended by Jerone Bowmers
Hament Tanna	Solair	Fouder & Director	Solar PV suppliers in Lilongwe
Francis Kambala	Solar Lite	Fouder & Director	Solar PV suppliers in Lilongwe
Karen Price	MEET	Executive Director	GEF project manager for Increasing Access to Clean and Affordable Decentralised Energy in Vulnerable Communities in Malawi, 10+ years field experience.
Stuart Miller	Calcon	Director	Energy consultant
Tawanda S. Madovi	IPCS House	Director	Energy entrepreneur
Winfred Kasakula	MERA	RE Specialist	Energy regulation

3 Results and discussion

This section presents the results of the analysis, joining together the findings from the three stages described in the previous section. Firstly, the energy access sector in Malawi is discussed, referring specifically to the sustainability of business models for small scale energy access projects in Malawi, mini-grids as a key opportunity, productive applications and the key drivers and barriers for rural access to energy. This is followed by a discussion on SWT manufacturing, wind/solar resource complementarity and the results of the techno-economic spatial modelling. Finally, these findings are drawn together to make an assessment of whether PV-wind hybrids are capable of addressing the issues faced by solar PV projects in Malawi.

3.1 Business models in the rural energy access sector in Malawi

It was not possible to find any case studies of successful and sustainable rural energy business models in Malawi. ‘Sustainable’ in this sense is defined as the creation of adequate capacity to operate and maintain the systems and the collection of tariffs that enable cost recovery of capital investment within a reasonable timeframe, as well as the ongoing operation and maintenance costs.

A variety of innovative solar delivery models have been piloted across Malawi, particularly in the southern region, such as the energy kiosks implemented by RENAMA and Powered by Nature. These involved the formation of energy committees with 2 people trained in maintenance. An engineer and Renewable Energy (RE) graduate were part of the initial training and are available for maintenance and upgrades according to community demand. The major issue is with the sustainability of remote systems, as they need technical assistance available locally. Although they are working on remote monitoring systems and hosting entrepreneurship courses led by women, they have found that having some men involved is beneficial, as they’re more confident at remote troubleshooting. The system also included renting out battery packs in order to bring electric lighting and phone charging opportunities to those predominantly using biomass and kerosene lamps. However the energy supplied was not adequate to power certain household appliances like TVs, initial estimation of what people would pay for systems was incorrect, in some cases equipment quality was not good enough. Although RENAMA and other players considered these very successful, there is a need for DoE to coordinate independent evaluations for these initiatives so that there is objectivity on what is a case that represent successful business model.

SunnyMoney (part of Solar Aid) has run a number of successful models in other countries but they are yet to demonstrate success in Malawi. SunnyMoney often uses school campaigns as the catalyst, getting the market started by offering affordable study lights at a promotional price. Agents and shops with dealers/distributors in key regions develop market further by selling and distributing the full range of affordable solar lights and products. They also drive demand via new products, promotions, advertising, media campaigns, brand building and customer care build demand for off-grid lighting. The experts cited a problem related to cost, i.e. households see the SunnyMoney products as expensive. Households prefer buying cheaper products most of which are of lower quality.

To improve energy access, a number of players (e.g. Alistair Lansden from University of Strathclyde) are piloting Pay As You Go business models. Although BBOXX has been piloted, there have been a lot of problems with loan repayment by most households, however this problem has partly been addressed by the introduction of a central charging system, where there are discounts for multiple charges.

In early 2000 or 2001, The Malawi Environmental Endowment Trust (MEET) signed an Agreement with the Department of Energy Affairs of the Ministry of Natural Resources and Environmental Affairs in which MEET was given the responsibility to manage funds called Credit Guarantee Funds. This fund was set aside by Malawi Government to provide loan guarantees to commercial loan Lenders for financing of Solar Home System (SHS) equipment purchases, in pursuance of its efforts to increasing access to affordable renewable resources of energy by the public in Malawi. The funds were provided by DANIDA (Danish International Development Agency) through the Department of Energy Affairs. Based on the experiences on how this project worked credit guarantees are key to sustain energy business models. This market assessment could take this business model into consideration or any other form of public private partnership arrangement.

Most renewable energy initiatives in the country have been short-lived, and a number of the experts indicated that there is no clear model that can be classed as most successful. In fact, even ESCOM is subsidised. Other experts felt it is difficult to showcase pure sustainable models for rural electrification that have a clear business sense, as there is a lot of interferences from government and NGOs. In Malawi, government wants to play the role of a market actor, whilst at the same time playing the role of regulator. NGOs are often accused of market distortion when carrying out hand out programmes in rural communities, as this can kill off any private sector activities. The role of NGOs is very confusing in Malawi as they do very limited advocacy. NGOs benefit from tax incentives and as such often out-compete private sector players, yet in terms of permanent operations it is the private sector that stay.

Most of the experts observed that subsidies cannot be ruled out, but these ought to focus on initial investment cost and build in cost recovery for operation and maintenance. A subsidy approach has been tried and tested, i.e. there is a diesel powered mini grid in Likoma managed by ESCOM, which receives national subsidy. This is a model where all other customers pay the same ESCOM national tariffs even though the cost on Likoma is higher. MEGA in Mulanje as a social enterprise working towards sustainable model, however even this case is not fully sustainable if you factor in recovery of capital investment costs. However, it is better compared to other initiatives when it comes to sustainability at operation and maintenance level. The PV-Wind Hybrids initiative by Dept. of Energy described in Box 1 was a failed case of donor investment with no adequate business modelling at project design, poor documentation, lack of capacity building etc. In fact, most donor projects are accused of bringing market distortion in the energy sector, in a similar way to the DoE systems, current subsidies for pico-solar products, subsidies in improved cook stoves etc.

Box 1: Case Study - Government of Malawi Solar Villages PV-Wind Hybrid in Elunyeni

6 government funded mini-grid systems (2 respectively in the north, centre and south) were installed starting in 2007, at a costs of 50 million MKW per system. Only 1 is currently working and this is only because it was not completed until 2 years ago.

In the other five systems, the batteries have failed and have not been replaced. Currently the estimates for replacement of the batteries is the same as the cost for extending the grid, and therefore these systems are scheduled for decommissioning as the communities are to be connected to the national grid.

Although there has been no formal evaluation conducted of these 6 projects, evidence collected during the field work in Elunyeni suggests that the following factors have contributed to the failure of that particular system:

- Wrong generation mix
  - About 2/3 of the rated power capacity is wind, however the wind resources in most of the 6 communities is poor yet the solar resources are excellent.
  - The data logged at Elunyeni during this study showed an average of just 1.3m/s. Even though this was at 10m (instead of the 30m hub height of the SWTs) and measurements were taken in the low wind season, this certainly suggests that it is a very poor wind site. Yet according to national wind maps, Elunyeni should have the best wind resources of all 6 projects.
- Battery bank not adequately designed or protected
  - No PV charge regulator
  - No current limitation on the loads
  - Sealed gel cells, so no possibility of adding more water if overcharging occurs and gas vents out of emergency release valve
  - 7 strings means high probability of imbalance between them
  - 12V batteries instead of 2V cells
- Lightning strikes and storms damaging equipment
- Lack of training
  - Operator unable to perform any maintenance
    - All repairs carried out by contractor with high labour and travel costs
  - Community not aware of need to manage demand
- Cookie cutter systems not designed to match local needs with locally available resources
  - Lack of community consultation
  - Lack of resource assessment prior to installation
- Lack of ownership
  - Vandalism
  - Abuse of the system leading to overloading
    - High power appliances such as hot plates and irons used
    - Additional households connected
- System donated and only 100 MKW per household per month fee
  - Difficulty collecting fees, as only introduced after one year, so people accustomed to using electricity for free
  - Productive uses discouraged by lack of daytime availability
    - Consequently no funds available for maintenance or upgrade

A solar powered barber shop in Elunyeni showing that there is clearly demand for electricity, despite the fact that the PV-wind mini-grid has been offline since 2012.

Other experts indicated that the best evidence for the keys to sustainable business models comes from CRED, MREAP and CEDP solar PV projects. CRED focuses on community support, with an energy committee formed to establish ownership for the project and Revenue Generating Activities (RGA) included to pay for O&M. Unfortunately, RGA wasn't enough to cover the costs so the systems were instead used for educational facility lighting. MREAP tried to make the projects more sustainable and identified the need for more RGA. CEDP implemented some apparently successful projects, however there is a need for a proper evaluation in order to verify this. Each project was operated under a CBO and the community ownership element was found to be especially key. SHS units were rented from teachers at schools and cash sales for solar lanterns formed part of the overall financial scheme. Future plans are to diversify from just providing power at school to include barbershop, mobile charging etc.

A solar PV sustainability study was mentioned by a number of experts that considered 45 systems (1 CRED, but everything else from other suppliers). The study considered economic, organisational and technical sustainability, such as the capacity of communities to continue with installations and income generating opportunities. It was found that only one of the systems generated sufficient revenue and none of the communities even had bank accounts. There were ownership challenges, but the more successful SHS projects had lines of business – video show, barber shop, battery charging and mobile charging and cold drinks. However, even in these cases, it wasn't enough to cover either the investment costs or the long term operational and maintenance costs.

3.1.1 Mini-grids as a key energy delivery model for Malawi

In very simple terms, a mini-grid can be defined as linking together demand points within a limited area without connection to the main grid. In terms of quality and quantity of power – something in between a main grid experience and a standalone experience. There was a consensus amongst experts on the role of community mini grids in Malawi to complement the currently overwhelmed national utility power supply via ESCOM. To date, Malawi has had some experience with mini grids in various models and approaches using different technologies i.e. hydro, solar and wind. Experts agreed that mini grids present a significant opportunity to both enhance energy access and promote private sector participation in energy delivery. However, what is unclear, even from the experts 'perspectives is whether there is a clear case where mini grids systems have been sustainable. The lack of valid evidence in terms of impact regarding mini grids in Malawi, which may soon be addressed by a new project with a focus of scaling up mini grids in Malawi under the GEF-UNDP GoM Increasing Access to Clean and Affordable Decentralised Energy Services in Selected Vulnerable Areas of Malawi. Among other issues the project will look at issues related to barriers for scaling up mini grids.

In terms of technology some experts felt the hydro mini grids like the case of MEGA (Lujeri estate and the MIRTD-funded) have already been proven, save for their differences in operational approaches. However they observed that solar mini grids have not yet been very successful, including the 6 DoE projects described in Box 1, citing issues of cost and durability of the installations. Other experts observed that there is massive potential for mini grids and that the broader the technology mix the better. Hybrids are seen as a less risky option, given resource variations, especially for wind and hydro (affected by water levels during drier parts of year), so combining these with diesel makes good sense. Table 10 lists the key barriers and drivers for mini-grid development in Malawi.

TABLE 10: KEY DRIVERS/BARRIERS FOR MINI-GRIDS IN MALAWI.

Driver/barrier	Description
Energy Security	Reduce current dependency on one watershed, the Shire Basin, where almost all of the country's power stations are located.
Capacity building	Capacity development required at various levels to make mini grids development a success, especially local capacity building for operation and maintenance
Lack of viable business modelling	This is a typical case of most projects including the 6 GoM projects. Business planning and modelling should come first before proceeding with any projects
Lack of resources assessment	Resource mapping critical, you cannot afford to make massive investments without being sure about the resources available.
Market Challenges	Energy pricing not attractive for private investors in mini grids. Sustainability should be built in through viable pricing of products and avoiding social subsidies that promote market distortions and lead to market failure
Investment	Capital for investment is a key challenge as banks hardly appreciate energy business models and there is a lot of risk averse financial players in the country, however most donors are now interested in funding these.
Political interferences	Main barrier is local party politics on development projects. The 6 GoM energy projects were all implemented in areas for political leaders who were in power. Obviously projects were not being led by technical aspects.
Licensing	For hydro mini grids, demand is often far away from generation and based on the regulations in Malawi, a producer cannot generate and transmit under one license so two licenses are required and the process to secure them can be very complicated.

3.1.2 Productive applications

Malawi has a mainly agriculture-based economy and as a result agro-processing potential is very high. There is suppressed economic activity currently due to insufficient energy frustrating investments across most sectors of the economy. Productive use of energy brings in sustainability, as there is cost recovery through household and/or community energy related enterprises. Cost recovery is critical both in terms of cost of generation and transmission but also the cost for enhancing access for the rural poor. DFID indicated categorically that experiences are indicating that sustainability is achieved with private sector engagement in development and this is a key opportunity in Malawi to be developed around energy access.

The review of experts' perspectives on productive uses of energy relevant for Malawi indicates that productive uses of energy are key to the sustainability of energy systems and should build on already existing development initiatives among the rural communities. The key productive uses cited include:

- Agricultural productivity:
  - Mainly water pumping for irrigation and domestic use, which is key given the drought situation which is prevalent in the current season. Drying tobacco to save loss of fuel wood is a suggested use but such requires proper assessments to be done. Maize is the staple crop in Malawi and all rural Malawians require milling services to process the maize they grow at home. Experts indicate wind power use in peanut production that is already happening. Wind can also be applied to water purification process.
- Social services with user fees:
  - Electrification of social services like schools and health centres with a user fee built in have also been seen as very productive.
- Other household small scale enterprises:
  - Household appliances that are used for small scale businesses likes fridges for cold drinks, television for video show, barber shops. There is a lot of evidence from current solar projects that barbershops and cold drinks, mobile phone charging and video can bring in significant income.

3.1.3 Main drivers and barriers for rural access to energy in Malawi

Table 11 summarises the key barriers and drivers cited by the experts interviewed during this study.

TABLE 11: THE KEY DRIVERS AND BARRIERS FOR INCREASING RURAL ENERGY ACCESS IN MALAWI.

Driver/barrier	Description
High poverty levels	Malawi is among the poorest countries in the world and as such there is a complex nexus of poverty, energy and sustainable development. There was a consensus among the experts interviewed that the need for economic and sustainable development and the effective delivery of social services like health, education, community services are the main drivers for rural energy access in Malawi.
Low ability to pay	Poverty prevalence is too high in Malawi and it is a key policy driver for pushing for energy access on one hand and on the other hand it is a driver for unsustainability of energy interventions as most Malawians think they are too poor to pay for energy services. Lower interest loans could be a facilitating factor may be donors can work with the government to make this available.
Low existing levels of access	There a huge need for households to meet the basic needs especially food and income for basic things like energy for lighting and cooking.
Increased appliance availability	There is a rapid increase of rural growth centres and increased access to technologies such as the mobile phone, radios and televisions that require energy to power them.
Historical dependence on grid connected hydro	Currently rural electrification is not progressing with the right speed with around only 1 % electrified regardless of dedicated rural electrification programme. Most of the experts expressed that there is a general stagnation and lack of long term visioning in the energy sector in Malawi worsened by historic overdependence on single technology i.e. large hydro systems run by ESCOM and population growth which has made demand overwhelmingly exceed ESCOM supply levels.
Safer, cleaner, more affordable lighting	Lighting with kerosene standard in rural areas is costly and dangerous.
Overdependence culture	Culture of overdependence on Government and NGOs inhibits sustainable development
Increased agricultural productivity	With increasing population there is also increasing agricultural expansion and irrigation development which is also a key potential user for energy.
Limited capacity	There has been a conventional grid extension focus. There are skill and knowledge gaps at various levels in ESCOM, including capacity gaps in operational, managerial and technical areas. These limit the size and scope of projects. E.g. Malawi could supplement hydro with large scale wind and solar farms that could potentially be managed by ESCOM. Human capacity limitation responsible for conventional electrification methods i.e. grid extension even if the capacity does not match demand. Limited capacity by the Department of Energy in terms of finance and technical expertise, this is worse at community level where such is required for operation and maintenance of community energy systems.
Poor access to energy resource data	Information on energy resource mapping is limited or non-existent. Wind resource data is not available, hydro not adequate and solar radiation data still being compiled. Without good resource mapping data it is so hard to motivate investment.
Low product awareness	Marketing costs high and limited access to infrastructure very limiting to energy product distribution. RENAMA Developing a radio programme on MBC in Chichewa on energy which will include a series of expert interviews on energy poverty, sustainability, RETs etc.
Low quality imports	Many low quality counterfeit energy products being sold. Vendors are supposed to have a license for supplying electrical systems, so in theory, market and roadside sellers of PV systems actually illegal. About 30 companies registered, but only 10 serious companies. Interviews for staff members in order to obtain certification, but some companies simply hire an RE student just before the interview, then fire them straight afterwards. No warrantees or quality control
Deforestation	Not just about electricity. 95 – 98% of energy use in Malawi is biomass with links to deforestation. There are drivers to increase efficiency and sustainability of biomass use through wood fuel and charcoal production. Technologies to improve this are needed. Driver to move population away from wood fuel demand.
Weak private sector	Political interferences play a huge role in inhibiting energy development in Malawi. All key institutions like ESCOM, MERA, MAREP and Department of Energy can't only function independently to a limit which is not helpful for enhancing energy access. The current model where Government raises money, does grid extension, passes ownership to ESCOM (commercial driver) is not good to motivate independent players to join the energy market. Price control and regulation currently not reflective of investment and operations cost. The change of government regularly slows down energy access by changing policy and investment agreements. Government payments very slow and not obviously good for private sector business.
Lack of clarity of stakeholder roles	Energy access in Malawi will never be sustainable with poor definition of roles of government, NGOs and Private sector. ESCOM tariffs are heavily subsidised as such it's a huge demotivation for independent power producers If DoE will be doing installations who will provide policy direction? NGOs could play a critical role in promoting energy literacy and mobilising community on key energy initiatives and going energy advocacy but once they start selling solar products at ridiculous prices since capital is coming from donors then there can never be sustainability at all.
Energy as an accelerator of wider human development	It is a nexus issue in that energy access can be enhanced to promote social services and on the other hand energy initiatives can potentially be mainstreamed in social projects like

	health and education. Energy covers a number of different forms, e.g. direct light, heating, cooling, shaft power as well as electricity, and for a huge number of different tasks (cooking, lighting, water pumping, refrigeration and communications). These can have a major impact in changing lives, improving health and education in rural areas of Malawi and help to reduce poverty.
Linking high level decision making with grass-roots needs	It is important to stay in touch with what is happening on a grass roots level. The furthest the government goes is to the district councils, which is often still a big step from what's happening on the ground. There is a need to find out what the energy requirements are of the rural communities, what energy technologies they need, and what the priorities are.
Lack of follow up studies	Some of the experts indicated that experience with solar PV and wind community projects are still not well documented and not available. Most projects are new and older projects mostly have failed or there is no adequate information for review of lessons. What is needed are cases where an intervention is sustainable for a minimum of 5 years and ideally 10 to 15 years of viable running is better.
Local levels of local capacity	Local capacity building is equally key so that basic parts replacement and repairs are done locally and cheaply. Literacy is very low across most Malawians which is a key factor that constrains development and energy related technology adoption too.

3.2 Key challenges and opportunities for locally manufactured SWTs in Malawi

This section discusses the key challenges and opportunities for small wind in Malawi, specifically in relation to the most comparable alternative, solar PV. Individual experts provided certain perspectives informed by their experiences that required technical validation by solar and wind technology experts. It suffices to note that the expert opinions are also limited by their experiences with technology, knowledge and project implementation. The level of familiarity that the experts interviewed for this study had with this relatively new technology in the Malawian context is discussed in *Appendix D - Experts' experience with small wind*.

BOX 2: CASE STUDY – WILLIAM KAMKWAMBA, THE BOY WHO HARNESSED THE WIND

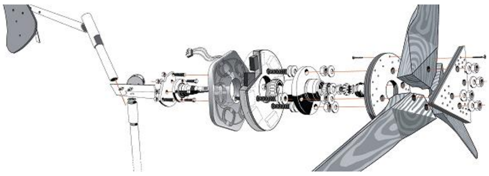
William Kamkwamba grew up in a village in the Dowa region. When his family ran short of money, he was forced to drop out of school. Frustrated by the lack of light after sunset and the inability to pump water to irrigate his family's maize plants, he saw a picture of a windmill in a book and decided he would build one himself. Through sheer determination and ingenuity, using eucalyptus poles for a tower, PVC pipe for blades and a bicycle for gearing, he managed to cobble together a machine that could indeed produce electricity from the wind. He got hold of a second hand car battery and was able to produce enough electricity to light his family's home.

William's inspiring story illustrates the appeal of SWTs, i.e. that everything can be sourced locally. However, the scalability of this solution is limited by two key factors:

1. The availability of the wind resource itself (William just happened to grow up in one of the windiest regions of Malawi).
2. William's incredible motivation and technical ability – is it possible to find someone like this in every Malawian village?

What is more, William built this machine over 10 years ago and since then, the price of PV has fallen greatly. Second hand PV panels are now available in Malawi, so it would be interesting to know if he were trying to do the same thing today, whether instead of going the trouble of designing and building a custom machine, William would have simply acquired a small PV panel along with the many other second hand components he used to build his off-grid system?

William with his windmill in 2007 (Kamkwamba 2009).



3.2.1 SWT manufacturing in Malawi

The idea of localised manufacturing of SWTs is seen as very attractive by all the experts, as it is critical to solving the key challenges relating to cost of maintenance and local capacity for managing the systems. However investment in a new product is costly for industry actors and without corresponding demand it will not make sense. Box 3 highlights some of the difficulties faced by the Students for Malawi group who have now manufactured 5 SWTs in Malawi. Some of the other experts highlighted the following issues:

Logistical complexity : It is easier said than one to have a fully functional and economically viable local production system for SWTs. Hydro technologies have been use in Malawi for years and still very little of the hydro technology components are being produced in Malawi. For poor countries like Malawi, production can be logistically very expensive. But if there is good demand and investment production of components for which it would be economical to produce may happen, this could firstly target those already in a similar business. Production would make more sense in a peri-urban setting to begin with, could then extend to rural areas. Distribution of either produced or imported SWTs systems and parts should leverage existing distribution networks, e.g. agricultural supply chain. Blantyre steel processing companies have tried manufacturing improved cooks stoves (ICS), which may be useful as starting point for SWT trials especially for prototyping. Local universities and vocational training schools currently offering RE training e.g. DAPP, Mikolongwe, TVVETA - technical vocational training schools mainly in remote areas. Fabrication industries and Malawi Industrial Research and Technology Development Centre would be better placed to manufacture SWTs. Initially there may be need for facilitation from donors or government to create an enabling framework and support R&D.

Piloting critical: Whist SWTs can and already have been fabricated in Malawi, the challenge is developing a locally appropriate design that capitalises on the materials, tools and techniques available locally. Pilot initiatives will be necessary to facilitate learning in terms of fabrication, installation and business models. There are already many imported products in Malawi that are simpler to manufacture than SWTs, but are imported as overseas mass production can produce them more economically. If the local manufacture of SWTs is to be successful, a clear strategy is required so that the manufactured products do not end up more expensive that the imported ones.

Critical mass of potential users: SWTs require significant amounts of maintenance. As a result, after-sales service is critical for sustainability, however **t**here must be a certain quantity of potential users clustered within a particular region in order to make the establishment of a service network viable. The scattered nature of the wind resource in Malawi makes this difficult.

Lack of awareness: Currently most wind experiences are limited to water pumping and if SWTs are to be successful, they should be launched alongside appropriate awareness raising campaigns.

Capacity development: The establishment of specific organisations to manufacture, install and maintain SWTs should only be made based on evidence of significant potential from credible data. If necessary, as a transitional arrangement, efforts could be made to build capacity of local NGOs, CBOs and even local communities. Community Technical Colleges are a recent government initiative and present a key opportunity that could be used to provide the SWTs practical skills. The country's universities (e.g. The University of Malawi – Polytechnic or Mzuzu University Centre for Energy Studies) already have facilities for engineering teaching, technical training and research and could offer training high level skilled personnel.

BOX 3: CASE STUDY - STUDENTS FOR MALAWI

Students for Malawi (SfM) is a Scottish charity that has experience with manufacturing and installing SWTs in partnership with local CBOs in the southern part of Malawi. They have conducted preliminary feasibility studies, using online data from mesoscale models for wind resource assessments.

To date, 5 SWTs have been installed and 3 more are planned for the summer. The key driver for installing these systems was to reduce paraffin and candle usage. The energy source was not so important, but the village chiefs wanted to create opportunities for people in the village, so the ability to manufacture the turbines locally was a strong driver for choosing wind energy. The development of local skills has the potential to create more employment and support many to escape from dependency culture which is a major problem in Malawi. SfM were able to obtain funding from the Scottish Government to cover the travel costs of students coming from Scotland to facilitate the manufacturing process, as well as for the component costs. Capacity building of both Scottish and Malawian students was a major factor in obtaining this funding and ultimately there were plans to set up a training program to teach young Malawians to establish profitable businesses manufacturing, installing and maintaining SWTs.

"If we didn't build the turbines, we wouldn't have enough money to do any projects at all, so its turbines or nothing"
Ryan Cassidy, SfM Director, 11th March 2016

In 2013, two SWTs were built with a local NGO, Green Malata. In 2015, three further SWTs were constructed in the villages of Sikoya, Mwamadi and Kumponda. All of which are located between Cholo and Mulanje in the South of Malawi. However, SfM were unsure as to whether any of the SWTs were still operating. The three SWTs constructed in 2015 were reported to be working, but on the brake awaiting operator training for local women to be delivered by the local partner, RENAMA.

Unfortunately, the wind resource assessment conducted prior to installation was not based on measured data and as there is a mountain nearby, the wind flow is distorted significantly, making it difficult to use online sources. An anemometer has since been installed on the tower of one of the SWTs and despite logging for 6 months during the high wind season (Aug 2015 – Feb 2016), the average wind speed was measured to be just 3.8m/s. As a result, even if the SWTs are put into operation, they are unlikely to produce a significant amount of energy.

SfM acknowledge the fact that the data suggests that SWTs are not the most appropriate technology for the communities they are working in long term and as a result, they will not do any further small wind projects. Instead, they plan to use the same student volunteer led local manufacture based business model with same model with other technologies, such as flood prevention materials.

The key challenges that they faced were:

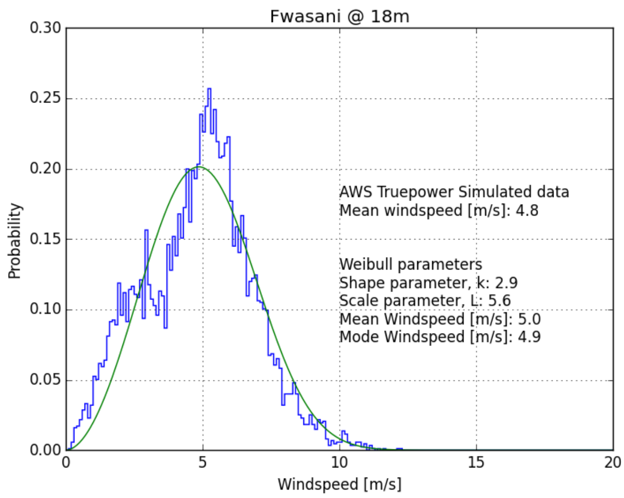
- Many components still had to be imported from the UK, which increased the cost significantly. The proportion of imported components could be reduced over time, however some will always need to be imported.
- Battery charging only income generation source, so unlikely that investment from SfM SWTs will ever be repaid with current business model. It would have been better to install SWT at the school to offer IT services, printing etc.
- Theft may be an issue with SWTs. There is no security at site, so batteries taken to people's homes at night, making the benefit of night time generation redundant.
- Communication with local partners challenging. RENAMA supposed to be involved with SfM initiative but this is yet to be defined and a proper engagement strategy put in place.
- Although positive in many sense, the capacity building element was challenging, as significant repetition is needed before people are able to perform all of the actions independently. For example, solar kiosk operators have now been trained 6 times and still the knowledge hasn't completely sunk in.
- Lack of wind resource and inadequate resource assessment prior to installation.

3.2.2 Wind/solar resource complementarity

This section focusses on the prospective case study of Kamilaza (Fwasani CBO) in the Mzimba region, which is predicted to have relatively good wind resources. A similar analysis was performed for Elunyeni, which yielded similar results, indicating that this analysis is representative of much of the Mzimba region. The yearly average wind speed on an unobstructed site (i.e. flat ground with no trees or buildings within 100m in the prevailing wind direction/s) in Kamilaza at 10m height is predicted by the AWS TruePower Dashboard to be 4.2 m/s (4.9 m/s at 20m). The data set used for the complementarity analysis below is scaled to 18 m height in order to match the hub height of the wind turbine used in the energy systems modelling.

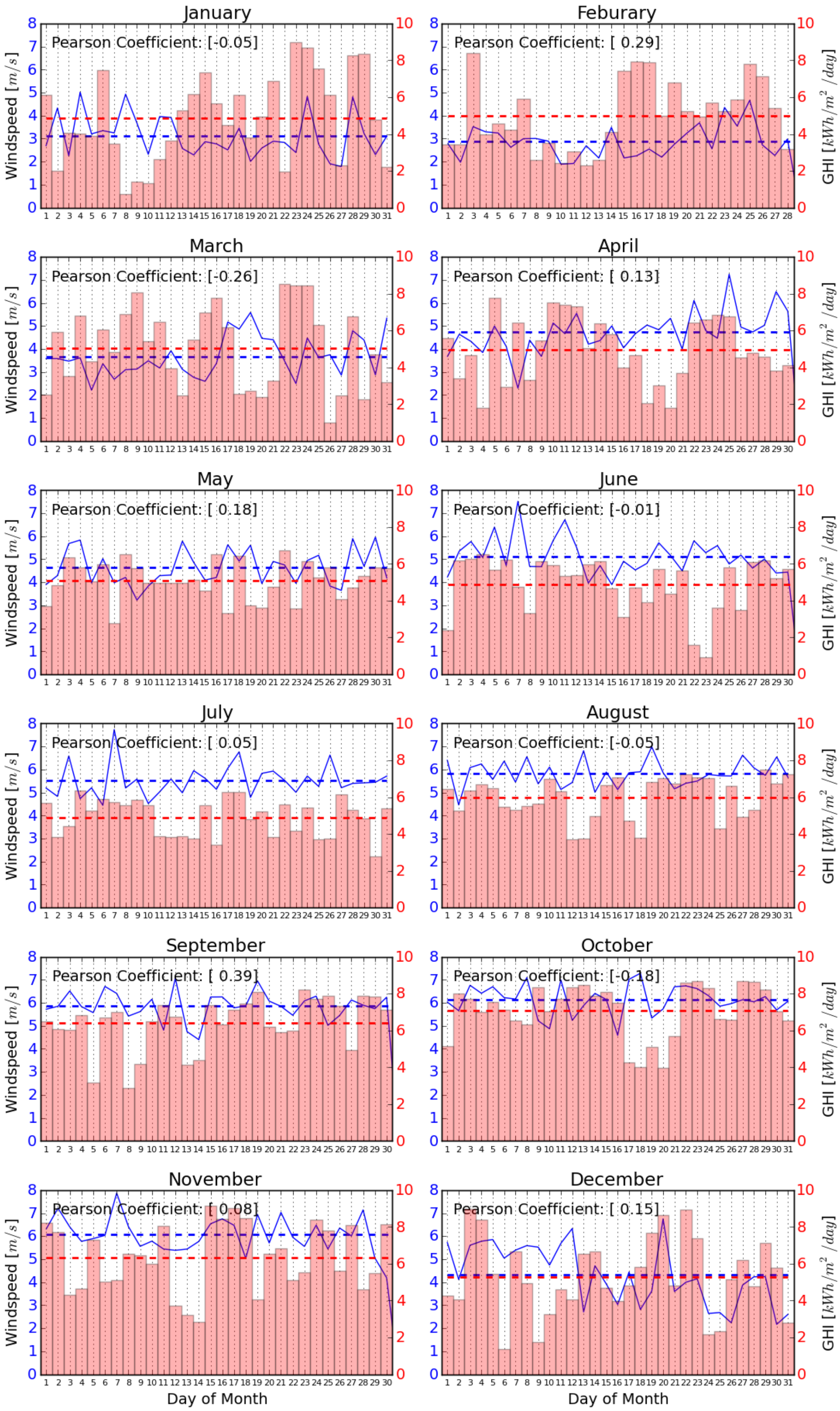
During the field visit in January 2016, a 10m mast with a data logger was installed to measure wind speeds and wind direction at an open site in Kamilaza, however the data set collected during the time available for this study is too small for in depth evaluation. Hence, the data presented here is the hourly wind speed at 18 m above ground, extracted from mesoscale modelling database, AWS TruePower Dashboard AWS Truepower (2016). Figure 20 shows that the likelihood for wind speeds above 10m/s is less than 1% (which actually has positive implications for maintenance, as these wind speeds can damage the SWT).

FIGURE 20: PROBABILITY WIND SPEED DISTRIBUTION IN KAMILAZA (FWASANI CBO) AT 18 M. DATA SOURCE: AWS TRUEPOWER DASHBOARD.



To predict the operation of a wind power system, further analysis is needed on the wind speed variations over shorter time intervals, as they will have significant effect on when the electricity is produced. In particular, the seasons of the year with lowest resources will set the required system size, unless energy services designed to utilise the excess wind in the high wind season can be found. For Kamilaza, the wind resources are lower in the beginning of the year and peak during dry season in August to November. The blue-dotted lines in Figure 21 show the predicted average wind speed for each month, which in February is down below 3 m/s yet in both October and November exceeds 6 m/s.

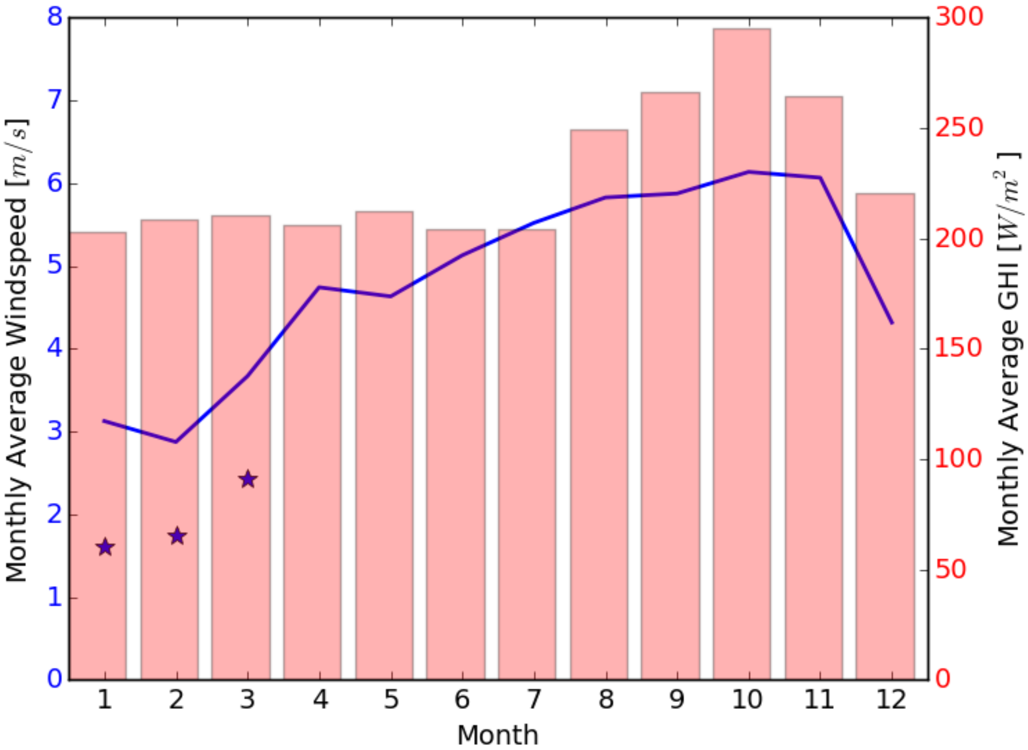
FIGURE 21: THE SOLID BLUE LINES SHOW THE AVERAGE DAILY WIND SPEEDS FOR EACH MONTH, WHEREAS THE DOTTED BLUE LINES GIVE THE AVERAGE FOR EACH MONTH. THE PINK COLOURED BARS SHOW THE SOLAR INSOLATION, ALONG WITH THE MONTHLY AVERAGE AS THE RED DOTTED LINE. DATA SOURCE: AWS TRUEPOWER DASHBOARD.



If the wind resources are high when the solar resources are low, designing hybrid systems would enable more consistent electricity generation and therefore either reduce the size of the battery bank, reduce diesel consumption and/or decrease the amount of unmet load. However, Figure 22 shows that in

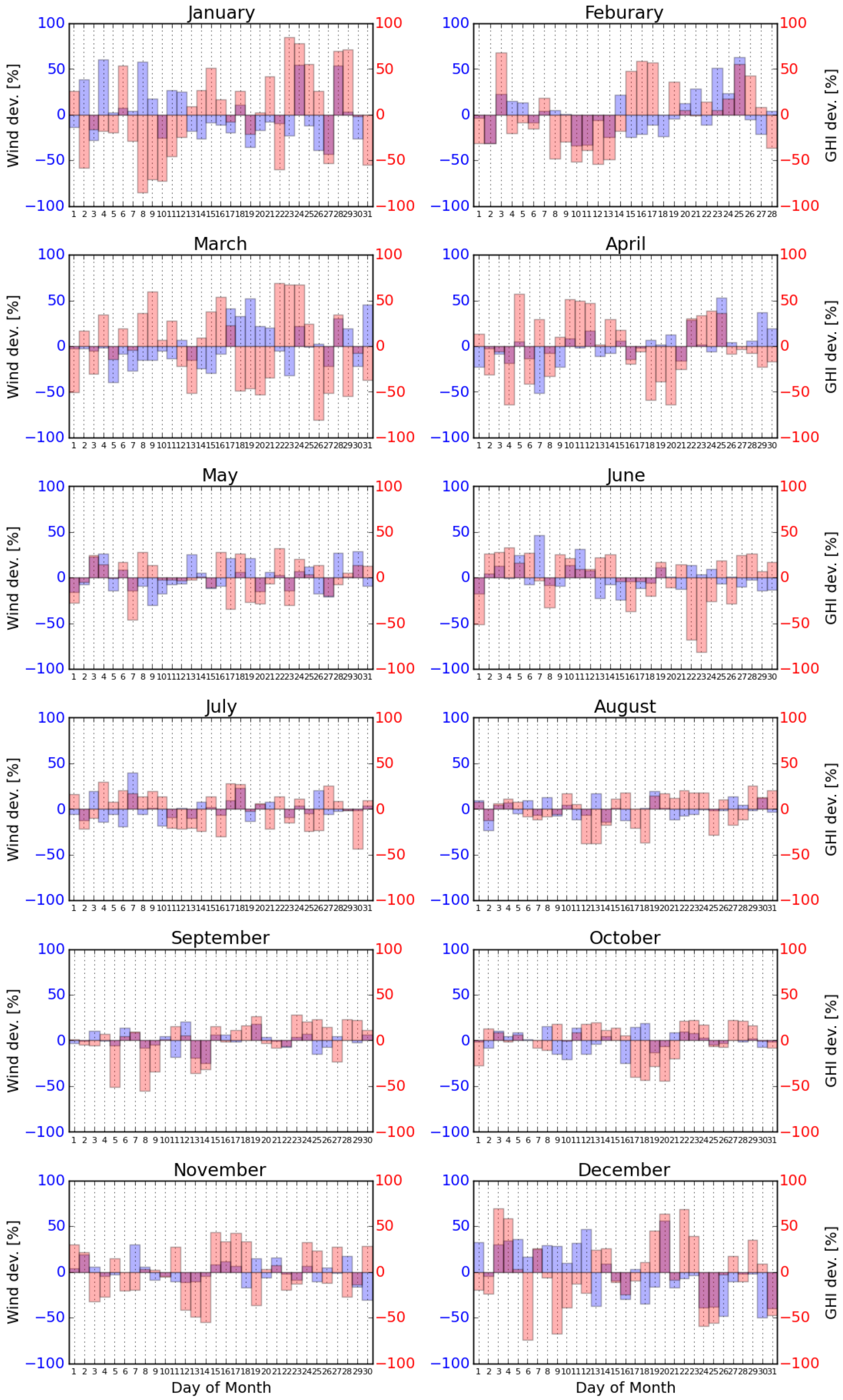
Kamilaza, both the wind and solar resources are at a maximum during the dry season. The monthly average solar resources stay rather constant from January to July and then increase significantly in August to November. The wind speeds change more gradually over the year but still have a minimum and maximum that correlate in time with the solar resources. The blue stars on Figure 22 show the preliminary results from the datalogger installed in Kamilaza. Clearly, the results are disappointing, with the monthly averages for this period around half what was predicted by the AWS TruePower Dashboard. *Appendix E – Preliminary datalogging* results contains a more complete analysis of this data and shows that the results for Elunyeni are equally disappointing.

FIGURE 22: AVERAGE MONTHLY SOLAR AND WIND RESOURCES IN FWASANI. DATA SOURCE: AWS TRUEPOWER DASHBOARD.



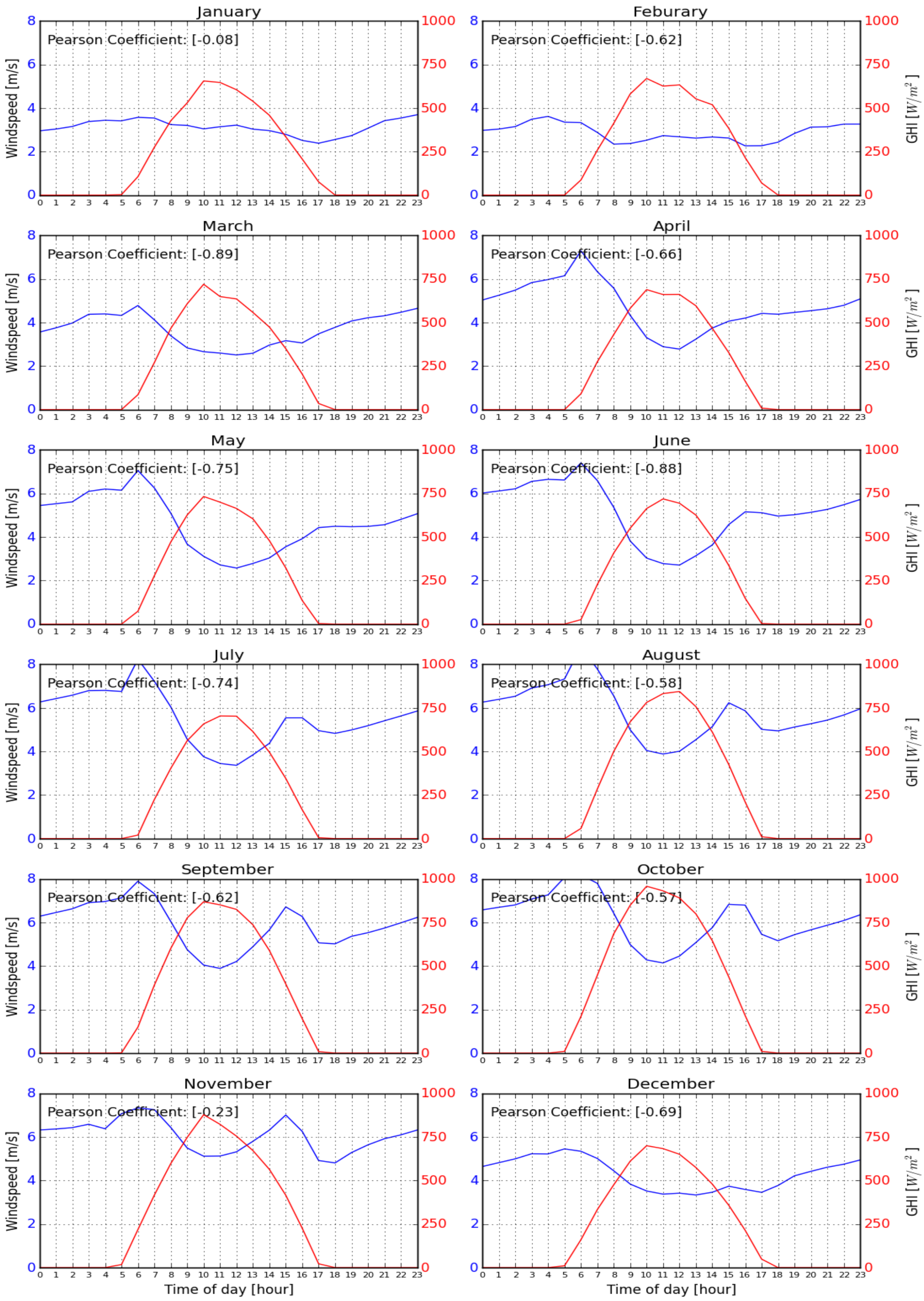
Within each month, the variations in wind speed and insolation from one day to another are hard to correlate to each other in a consistent way, which may be related to the nature of the simulated data, which is averaged over several years. However, hybrid electricity production from both wind turbines and solar panels would add some value if the fluctuations of solar and wind resources are rather random. The solid blue lines in Figure 21**Error! Reference source not found.** show the daily average wind speed and the pink bars give the daily solar insolation. There is no obvious visible trend to be seen, but if instead looking at the daily variations from the monthly averages (Figure 23), it can be seen that the relative fluctuations decrease when the magnitude of the resource increases during dry-season. This is to be expected for the insolation, as there are few clouds in the sky in dry-season, but it is also interesting to see that the wind speeds follow the same pattern and provide more stable wind conditions during dry-season. Again, it illustrates the fact that an off-grid energy system based on these renewable energy sources would need to be designed for the worst case (rainy season), where there might be several calm and cloudy days in a row.

FIGURE 23: INCREASE IN DAILY FLUCTUATIONS OF WIND SPEEDS AND INSOLATION RELATIVE TO THE AVERAGE MONTHLY VALUES DURING THE DRY-SEASON (JULY-AUGUST TO NOVEMBER). DATA SOURCE: AWS TRUEPOWER DASHBOARD.



Looking at the diurnal variations, there is a much more pronounced complementarity between wind speed and insolation. The graphs in Figure 23 show the daily averages of hourly wind and solar resource availability for each month. They show that wind speeds pick up in the mornings, decay during the middle of the day when the sun is strong, and then pick up again in the afternoon when sun is setting. The trend is again weak in January and February and is most pronounced in June-July when wind speeds seem to also be good during night time. This trend would allow a PV-wind hybrid system to produce electricity more evenly throughout each day compared to systems that would use either one of the technologies alone.

FIGURE 24: DIURNAL PATTERNS OF WIND SPEEDS AND INSOLATION SEPARATED BY MONTH. DATA SOURCE: AWS TRUEPOWER DASHBOARD.



Pearson's Correlation Coefficient has been employed to attempt to quantify the complementarity with linear correlations (Kougias et al. 2015). The coefficient gives a negative value if the linear correlation is such that wind speeds pick up when insolation goes down. If the value is close to zero, the linear correlation is weak and if the value is close to 1 the correlation is strong. No information is given for the slope of any linear dependency. As can be seen in Figure 24, all months show a negative value indicating that there is a consistent complementarity, which in most cases show values well below -0.5, indicating that the complementarity is moderate to strong. However, the use of complementarity in renewable resources all depends on if the off-grid energy system is implemented and tuned to meet them (Kougias et al. 2015) as the load profile dictates whether a complementary energy production can be used directly, or needs to enter the battery bank (and therefore reducing the benefits of hybridisation).

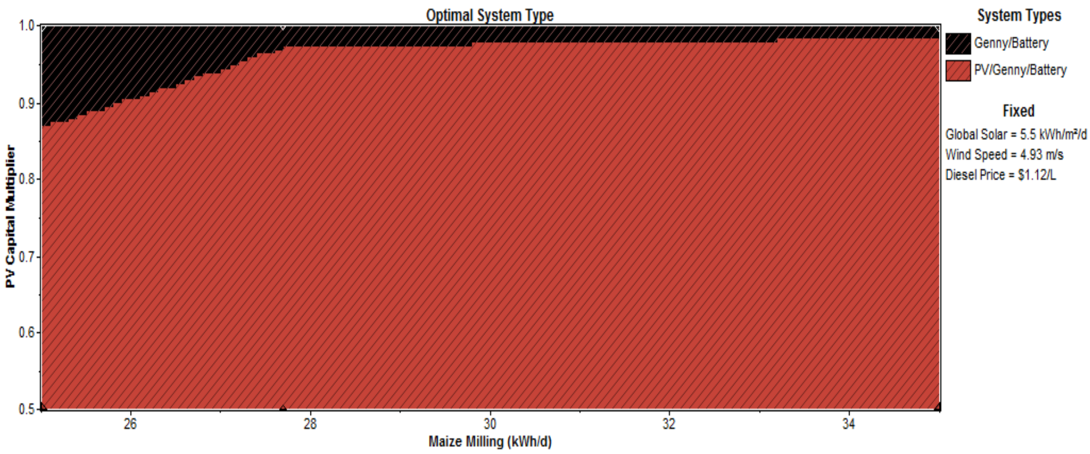
3.2.3 Quantifying the potential market:

This section presents and discusses the results of techno-economic spatial modelling. Intermediary results are presented in *Appendix B – Input data for techno-economic spatial modelling*, with only the final results from each of the two filters presented and discussed here. Firstly, the results of the optimal system architecture filter are presented in graphical form. This is followed by the market size filter results, which are presented in tabular form.

3.2.3.1 Optimal system architecture filter

This filter applies the results of the energy systems modelling in HOMER across Malawi, taking into account the key sensitivities of diesel price and solar/wind resource availability in each place. The results are presented for each load profile in graphical form, with two maps for each load profile, showing the optimal system architectures and the renewable energy share across Malawi. The results of the HOMER simulations are shown as x-y plots (e.g. Figure 25), with increasing load size on the x-axis and the four key sensitivities on the y-axis (diesel price, solar/wind resources and PV panel price).

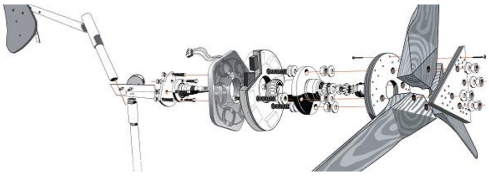
FIGURE 25: SAMPLE HOMER SENSITIVITY OUTPUT PLOT SHOWING THAT EVEN A SMALL DECREASE IN PV COST (Y-AXIS) SHIFTS THE OPTIMAL SYSTEM ARCHITECTURE FROM GENERATOR TO PV-GENERATOR. IN CONTRAST, INCREASING THE MAIZE MILLING LOAD (X-AXIS) HAS LITTLE INFLUENCE.



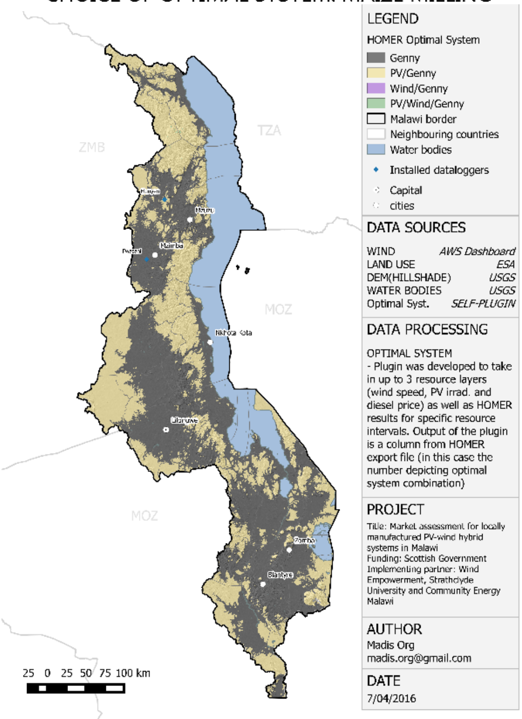
3.2.3.1.1 Maize milling load

The maize mill is a very difficult load to power using a renewable energy system as it consists of a very low but regular load for lighting and a high level, short duration load to represent the maize mill. This means that a large converter and large battery bank is required to fully incorporate variable renewable energy. At present, the diesel generator capital and fuel cost is such that the NPC for a diesel generator based system with a small converter and battery bank is optimal for most of Malawi.

FIGURE 26: OPTIMAL SYSTEM ARCHITECTURE AND RENEWABLE ENERGY FRACTION MAPS FOR MAIZE MILLING LOAD.



CHOICE OF OPTIMAL SYSTEM: MAIZE MILLING



RENEWABLE ENERGY SHARE FOR OPTIMAL SYSTEM:
MAIZE MILLING

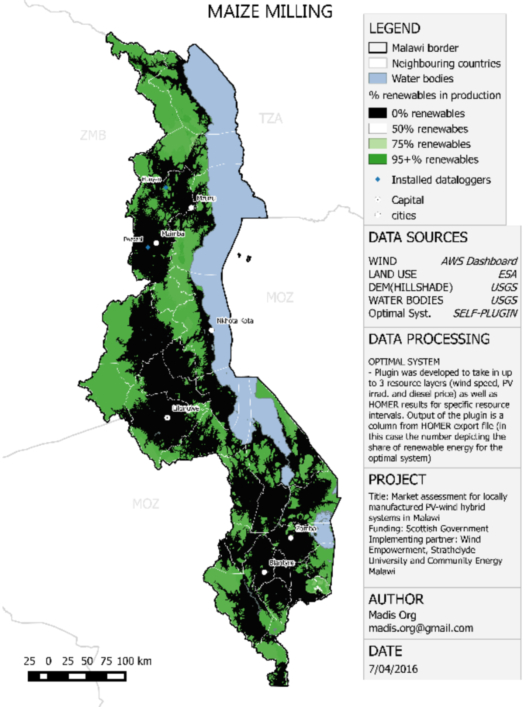
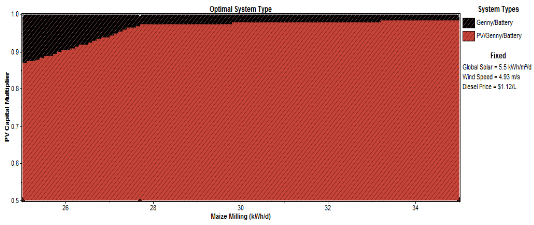


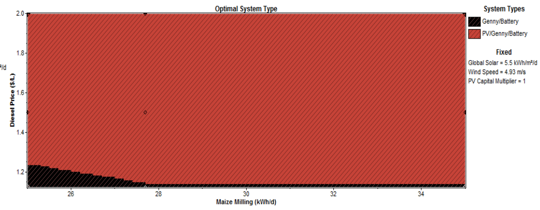
Table 12: Sensitivity results for maize mill load.

Reduce PV cost:



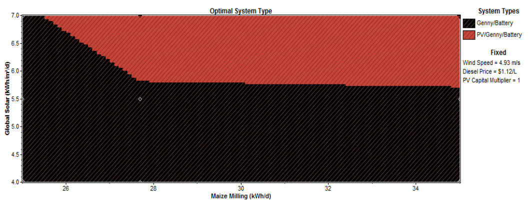
A small reduction of PV price (of around 10-20%) will start to make a PV/Generator system the optimal system type. The amount of PV penetration would be low, though.

Increased diesel fuel cost:



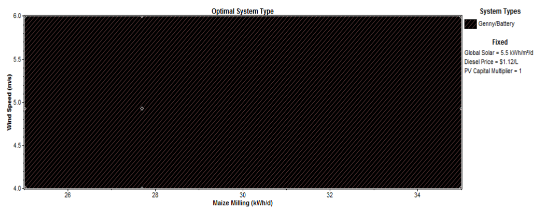
A small increase in diesel price will make a PV/Generator system viable, although the amount of PV penetration would be low.

Increased solar resource:

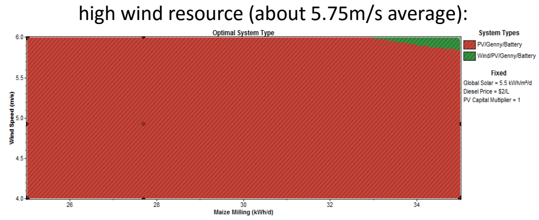


With a solar resource above 5.75kWh/m2/day we start to get PV into the system mix.

Increased wind resource:



With diesel at its present price, then a diesel generator based system makes sense and wind turbines do not play any part in the energy mix, even with higher wind speeds. If diesel prices are doubled, then a PV/generator system becomes sensible, with wind playing only a very limited role in locations with a high wind resource (about 5.75m/s average):



3.2.3.1.2 Egg incubation load

This is a constant load throughout the day and night. The load is relatively low, so this type of load favours a PV or PV/generator hybrid. The high initial capital cost of the wind turbine makes it unviable for these systems. With the addition of a thermal mass, a solar thermal is another option for meeting a constant thermal load like egg incubation, however controlling the temperature would be more difficult and the authors are not aware of any off-the-shelf systems that could perform this function.

FIGURE 27: OPTIMAL SYSTEM ARCHITECTURE AND RENEWABLE ENERGY FRACTION MAPS FOR EGG INCUBATION LOAD.

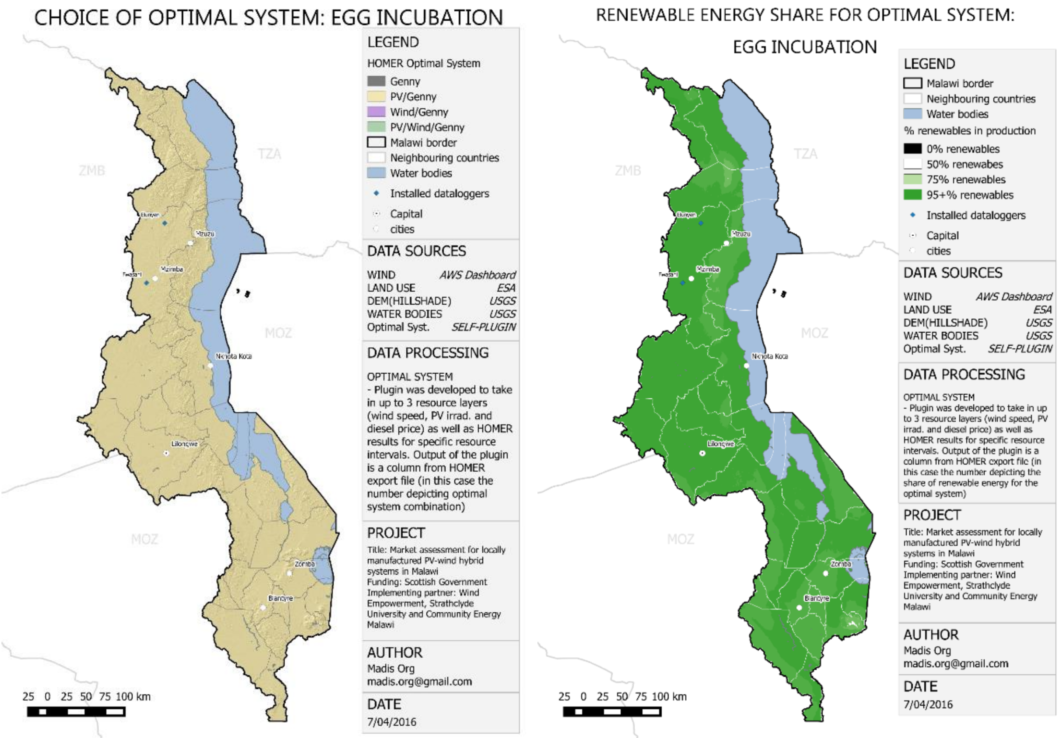
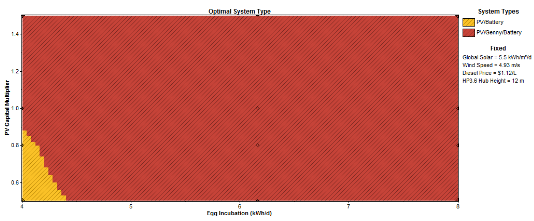


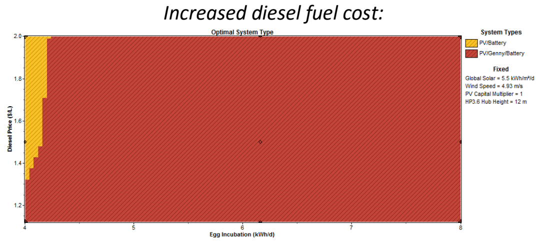
TABLE 13: SENSITIVITY RESULTS FOR EGG INCUBATOR LOAD.

Reduce PV cost:



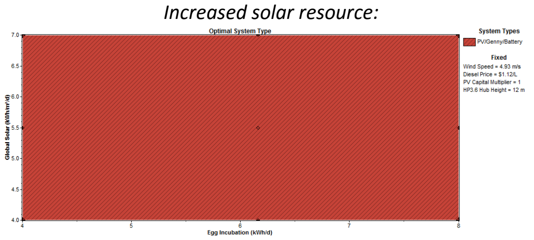
As would be expected, a drop in PV prices makes a fully PV based system more viable, especially at low loads.

Increased diesel fuel cost:



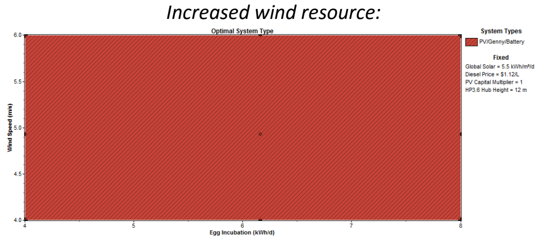
As diesel prices increase, then more PV would be in the mix, with a PV only system becoming viable at lower loads and slightly higher diesel prices.

Increased solar resource:



Increasing the solar resource simply increases the amount of PV in the generation mix.

Increased wind resource:



Wind never starts to play a part of this energy mix, even with increased resource.

3.2.3.1.3 Small workshop load

The small workshop has high peaks of use during the day, but a relatively low overall energy use. Systems to power this type of load are nearly all based on PV/Generator hybrid. Again, this is due to the high initial capital cost of the wind turbine installation. A wind turbine starts to play a part of the energy mix when the diesel cost is high.

FIGURE 28: OPTIMAL SYSTEM ARCHITECTURE AND RENEWABLE ENERGY FRACTION MAPS FOR WORKSHOP LOAD.

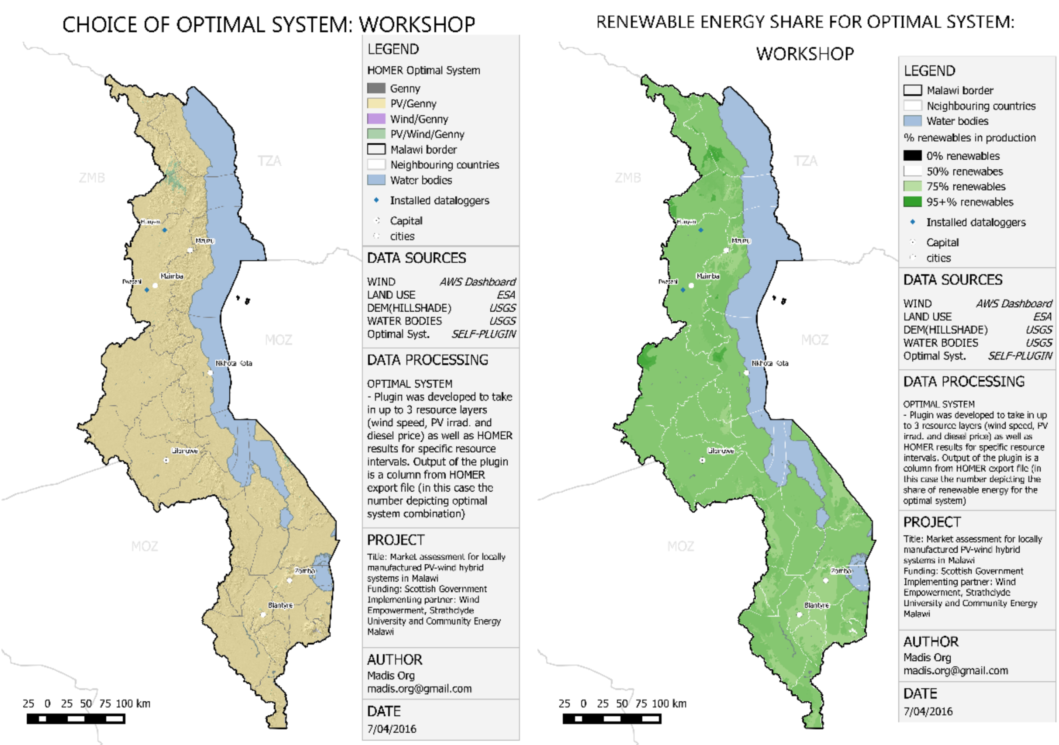
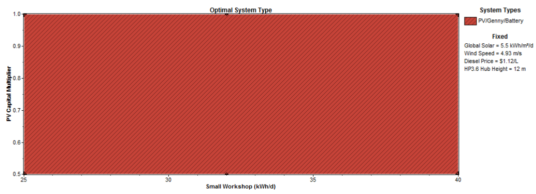


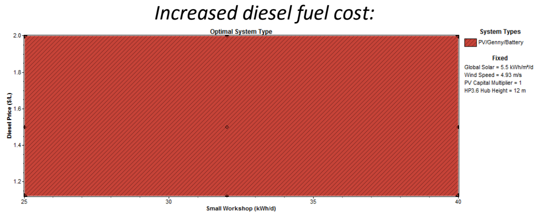
TABLE 14: SENSITIVITY RESULTS FOR WORKSHOP LOAD.

Reduce PV cost:



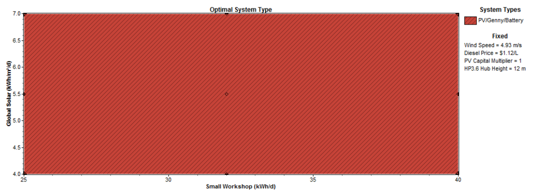
Lowering of cost of PV does not change the optimal system type, although it would mean increased penetration of renewable energy.

Increased diesel fuel cost:



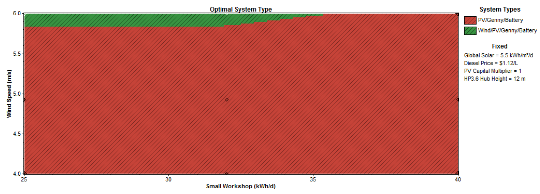
Change in diesel price does not change the optimal system type, although it would mean increased penetration of renewable energy.

Increased solar resource:

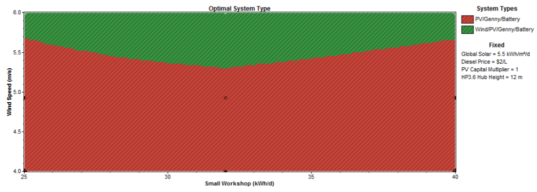


All optimal systems are based upon PV, so having more resource does not change the system type. It will increase the amount of solar energy in the mix.

Increased wind resource:



At higher wind speeds, then systems including a wind turbine just about become viable. With the diesel price doubled ($2/l), then wind can start to play more of a part in the energy mix, even at lower wind speeds:



3.2.3.1.4 Mini-grid Load

This is the only system where wind is an economically viable solution, even with a relatively low diesel price. This is because it is a larger load, so it would require a series of 1kW wind turbines in order to deliver the required energy yield. This has positive implications for operation and maintenance, as spare parts can be stored locally and shared between these modular systems. All wind systems identified in this analysis also have PV and a diesel generator as energy sources. This analysis also shows that the greater modularity of PV makes it possible to tailor energy generation much more closely to the required load, whereas adding another wind turbine is a significant investment and often cannot be justified.

FIGURE 29: OPTIMAL SYSTEM ARCHITECTURE AND RENEWABLE ENERGY FRACTION MAPS FOR MINI-GRID LOAD.

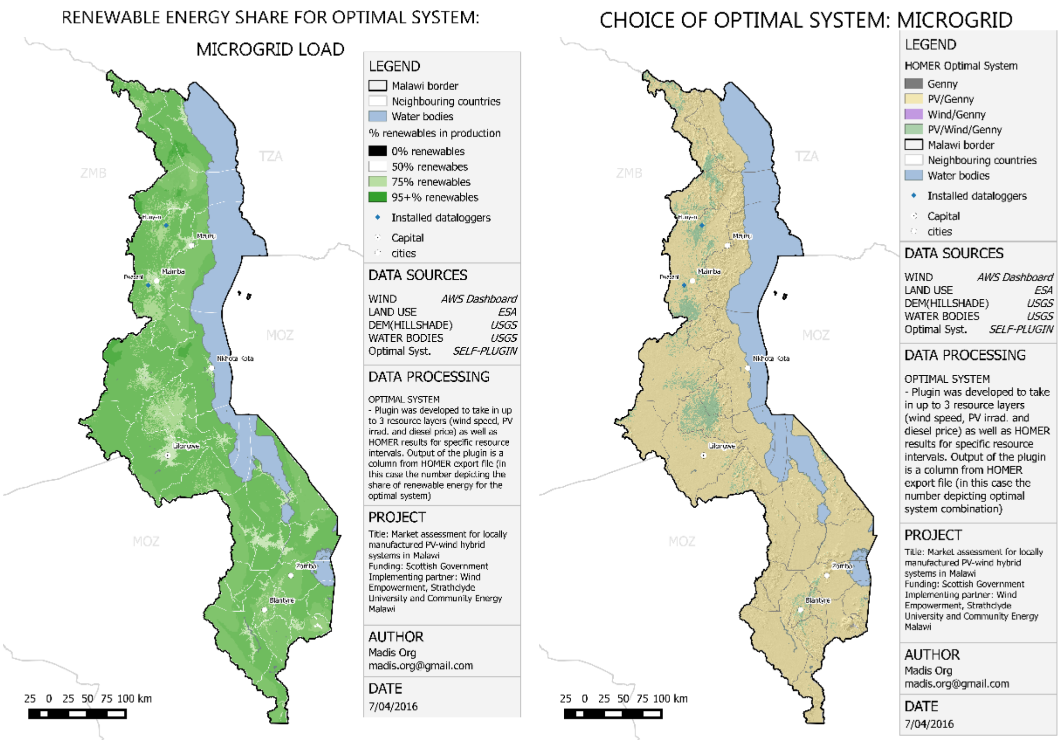
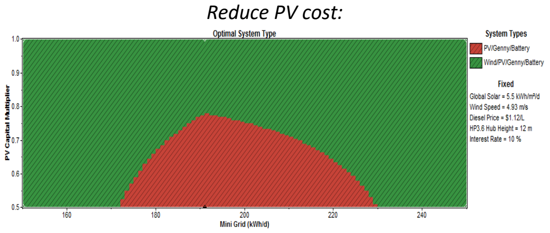
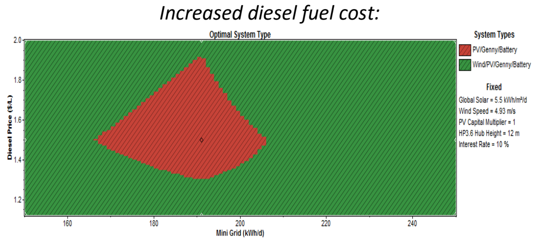
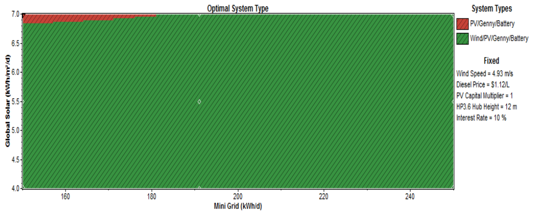


TABLE 15: SENSITIVITY RESULTS FOR MINI-GRID LOAD.

Reduce PV cost:	*Increased diesel fuel cost:*
	
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	The 'triangle' where the optimal system type is PV/generator, rather than Wind/PV/Generator, is, again, due to the high incremental cost of adding a wind turbine. Adding more PV make sense up to a point as it is more modular. At a certain point then adding a wind turbine becomes most sensible within certain locations.

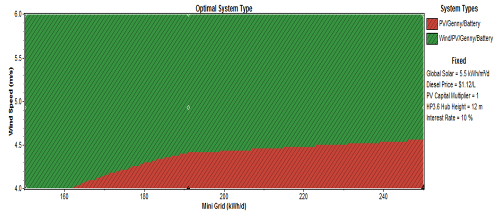
adding another wind turbine becomes most sensible within certain locations.

Increased solar resource:



In most locations, a Wind/PV/Diesel system makes sense.

Increased wind resource:



As would be expected, solar starts to play more of a part at lower wind speeds.

3.2.3.2 Market size filter

Table 16 shows the estimated market size in the regions of Malawi that are expected to remain off-grid in the short-medium term. Market size is given as a percentage of the total population of Malawi, which therefore represents the number of people who should choose that system architecture if they needed that particular energy service. The actual number of systems that could be implemented is clearly much smaller than this, as larger settlements with smaller distances between buildings may choose to invest in larger scale mini-grids, particularly those with a nearby watercourse that is suitable for hydroelectric power generation. What is more, additional complexity is added by the fact that each energy system is capable of serving multiple people (for example, many households will share a single maize mill), yet each household will need multiple energy services (a single household is likely to need to mill maize, fabricate/repair wooden/metal items, incubate eggs, cut hair, light their home at night, etc.). As a result, going to the next stage and providing a definitive figure for the number of potential systems that could be implemented is considered beyond the scope of this study.

TABLE 16: ESTIMATED MARKET SIZE IN OFF-GRID REGIONS AS A PERCENTAGE OF THE TOTAL POPULATION OF MALAWI FOR EACH LOAD PROFILE CATEGORY AND EACH SYSTEM ARCHITECTURE.

	MINI-GRID	WORKSHOP	MAIZE MILLING	EGG INCUBATION
GENERATOR	0%	0%	71%	0%
PV/GENERATOR	79%	86%	15%	86%
WIND/GENERATOR	0%	0%	0%	0%
PV/WIND/GENERATOR	7%	0%	0%	0%
GRID-PROXIMITY	14%	14%	14%	14%

Table 17 shows that as would be expected, off-grid regions generally have higher levels of poverty. This means that there is a greater need for access to energy in order to enable these people to escape from poverty. However, it also means that the ability to pay for access to energy will be lower. As a result, innovative financing mechanisms will be needed, as all off-grid regions have poverty levels in excess of 80%, which means that households will have little disposable income with which to pay for energy services.

TABLE 17: POVERTY LEVEL (FRACTION OF PEOPLE LIVING UNDER 2USD/DAY) IN DIFFERENT OPTIMAL SYSTEM ZONES OUTSIDE THE GRID PROXIMITY AREA.

	MINI-GRID	WORKSHOP	MAIZE MILLING	EGG INCUBATION
GENERATOR	-	-	84%	-
PV/GENERATOR	86%	86%	91%	86%
WIND/GENERATOR	-	-	-	-
PV/WIND/GENERATOR	87%	-	-	-
GRID-PROXIMITY	68%	68%	68%	68%

3.3 Can PV-wind hybrids address the challenges faced by solar PV in Malawi?

While solar technology clearly has significant potential for enhancing energy access in Malawi, there are aspects that need to be addressed to make the technology more viable. However, based upon the key experts' perspectives and the results of the techno-economic spatial modelling, there is no conclusive indication that PV-wind hybrids could present a more appropriate alternative to solar PV.

> *"If we can transfer the skills to local technicians and produce everything within the country, then all other things being constant, this is a very powerful economic argument."*
> *Conwell Chisale, Government of Malawi, Department of Energy Affairs, 28th January 2016*

Whilst the potential for job creation, local capacity building and strengthening of the local economy is a strong driver for small wind, unfortunately not all the other things are constant, as the evidence from this study shows that the wind resource in Malawi is much more variable, and the maintenance requirements for SWTs are much higher.

TABLE 18: THE CHALLENGES FACED BY SOLAR PV IN MALAWI.

Challenge	Description	Addressed by SWTs?
High upfront cost	Panels, battery and controller expensive	No
Low potential for local manufacture	Some potential for assembly, but cells will still need to be manufactured overseas.	Yes, but the market size is very small, which is unlikely to make establishment of a local SWT manufacturing industry profitable.
Limited power/energy consumption	Most systems were under designed or poorly sized. No clear sustainability schemes were in place, especially regarding care of the batteries. Grid electricity by ESCOM sets a standard of the sort of energy access that people in the rural areas expect	No
Resource availability during the rainy season, on cloudy days & at night time	Most experts feel Malawi has such a good solar resource everywhere, but some of the experts felt that the wind resource could be complementary a hybrid system.	Full wind resource assessment required for every new site. Resources not complimentary on a seasonal basis, but potentially daily and diurnally complimentary.
Batteries expensive & unreliable	Batteries often cited as weak point of solar PV systems	No

4 Conclusion and recommendations

The results of this study indicate that 1kW scale PV systems have a significant role to play in the electrification of off-grid communities in Malawi. **PV is scalable** across the entire country and its modularity and simplicity are ideally matched to the needs of off-grid communities, where technical capacity and individual household demand is low. However, **the promotion of 1kW scale locally manufactured SWTs in PV-hybrid systems is not recommended**, primarily due to the fundamental and insurmountable barrier of the limited and wind resources scattered across in Malawi.

> *"Malawi is much better endowed with solar than wind resources, which means that the role for SWTs is much smaller. In almost all areas, solar out competes wind."*
> *Conwell Chisale, Government of Malawi, Department of Energy Affairs, 28th January 2016*

Whilst scattered pockets of high winds do exist in Malawi, in practice, locating these regions will require significant time and effort due to the need to conduct on site measurements at each new location, ideally for an entire year. This increases the cost of such systems and requires new technical capacity to be built. It also slows down the project implementation timeline and adds an additional element of risk, as even after a year of data is obtained, the result may well be negative. In contrast, the solar resource is high throughout the entire country, meaning that individual site assessments are not necessary. What is more, PV power production is linearly proportional to solar irradiation, meaning that small variations in the resource make little difference to energy yields. In contrast, SWT power production is proportional to the cube of the wind resource.

All four modelled load profile categories are compatible with the PV-generator system architectures. The demanding maize milling load is the only one that is currently potentially incompatible in some regions, however with just a small increase in diesel price or decrease in PV price, PV-generator systems soon become the architecture of choice. In contrast, only one load category (mini-grid) shows any potential for PV-wind hybrid systems and although the techno-economic spatial modelling predicts that around 1.1 million people (7% of the population) live in these regions they are scattered all over the country. SWTs have much higher maintenance requirements than solar PV and must therefore be supported by a strong service network that is capable of offering technical knowledge, tools and spare parts on a local level. As a result, a critical mass of potential users is required in any one area in order to make the establishment of such a network cost effective. The only places where this may be possible are Dowa and Mzimba and even in these regions, only a small area of these districts actually have sufficient wind resource. As a result, whilst individual projects may find sufficient wind resources, the scalability of the technology is extremely limited.

Most donors and development workers that were interviewed for this study stated that they feel there is there high potential for wind energy in Malawi, however, most of the energy technical experts pointed to wind resource assessment as the means to answer this question. From the expert perspectives, the northern region was cited as having more potential, however the techno-economic spatial modelling results show that at the 1kW scale, even in these regions, the wind resources are insufficient for a scalable locally manufactured PV-wind hybrid electrification initiative. Most experts felt there is limited potential for wind compared to hydro power. It is also noted that the issue of potential goes beyond technical resource assessment but more importantly there wider aspects of local capacity, supply chain, enabling policy plus regulation and business viability. The key findings of the study are listed below, each of which is linked to a specific recommendation, as many also apply to PV and to larger scale wind turbines, which may still have a role to play in increasing access to energy in Malawi.

Prioritise innovation with resource seasonality: Since the wind resource availability has high seasonality, users can link productive activities that occur in the high wind season, e.g. irrigation, which peaks in the dry season. Water pumping is fast becoming a key initiative in Malawi now, especially through solar PV.

Develop financing schemes in sync with income generating activities: Communities can easily afford to make payment when they are selling an agricultural product or there are labour selling opportunities as in tea estates, however anything above MK 50,000 is a serious investment at household level and must be split into smaller repayments.

Investigate potential for wind pumping: There is undoubted potential for wind as a standalone technology when used for direct mechanical wind pumping. There are many places in Malawi that are using windmills to do water pumping, making use of the Mwera winds that the country usually experiences.

Conduct a full resource assessment prior to installation: Hydro and wind require a good resource assessment, while solar is envisaged to be available across the country. The government should invest in better wind resource mapping and make the results available to all interested parties. CEM should use the new datalogging equipment and skills that they are now equipped with to offer on-site wind measurements to mini-grid developers. Wind data collection should continue in Kamilaza (Fwasani CBO) and Elunyeni, as it is possible that the two months in which the data included in this report was collected were statistical anomalies.

Investigate potential for larger scale wind turbines: Very high demand for energy means there is huge potential for renewable energy systems. Where the resource is available, wind has significant potential in Malawi, given the huge driver to diversify the energy mix and reduce over reliance on hydro power. However, there is need for detailed studies to compare the costs for importing this equipment compared with the other viable options. There is an opportunity, as Malawi has duty and excise free provisions for renewable energy imports, however, the Malawi kwacha is a very unstable currency, and such instability is key challenge to viable supply chains based on imports.

Develop local capacity for operation and maintenance: Local capacity building for operation and maintenance must be considered critical so that projects can be sustainable. Currently the image of solar and wind energy are marred with poor installations and a lack of capacity building activities for local communities, which has ultimately resulted in vandalism and abuse of these systems. Technical and business training should be prioritised and efforts must be made to ensure that there is local supply chain for parts and components of the systems. Operation and maintenance is simpler with solar systems i.e. cleaning of panels is very easy. With wind turbines, the challenge is that it is very mechanical. One needs to consider bearings, elevation and lightning prevention all of which are complicated for local communities, engineering skills are required and parts supply chain is not often good.

Improve access to information: Foreign companies working on wind data are not making information freely and readily available. Data on wind speeds are not available as such past initiatives like the DoE Solar and Wind Hybrid schemes were done without proper information. There is no clarity of roles for past wind projects as such information for most projects is not accessible i.e. designs for DoE projects.

Develop national technical capacity: Lack of knowledge/information/research to drive and/or promote the technology in general among Malawians although this is likely to change with more graduates from Mzuzu University entering the job market.

Invest in better wind mapping: There is need for better quality wind mapping across Malawi to identify potentially wind rich areas. Some initial work was done by the Polytechnic (University of Malawi) in this regard, but it was not completed. Current wind speed data collect by the MET Department is collected at 2m which too low for wind projects designs. There is however a lot indigenous knowledge around wind in Malawi that maybe an opportunity to combine with science to map our wind resource for better decision making i.e. Mvuma winds and Mwera winds. Wind data currently available is not very specific to most locations, for example, in the southern region, models are based on data from just 2 or 3 met stations.

Develop and trial viable business models that engage communities: More work needs to be conducted to develop and trial energy ownership/business models. These should be linked with innovative financing mechanisms, such as MEET's donor supported credit guarantee approach. Innovation is also key around community engagement so community dynamics are handled well. If project or initiative is not owned by communities themselves it is unlikely to be sustainable. To reach financial viability faster, schools should be targeted as they give adequate numbers for a business to flourish. Credit default culture has been made worse by government and NGOs that give the poor people an impression that they are entitled to free things. The economics of community systems is complicated in Malawi, as battery replacement is required every 5 years, yet this is hard to achieve with minimal household contributions as the unstable economy means savings in Kwacha get easily eroded. Experience to date has shown that the number of households that connect and pay for most systems too few in most cases that limits revenue generation.

Increase awareness of the benefits and limitations of off-grid systems: Community awareness limited, as illustrated by the case of various DoE owned projects. Perception challenges also prevent adoption of wind and solar technologies. Some Malawians have put their faith in ESCOM Power and they believe such power is far superior to off grid options due to their limited capacity and range of household appliances. Lack of familiarity with the basics of the wind and solar technology among most Malawians is a significant constraint, as there are high levels of illiteracy and limited access to information sources such as the internet.

Increase quality control and raise consumer awareness of product quality: The quality of RE products is not currently regulated and as such, there are varying qualities of products with some very poor quality. Border control is done by Malawi Revenue Authority (MRA) and they have no technical guidance on RE product quality compared to MERA who are the regulators. There is currently no quality certification, as the current focus is revenue generation through VAT since there is a duty exemption. Due to illiteracy household decisions are often very complicated, and many prefer a bicycle to RE products. Most Indians who trade in Malawi understand the Malawian mentality and bring products on the market because the price is right not because the product is of good quality.

Increase access to capital: Capital access in Malawi is generally a huge challenge, Malawi has no investment bank and this limits the extent to which potential investors can access capital for renewable energy. Financial institutions in Malawi do not understand how the energy sector works. They propose very short and unrealistic loan periods for those interested to invest in energy. Interest rates are also generally higher in Malawi and it becomes risky if you consider that in the initial year's household awareness limited that affects the number of house that can get connections and pay for consuming power. Local banks also give a very short payback period for loans which does not suit RE projects. The checklists that banks use to approve loans often finds energy projects too risky business to be financed. Weak local currency means importation of spare parts becomes a huge challenge as local revenues get eroded so easily in value. Key for success is business modelling that should inform investment options without this not even financial institutions can lend you money. There is room for a moderate but sustainable financial and market facilitation. A typical example was done by the Malawi Environmental Endowment Trust (MEET) where they provided credit guarantees for households purchasing RE products especially solar home systems.

Introduce policy support for wind power if potential identified: There is currently no policy or regulatory framework in place for SWTs. If potential is identified, then it would be beneficial to proactively develop standards, offer targeted subsidies (for wind resource assessments and maintenance) and support the development of a viable market that attracts private investment. Currently most private sector players have lost out due to high default levels among rural Malawians when they get energy products on credit. Repossessing the products has its own difficulties as the quality is never the same. This has been made worse because of the confusing role played by NGOs and government at times in giving free handouts to people including energy products. The current model of development financing is more skewed towards donors and grants, but this can change with renewable energy as there is business potential that can attract private companies with space for financing institutions as well.

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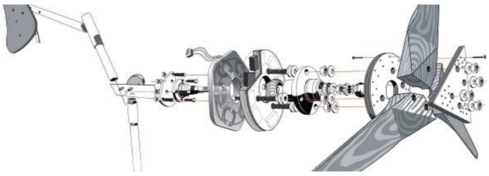


6 Appendix

6.1 Appendix A – Preventative and corrective maintenance requirements for Piggott turbines

- *Preventative maintenance* – a regular maintenance routine significantly reduces the risk of failure and is essential if SWTs are to achieve their expected lifetime. The procedure detailed in Table 6-1 is specific to Piggott turbines, as each SWT will have its own recommended procedures as specified by its manufacturer.

Table 6-1: Preventative maintenance routine to ensure reliable operation of Piggott turbines

Task	Description	Frequency	Time commitment	Expertise	Tools & consumables
Battery service	Check battery health and top up electrolyte if necessary	Every 2 weeks	10 mins	Well trained end-user or community technician	Multimeter, hydrometer, deionised water
Wind turbine service	Lower tower, inspect turbine & repaint blades/tighten bolts/grease bearings etc. as required	Every 6-12 months	2 days[Error! Bookmark not defined.]	Community technician (+10 strong people)	Spanners, screwdrivers, paintbrush, paint, grease, rope winch/pulley & rope

- *Corrective maintenance* – even with the most stringent preventative maintenance regime, it is only a matter of time before a failure occurs. Table 6-2 lists the failures that present the highest levels of risk. Although this is specific to Piggott turbines, many of the failures (e.g. blade failure or generator seizing up) are common to all SWTs. Corrective maintenance is classified into advanced and basic, to distinguish what can/cannot reasonably be carried out by a community technician. In general, it is expected that basic corrective maintenance can be carried out by a well-trained community technician, whilst advanced corrective maintenance will require a site visit by an engineer (or for the community technician to disassemble the failed component and send it back to the manufacturer for repair or replacement).

Table 6-2: Common failures of Piggott turbines and their consequences.

Failure	Probable cause	Safety risk	Likelihood[11]	Repair	Spare parts	Tools & consumables[12]
BASIC CORRECTIVE MAINTENANCE						
Worn bearing	Bearing reaches end of life	None	Medium	Replace bearing[13]	New bearing	Screwdrivers, spanners, jacking screws[14], rope winch/pulley & rope
Pendant cable twisting	Excessive yawing on turbulent sites	None – turbine stuck facing one direction only	High	Untwist cable & repair broken section (if necessary)	None (except in extreme cases)	Wire strippers, electrical connecter, electrical tape
Blown rectifier	Overspeed protection system jamming	Small fire risk	Medium	Replace rectifier	New rectifier	Screwdrivers
ADVANCED CORRECTIVE MAINTENANCE						
Blade failure	Blade hitting tower, blade	Flying blade fragments	Medium	Replace or repair blade/s	New set of blades	Screwdrivers, spanners, rope

[11] High probability = likely to occur within the lifetime of each LMSWT.
Medium probability = may occur during the lifetime of some turbines.
Low probability = unlikely to occur.
[12] To install spare part, not to manufacture new spare part.
[13] Unless bearing has become so loose that friction between the stator and rotor has also caused these parts to fail.
[14] Short lengths of threaded bar designed to raise and lower the magnet rotor discs.

Failure	Probable cause	Safety risk	Likelihood[11]	Repair	Spare parts	Tools & consumables[12]
	mounting failure					winch/pulley & rope
Tower collapse	Guy rope failure	Falling tower & turbine	Low	Replace or repair broken components	Typically 1 or 2 new blades & a new tower section	As required for installation
Generator seizing up	Magnets corroding & swelling up	None	High	Replacement of magnets	New rotor disc/s (and stator in severe cases)	Screwdrivers, spanners, jacking screws, rope winch/pulley & rope
Burnt out generator	Overspeed protection system jamming	Small fire risk	Medium	Replacement or repair of stator	New stator (and often also rotor discs)	Screwdrivers, spanners, jacking screws, rope winch/pulley & rope
Lightning strike	Lightning storm	Fire	Dependent on location – see **Error! Reference source not found.**	Replacement of stator/electronics	Stator/electronics	Screwdrivers, spanners, jacking screws, rope winch/pulley & rope

6.2 Appendix B – Input data for techno-economic spatial modelling in Stage II

This section describes the data sources, data processing and intermediary results for the techno-economic spatial modelling conducted in *Stage II: Quantifying the potential market*.

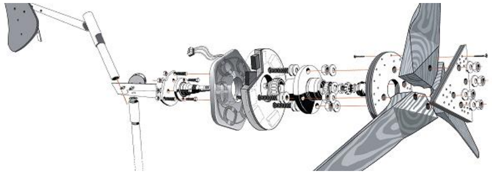


Table 3 The table presents the main figures that define the HOMER-model used to evaluate an off-grid energy system for a number of load scenarios, given the solar and wind resources in Kamilaza (Fwasani CBO). The values in the columns under each load scenario give variations (both technical and economic) the model allows for optimizing the design. Further detailed and constant settings of the model are not presented in this table.

Technical system									
Component	Basic Characteristics					Costs			Comments
PV-panel	Lifetime	Derating Factor [%]	Slope [deg]	Azimuth [deg W of S]	Eff. @ STD [%]	Capital [$/kW]	Replacement [$/kW]	O&M $/yr	
	15 yr	80	12	180	13	146	146	10	check price
Generator	Lifetime	Min. Load Ratio [%]	Intercept coeff. [L/hr/kW rated]	Slope [L/hr/kW output]		Capital [$/kW]	Replacement [$/kW]	O&M $/hr	
	15000 hr	50	0,08	0,25		356	356	0,075	check price
SWT	Lifetime	Diameter [m]				Capital [$/kW]	Replacement [$/kW]	O&M $/yr	
	15 yr	3,6				3000	3000	250	
Battery	Lifetime	Nom. Capacity [Ah]	Voltage [V]	Chemistry		Capital [$/kW]	Replacement [$/kW]	O&M $/yr	
	>4 yr	260	12	Lead-Acid		425	425	25	Each string with 4 batteries (48V)
Inverter	Lifetime	Inv. Efficiency [%]	Rect. Efficiency [%]			Capital [$/kW]	Replacement [$/kW]	O&M $/yr	
	10 yr	90	85			360	360	28	

	Input	Comment
Econonic Environment	Diesel	
	Project Lifetime	
	Annual real Interest rate	
Natural Resources	Wind	yearly avergae
	Solar	yearly average
	Amb. Temp.	yearly average
Load	Electricity Use	daily average

Egg Incubation – Search Space/Sensitivities

	Value							
PV-panel	0	1	2	4	6	8	10	
PV-panel (cost)	1	0,8	0,5	1,5				
Generator	0	1	2	3				
Generator (cost)	1	2	3					
SWT	0	1	2	3				
SWT (2nd row)								
Battery	0	1	2	4	6	8	10	16
Battery (2nd row)								
Inverter	0	0,6	0,8	1				
Diesel	1,12	2						
Project Lifetime	15							
Annual real Interest rate	25							
Wind	4	4,93	6					
Solar	5,5							
Amb. Temp.	19,9							
Electricity Use	2	4	6,16	8				

Maize Milling – Search Space/Sensitivities

	Value							
PV-panel	0	0,5	1	2	6	10	12	14
PV-panel (cost)	1	0,8	0,5	1,5				
Generator	0	5	7,5	10	12,5	15		
Generator (cost)	1	2	3					
SWT	0	1	2	3	4			
SWT (2nd row)	0,5	1						
Battery	0	1	2	3	4	8	16	32
Battery (2nd row)								
Inverter	0,5	1	2,5	5	7,5	10	12,5	15
Diesel	1,12	1,5	2					
Project Lifetime	15							
Annual real Interest rate	25							
Wind	4	4,93	6					
Solar	5.5							
Amb. Temp.	19,9							
Electricity Use	20	25	27,7					

Small Workshop – Search Space/Sensitivities

	Value								
PV-panel	1	2	4	6	8	10	12	15	20
PV-panel (cost)	0,5	1							
Generator	2,5	5	7,5	10	12,5	15	20		
Generator (cost)	1	2	3						
SWT	0	1	2	3	4				
SWT (2nd row)	0,5	1							
Battery	0	2	4	6	8	16	32		
Battery (2nd row)									
Inverter	2,5	5	7,5	10	15	20			
Diesel	1,12	1,5	2						
Project Lifetime	15								
Annual real Interest rate	25								
Wind	4	4,93	6						
Solar	5.5								
Amb. Temp.	19,9								
Electricity Use	20	25	32						

Mini-Grid – Search Space/Sensitivities

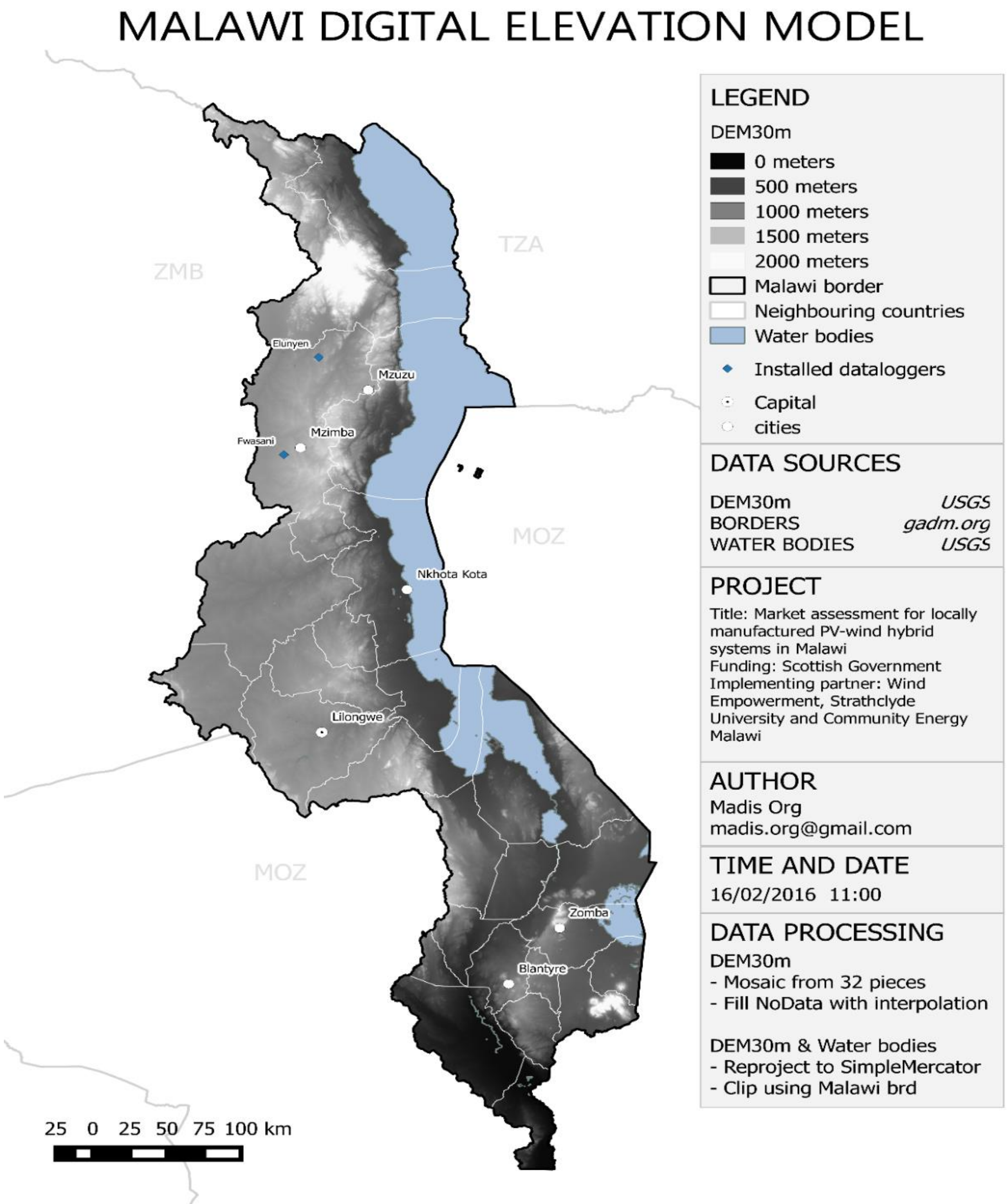
	Value							Unit
PV-panel	10	20	30	40	50	60	70	kW
PV-panel (cost)	0,5	1						cost mult
Generator	0	20	40	60	80			kW
Generator (cost)	1	2	3					cost mult
SWT	0	1	2	3	4	5		turbines
SWT (2nd row)	0,5	1						
Battery	0	3	4	8	16	32	48	Strings
Battery (2nd row)								
Inverter	20	40	80	100				kW
Diesel	1,12	2						$/L
Project Lifetime	15							yr
Annual real Interest rate	25							%
Wind	4	4,93	6					m/s
Solar	5,5							kWh/m/d
Amb. Temp.	19,9							
Electricity Use	150	191	250					kWh/day

6.2.1 Elevation

Digital elevation model (DEM) serves as a base layer for many height related geospatial analysis. In 2009 Shuttle Radar Topography Mission (SRTM) was completed to provide most up to date and accurate DEM of Earth that was also made publically available. SRTM data is of 30 meter spatial resolution and available for download via USGS web platform after registration. For the purposes of this project, 32 tiles covering the area of Malawi were downloaded and then mosaicked together using QGIS software. Due to the imperfections in the data capture of the SRTM (deserts, mountain areas), some cells of the raster dataset appear as NoData values. Again, QGIS software built-in functionality Fill-NoData was used to approximate the missing values based on the raster values within the neighbourhood.

To enhance the elevation differences on land, the layer of water bodies was added to this map. The data source for water bodies was again USGS (2003). To further enhance the final DEM map, the borderlines of neighbouring countries were also added (GADM 2015).

FIGURE 30: DIGITAL ELEVATION MODEL OF MALAWI.



6.2.2 Land cover

Land cover data is needed in this project for two purposes. Firstly, diesel cost haulage data is dependent on the travel time not only on roads, but also on other surfaces such as forests, fields, etc. Hence, land cover data is used for the assessment of travel time across the whole of Malawi. The surface roughness of the local land area affects the wind speed and hence the wind speed when adjusted for different hub heights. Based on a wind map at a certain height, it is possible to interpolate wind speeds at other heights. Manwell (2003) presents two separate formulae for this, a power law and log law. The log law is used mainly for wind speeds below 100m of altitude:

$$v \approx v_{ref} \cdot \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_{ref}}{z_0}\right)}$$

v = velocity to be calculated at height z

z = height above ground level for velocity, v

v_{ref} = known velocity at height z_{ref}

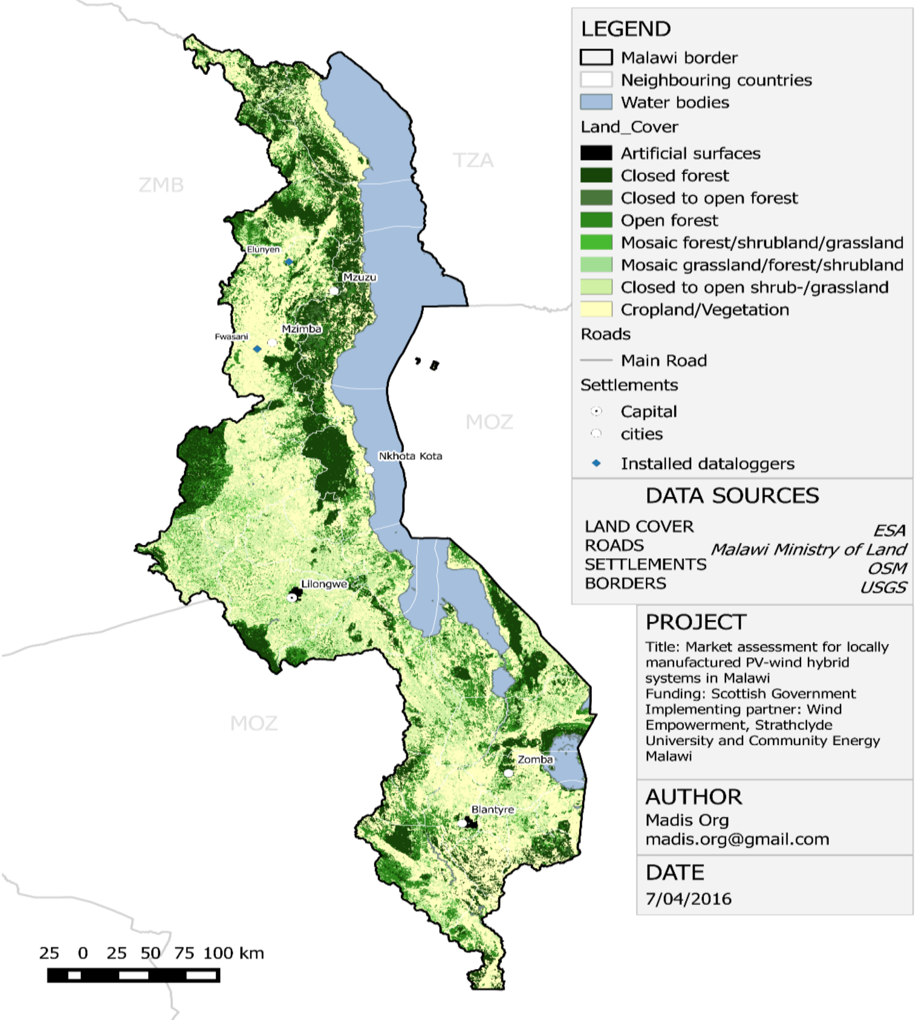
z_{ref} = reference height where v_{ref} is known

z_0 = roughness length in the current wind direction

To incorporate this into the wind speed data, the land use is used to give a surface roughness length for the wind speed calculations. The land cover data for this map was obtained from the European Space Agency (2010) 300m resolution data set.

FIGURE 31: LAND COVER MAP OF MALAWI. DATA SOURCE: EUROPEAN SPACE AGENCY (2010).

LAND COVER MALAWI (BASED ON ESA DATA)



The attribute table of the land cover data was altered to reflect the needs of the project. The speed of corresponding land cover types was adopted from Nelson (2008) and the roughness lengths were adopted from Davis & Badger (2013).

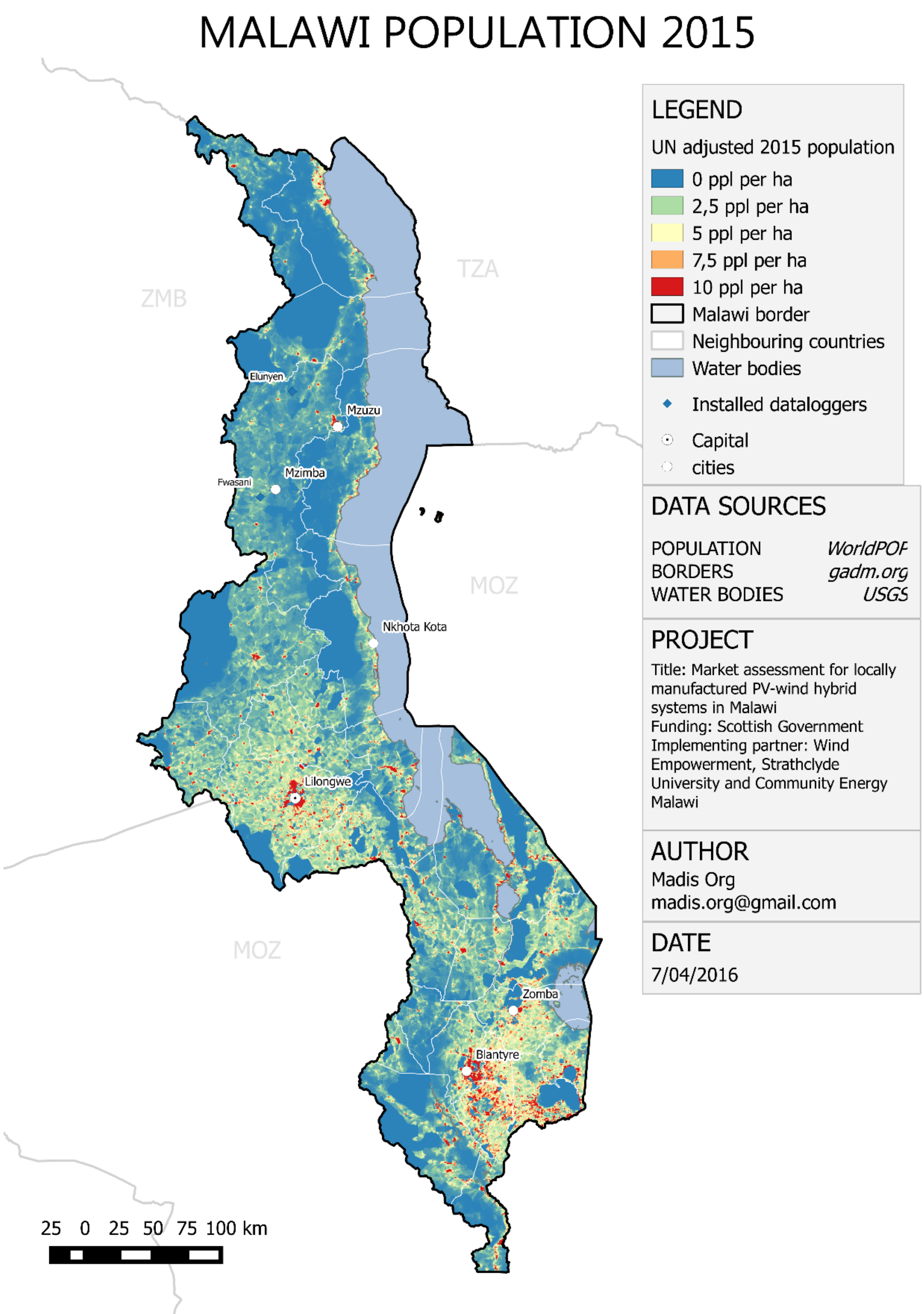
Table 4: Attribute table for land cover map. Data sources: Nelson (2008) and Davis & Badger (2013).

ESA Land Cover type	Speed (km/h)	Roughness length (m)
14 Rain-fed croplands	1.67	0.1
20 Mosaic Cropland (50-70%) / Vegetation (grassland, shrubland, forest) (20-50%)	1.67	0.3
30 Mosaic Vegetation (grassland, shrubland, forest) (50-70%) / Cropland (20-50%)	1.25	0.3
40 Closed to open (>15%) broadleaved evergreen and/or semi-deciduous forest (>5m)	1.09	1.5
50 Closed (>40%) broadleaved deciduous forest (>5m)	1.00	1.5
60 Open (15-40%) broadleaved deciduous forest (>5m)	1.25	1.5
90 Open (15-40%) needle-leaved deciduous or evergreen forest (>5m)	1.67	1.5
110 Mosaic Forest/Shrubland (50-70%) / Grassland (20-50%)	1.25	1.5
120 Mosaic Grassland (50-70%) / Forest/Shrubland (20-50%)	1.67	0.5
130 Closed to open (>15%) shrubland (<5m)	1.67	0.1
140 Closed to open (>15%) grassland	2.00	0.03
150 Sparse (>15%) vegetation (woody vegetation, shrubs, grassland)	2.50	0.05
180 Closed to open (>15%) vegetation (grassland, shrubland, woody vegetation) on	1.67	0.2
190 Artificial surfaces and associated areas (urban areas >50%)	30	1
210 Water bodies	20	0.0001

6.2.3 Population Density

To perform any spatial analysis on the potential market size, a reasonably good estimate of the spatial distribution of the population within Malawi was needed. Unfortunately no local Malawi-specific dataset could be identified. Hence, an extract from a global 100m spatial resolution dataset Worldpop (2015) was used. The WorldPop population data for Malawi in the year 2015 is based on the national census data from year 2008. As no newer census data exists, WorldPop uses other historic census data, satellite images and other sources of information to model population for the year 2015.

FIGURE 32: POPULATION DISTRIBUTION MAP OF MALAWI. DATA SOURCE: WORLDPOP (2015).

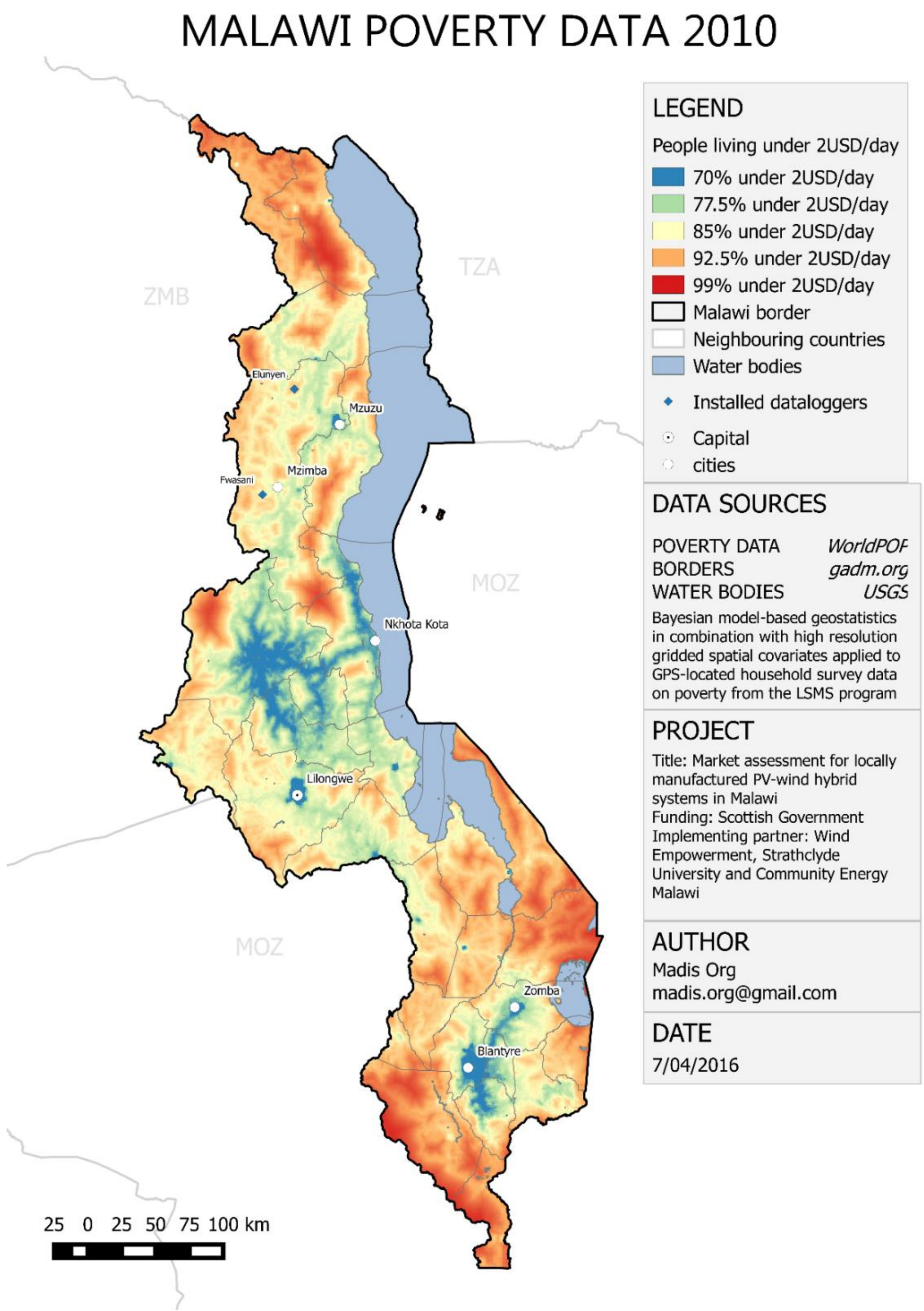


6.2.4 Poverty

Similarly to population data, it is difficult to find any local information on ability or willingness to pay with a reasonable spatial resolution. Again, Worldpop (2015) dataset on poverty data was utilized to create the Malawi poverty map. WorldMap have developed and applied novel approaches to poverty mapping built on geo-located household survey data.

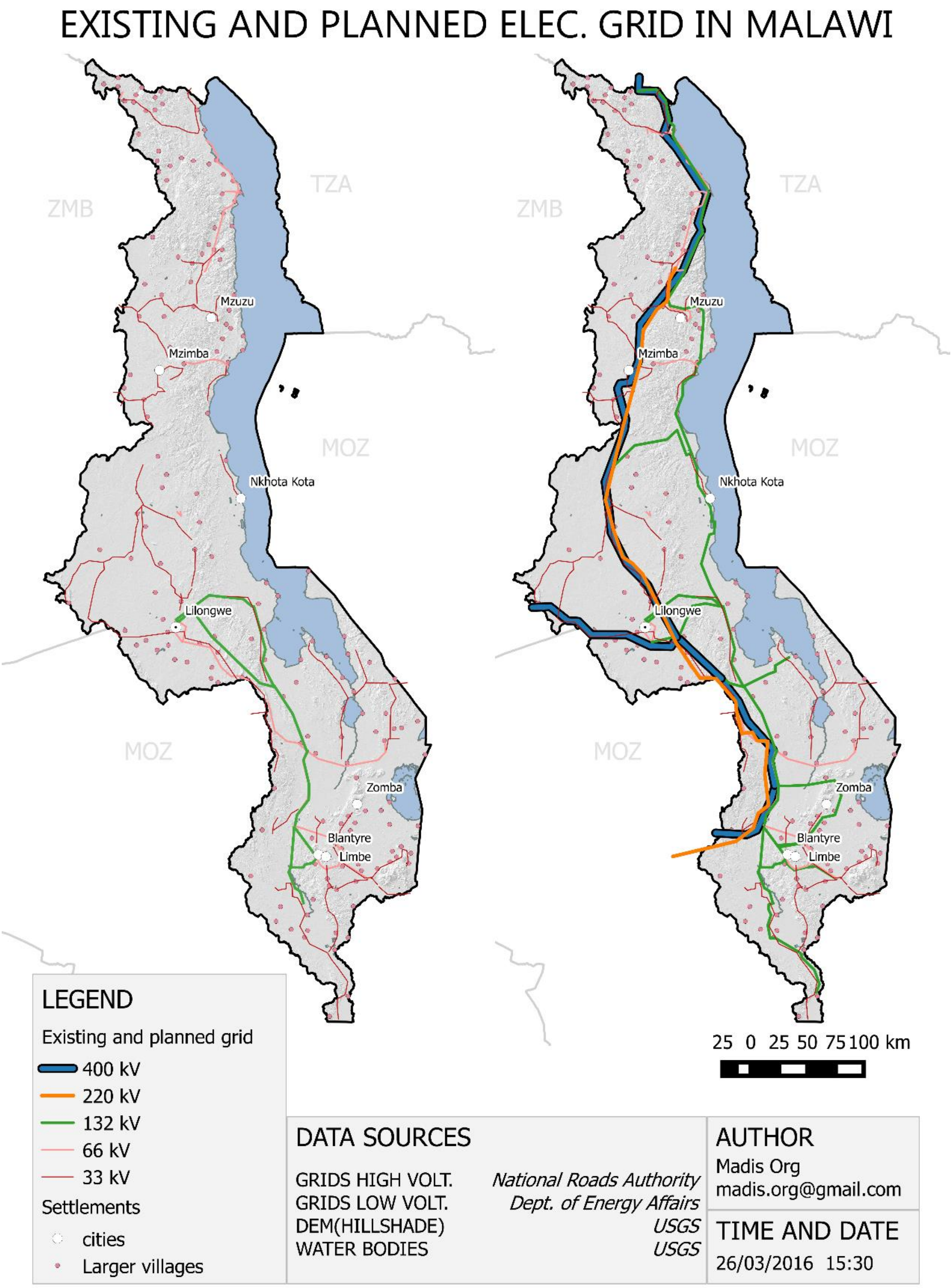
In the current project Malawi poverty data (percentage of people living under 2 USD/day) is used to assess the willingness to pay for renewable energy technologies.

FIGURE 33: POVERTY MAP OF MALAWI. DATA SOURCE: WORLDPOP (2015).



6.2.5 Grid Infrastructure

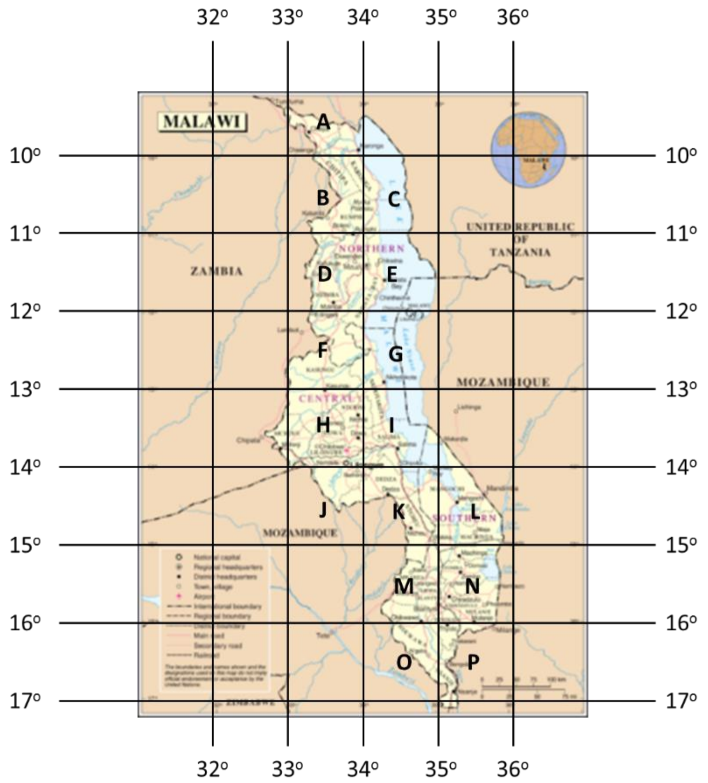
FIGURE 34: EXISTING AND PLANNED ELECTRICITY GRID INFRASTRUCTURE IN MALAWI. DATA SOURCES: (Merz and McLellan Consulting Engineers 2010; National Roads Authority 2006).



6.2.6 Wind and solar resources

To simplify the country-wide data analysis of the seasonal variation of wind and solar resources, this data was analysed for squares of 1 degree latitude and longitude, as shown below.

FIGURE 35: LOCATION OF THE AREAS ANALYSED FOR THE SEASONAL VARIATION IN WIND/SOLAR RESOURCE DURING THIS STUDY. DATA SOURCE: (MetMalawi 2016).

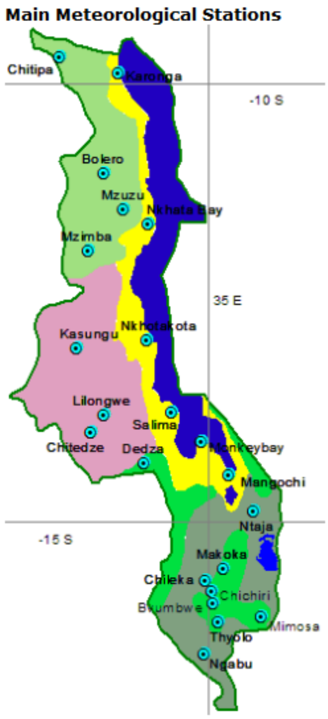


6.2.6.1 Wind resource

Malawi's present network of meteorological (met) stations comprises 22 full meteorological stations, 21 subsidiary agro-meteorological stations and over 761 rainfall stations, as shown here. The numbers relate to the number of met monitoring stations.

FIGURE 36: LOCATION AND DESCRIPTION OF MALAWI'S MET STATIONS. DATA SOURCE: (MetMalawi 2016).

STATION	NUMBER S
Rainfall	761
Air temperature	81
Atmospheric pressure	13
Upper winds	7
Upper Air	1
Wind at 2 metres	39
Wind at 10 metres	5
Weather (clouds, visibility etc)	25
Sunshine duration	30
Global Solar radiation	9
Diffuse Solar Radiation	3 (1987)
Evaporation	28
Soil temperature	10
Soil Moisture	5
Phenological Observations	5
Seismic data	2



Data from these stations was not used in this market assessment due to the following issues:

- Wind data generally recorded at 2m height. This is too low to extrapolate up for wind power generation.
- Where wind data was recorded at 10m, the data was not readily available.
- No information on local obstructions, such as tree and buildings.
- Inconsistent data with large sections of missing data.
- Data typically recorded manually during the day prior to automatic weather stations (AWS).

Table 5 shows that there are many dashboards that publically display annual average wind maps for Malawi, however no spatial wind data of sufficient resolution could be found that was freely available for direct download. The two sites where SgurrEnergy has installed data-logging systems (Rhumpi West and Mzimba) were used for comparison between the available data sets. The AWS TruePower data set was chosen as it has the highest spatial resolution and showed good agreement with the measured data from the SgurrEnergy mast. As the data set is not freely available, the AWS TruePower (2016) dashboard was used to display wind data at 30m height for the region of Malawi and using Windows snipping tool to capture screenshots, the wind speeds on the area of Malawi along with the national border were captured into 5 RGB images. These images were cropped and merged in QGIS. Then, the RGB values were reclassified to correspond to the values (in m/s) on the AWS TruePower colour scale. Finally, the reclassified raster layer was geo-referenced using the border of Malawi. The final wind map is made 50% opaque with the hill shade layer as a background layer.

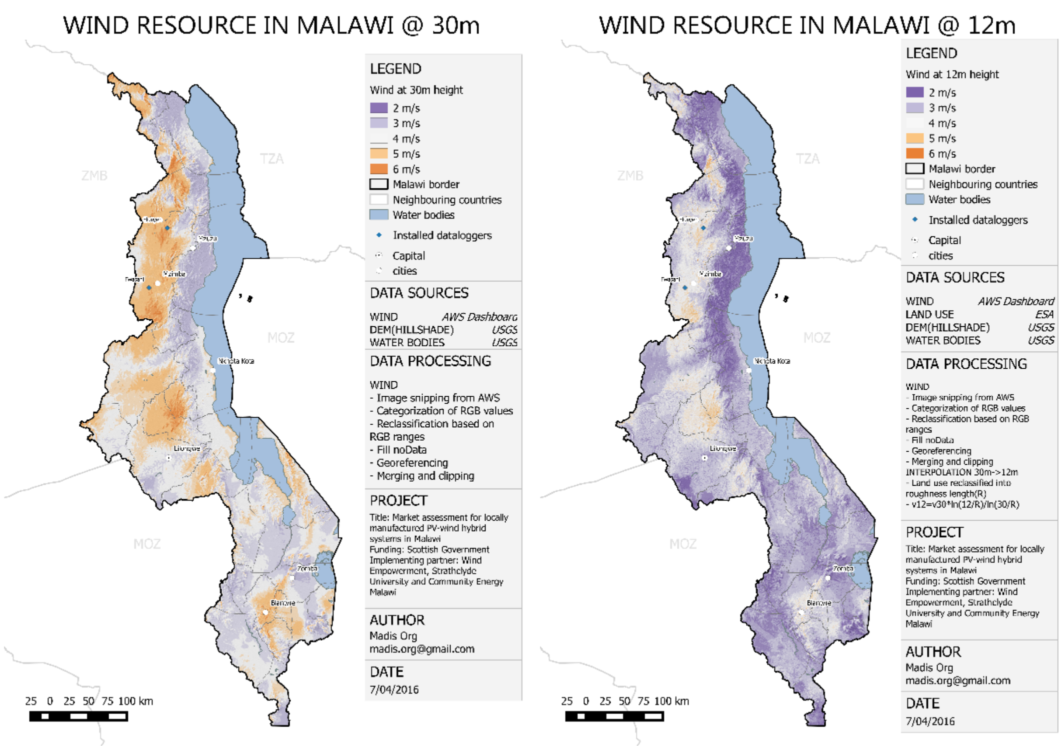
TABLE 5: REVIEW OF SPATIAL WIND DATA SOURCES AVAILABLE FOR MALAWI. NOTE: RIGHT HAND COLUMNS SHOW DATA NORMALISED TO 50M HEIGHT IN ORDER TO COMPARE THE DATA SETS.

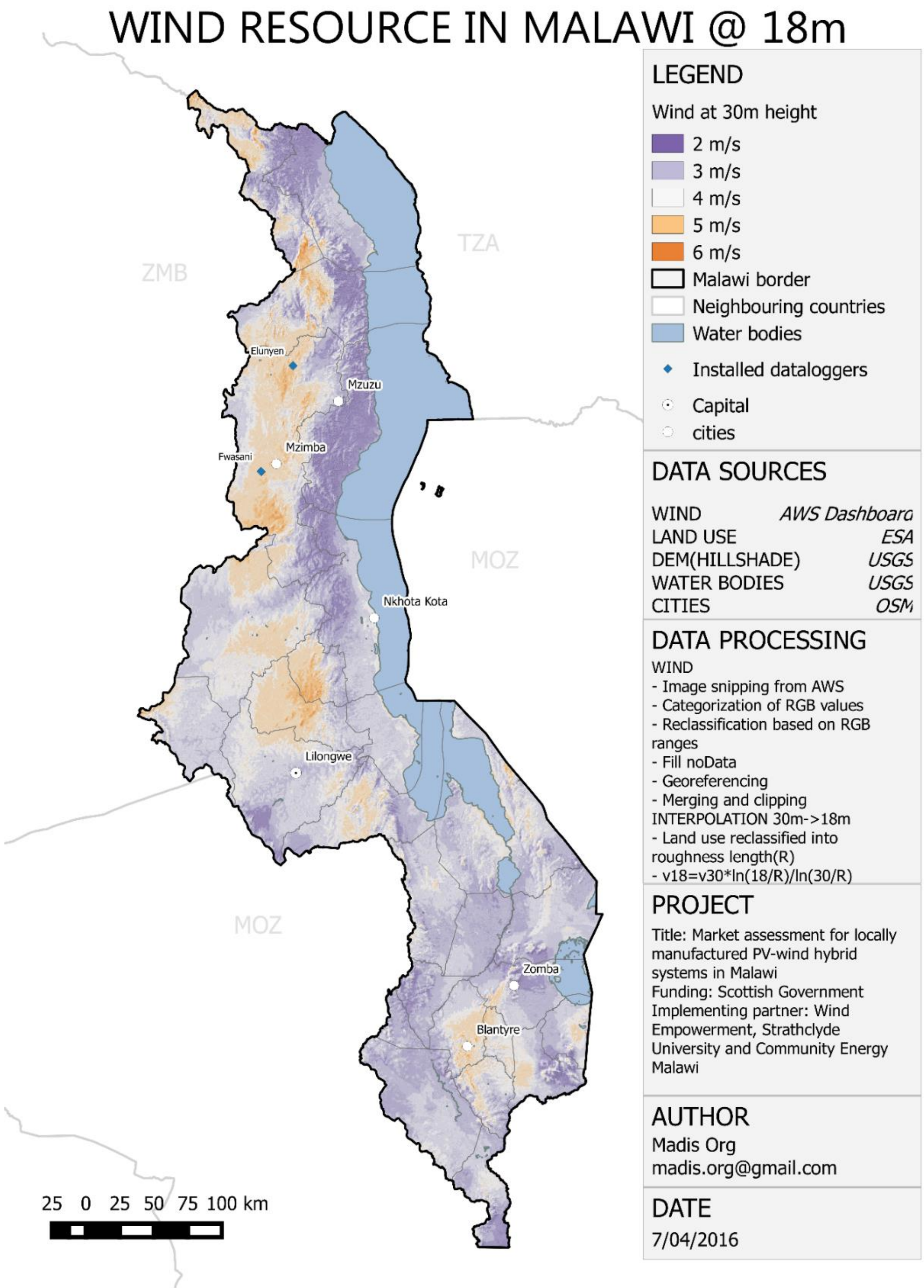
Data Source	Website	Ref. height (m)	Spatial resolution	Notes	50m wind speed (m/s) @ Rhumpi-West Mast site	50m wind speed (m/s) @ Mzimba Mast site
SgurrEnergy/ WEPP 2014	http://strath-e4d.com/2014/12/05/malawi-wind-wepp-data-preview/	70	POINT	Datalogging systems installed by SgurrEnergy at Rhumpi-west 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

Using the formula described above in *Land cover*, the roughness lengths from Figure 31, and the wind map at 30m height, the wind maps for Malawi at 12m and 18m heights shown in were calculated. It should be noted due to the presence of obstacles such as trees and buildings, lower hub heights have more uncertainty in the calculated/simulated wind speed data. The 18m wind map was used for the spatial modelling conducted throughout this study, as the wind speeds indicated by the 12m map are very low. As a result, economic data for 18m towers was used in the HOMER modelling.

FIGURE 37: WIND RESOURCE MAPS FOR MALAWI AT 30M, 18M AND 12M HEIGHT. DATA SOURCE: AWS TRUEPOWER (2016).





Simulated data from AWS TruePower was compared with real measured data taken with a data-logged anemometer in order to give confidence in the simulated data. SgurrEnergy installed data logging systems in two locations, Mzimba and Rhumpi-West. These were installed as part of the WEPP wind assessment for large wind projects in Malawi (SgurrEnergy 2013). These systems have 3 anemometers at 30m, 50m and 70m height. They have been installed for >1 year.

The wind-speed distribution over the year as recorded by the SgurrEnergy mast verifies the seasonal variation in the simulated data from AWS TruePower for the Mzimba region (see Figure 39), i.e. January to March is the low wind season, with winds gradually increasing until November. Figure 38 shows that this is clearly the case for both 2014 and 2015. Figure 40 shows that this pattern is similar across the country.

FIGURE 38: DAILY AVERAGES OF RECORDED WIND SPEED FROM 11/5-2014 UNTIL 17/01-2016 AT THE MZIMBA MAST AT 30M HEIGHT (SGURRENERGY 2013).

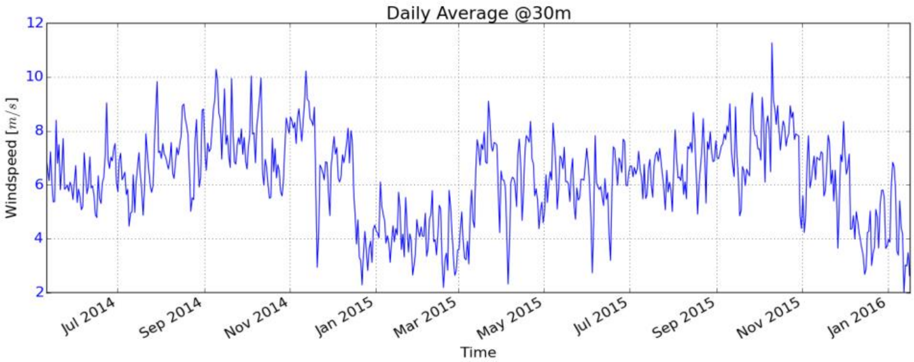


FIGURE 39: MONTHLY AVERAGE WIND SPEEDS AT 18M HEIGHT FOR KAMILAZA (FWASANI CBO), MZIMBA. ANNUAL AVERAGE = 4.8M/S. DATA SOURCE: AWS TRUEPOWER (2016).

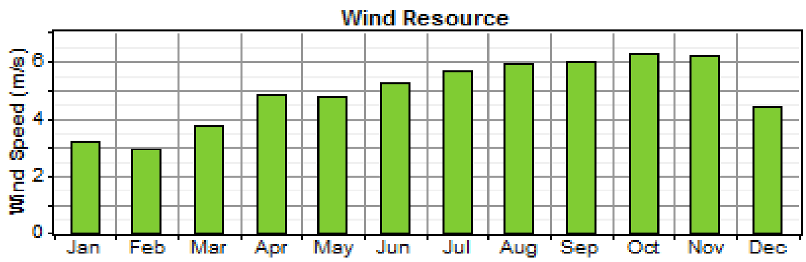
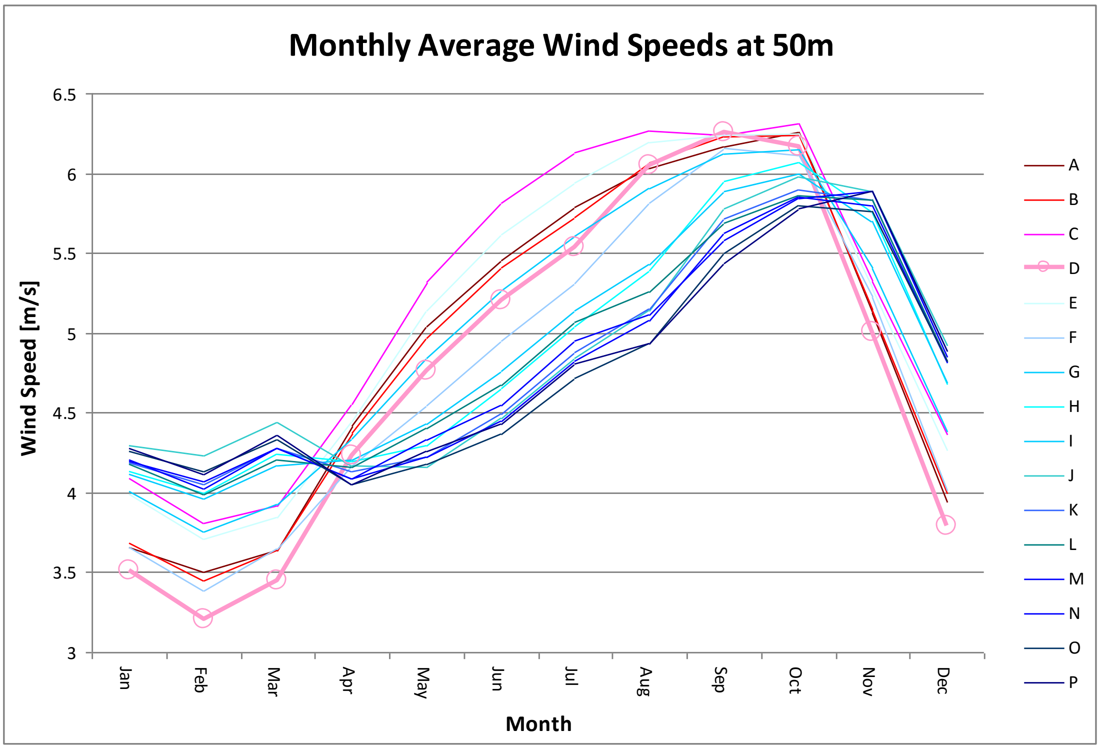


FIGURE 40: NORMALISED SEASONAL VARIATION OF THE WIND RESOURCES IN MALAWI. DATA SOURCE: (STACKHOUSE 2014).



6.2.6.1 Solar resource

The HOMER modelling takes hourly time series solar irradiance data from Meteonorm (2016) for simulation. The source for the spatial data was the Global Renewable Energy Atlas (IRENA 2016) dashboard displaying global horizontal irradiation data for Malawi with 200m spatial resolution from The World Bank Group data set. The map is an un-validated, satellite-derived estimate of the irradiation, however for the purposes of this study the accuracy suffices. Solar data was snipped, cropped, merged, reclassified and geo-referenced to produce the map shown in Figure 42. Figure 43 shows that all areas follow a very similar seasonal pattern. The maximum variation between areas is 18%.

FIGURE 41: GLOBAL HORIZONTAL IRRADIANCE FOR AREA D, WHERE KAMILAZA (FWASANI CBO) IS LOCATED. DATA SOURCE: WORLD BANK GROUP DATA SET FROM GLOBAL RENEWABLE ENERGY ATLAS (IRENA 2016).

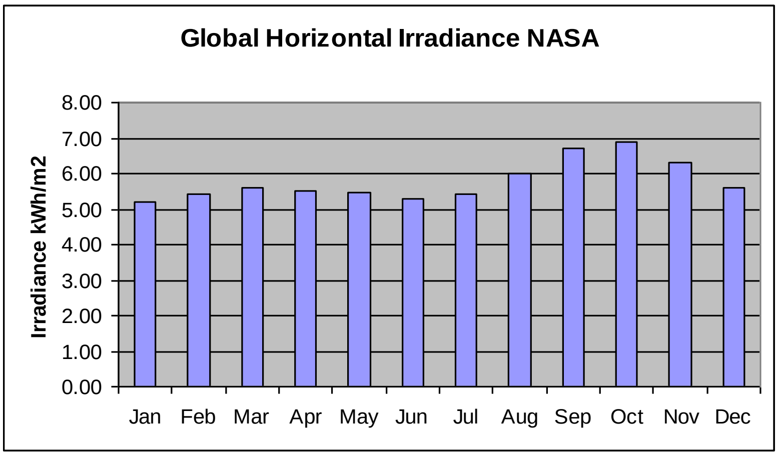


FIGURE 42: GLOBAL HORIZONTAL IRRADIATION IN MALAWI. DATA SOURCE: METEONORM (2016).

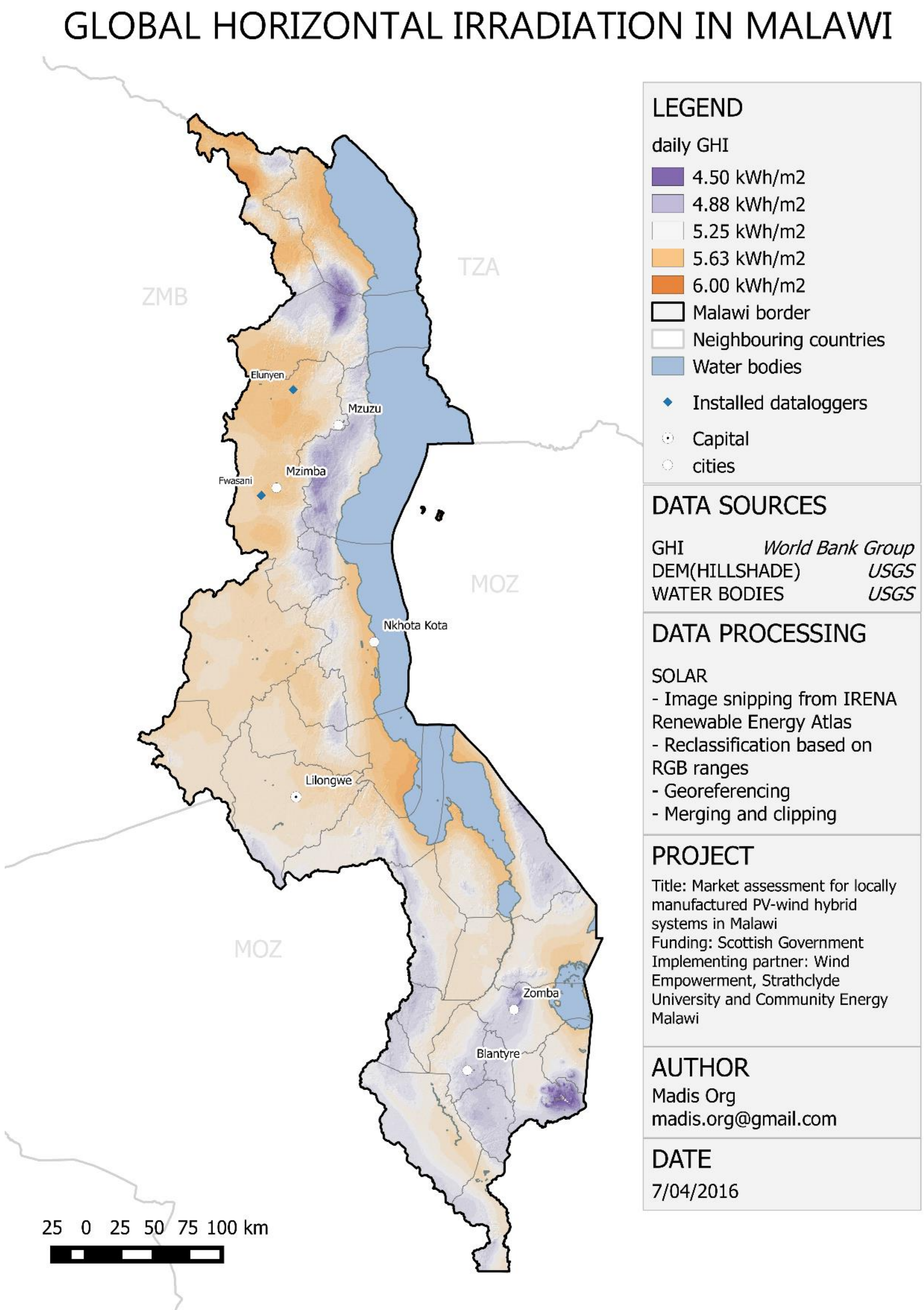
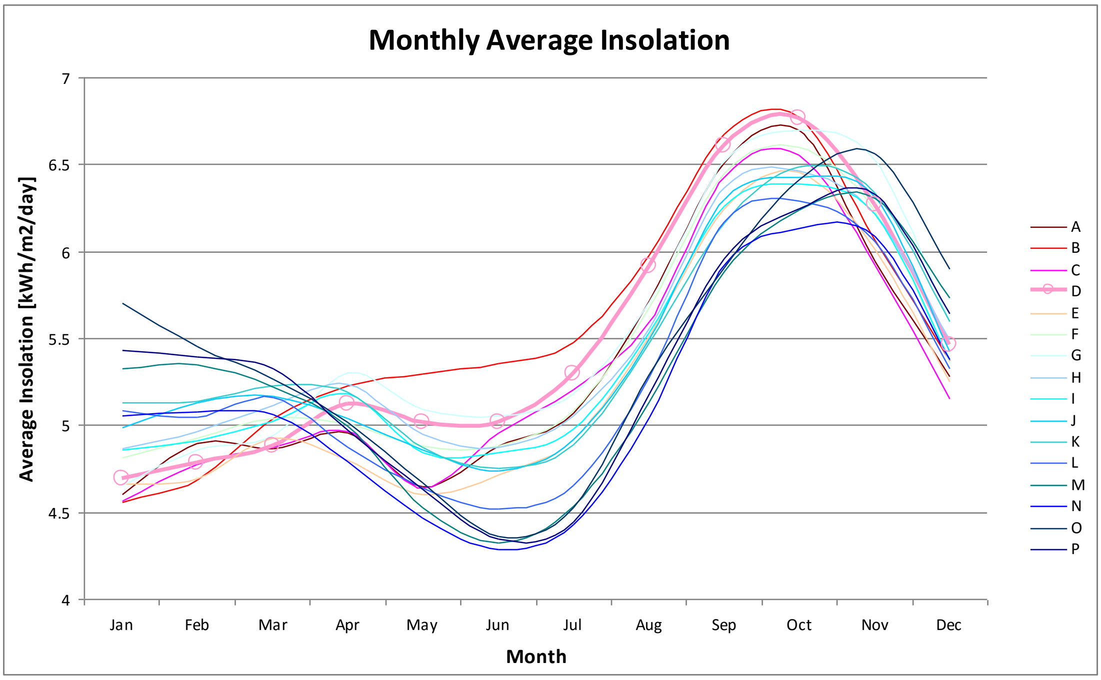


Figure 43: Seasonal variation of the solar resource across Malawi. Data source: Meteonorm (2016).



6.2.7 Transportation

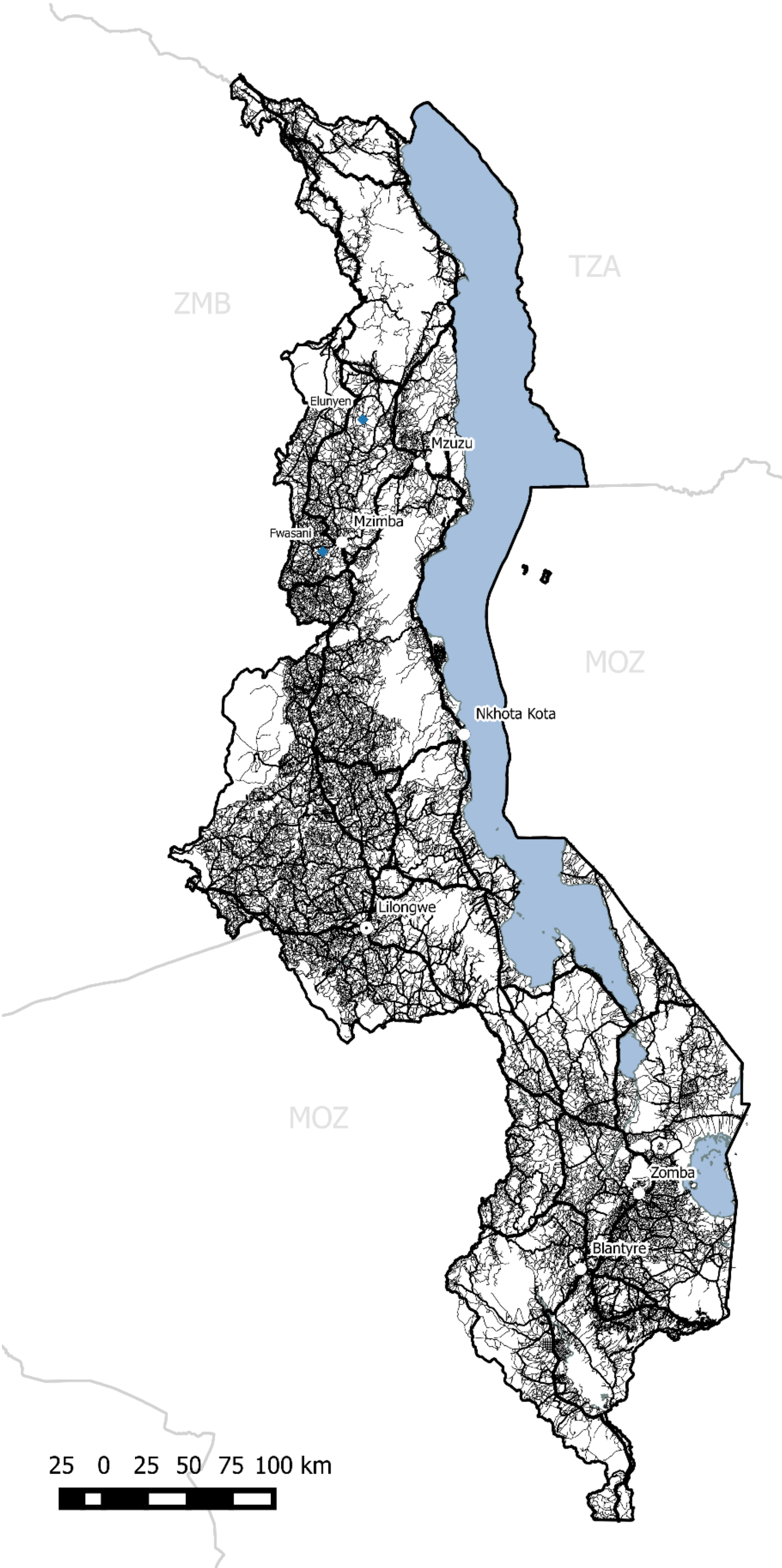
The road network is an important layer for the assessment of travel times across the country. The road network data for the map was obtained from the Malawi Bureau of Land (2016) in Lilongwe. The data contained information on the type of road. Based on other similar studies in Africa, the road types were reclassified and an average speed for each of the new road types was suggested as seen in the table below.

TABLE 6: ROAD CLASSIFICATIONS.

Road type in the Bureau of Land dataset	Reclassified road type	Suggested average speed
District Road	Secondary Road	20 km/h
Main Road	Main Road	60 km/h
Other Roads	Other Road	10 km/h
Secondary Road	Secondary Road	20 km/h
Tertiary Road	Secondary Road	20 km/h

FIGURE 44: ROAD MAP OF MALAWI. DATA SOURCE: (MALAWI BUREAU OF LAND 2016).

ROAD NETWORK IN MALAWI



LEGEND
- Malawi border
- Neighbouring countries
- Water bodies
- Installed dataloggers

Settlements
- Capital
- cities

Roads (estimated speed [km/h])
- Major roads (60)
- Secondary roads (20)
- Other roads (10)

DATA SOURCES

ROADS	*Malawi Bureau of Land*
SETTLEMENTS	*OSM*
BORDERS	*USGS*

PROJECT

Title: Market assessment for locally manufactured PV-wind hybrid systems in Malawi
Funding: Scottish Government
Implementing partner: Wind Empowerment, Strathclyde University and Community Energy Malawi

AUTHOR

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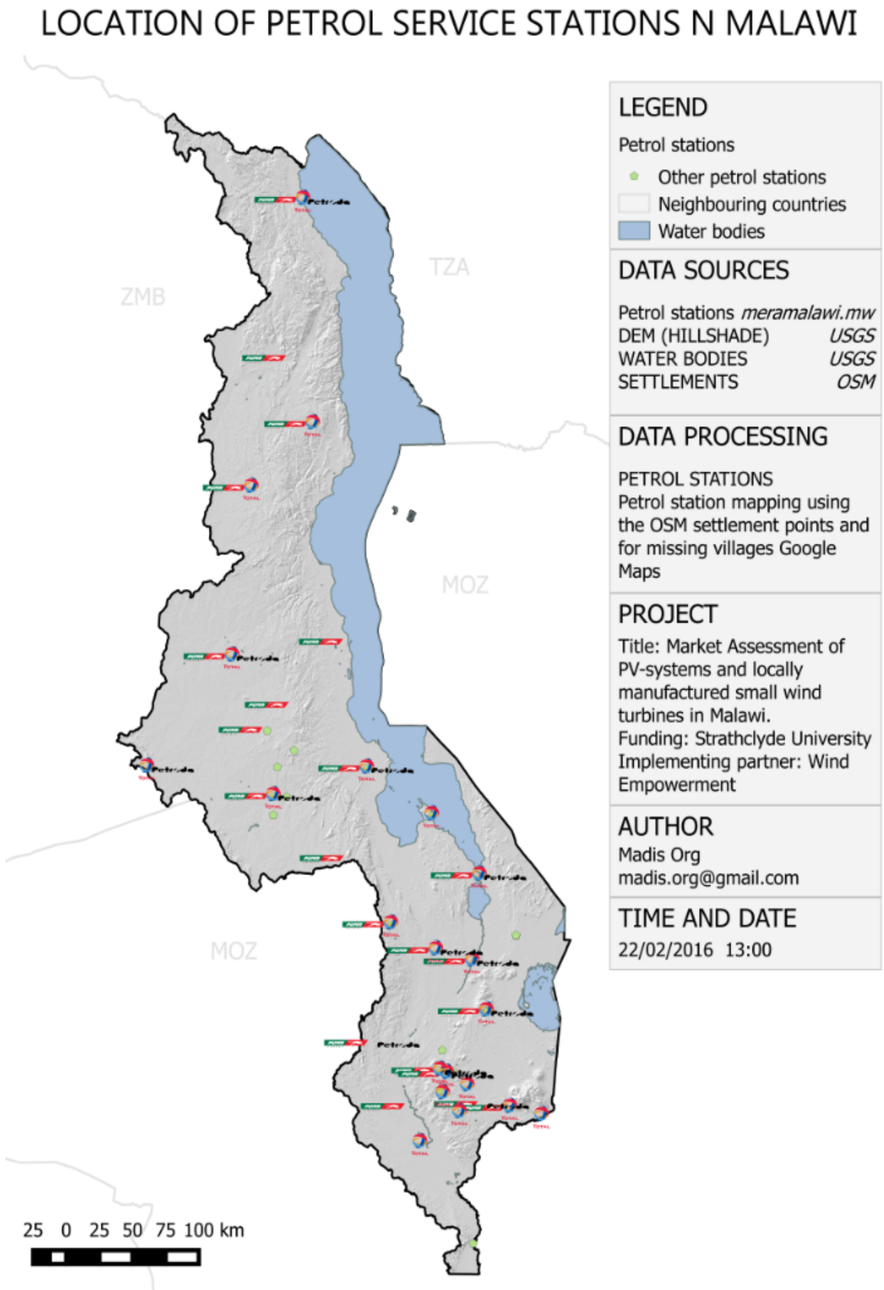
madis.org@gmail.com

DATE

7/04/2016

For the assessment of diesel haulage costs a base layer of petrol service stations within Malawi had to be created. The Malawi Energy Regulatory Authority (2015) has recently published the list of all petrol service stations within the country. This document was used in combination with settlements layer from Open Street Maps (2016) information to map out the petrol station locations. The main suppliers in Malawi are TOTAL, PUMA Energy and Petroda.

FIGURE 45: PETROL STATION LOCATIONS IN MALAWI. DATA SOURCES: MALAWI ENERGY REGULATORY AUTHORITY (2015) AND OPEN STREET MAPS (2016).



6.2.8 Economics

6.2.8.1 Diesel cost

The diesel price within Malawi is fixed by the Malawi Energy Regulatory Authority at a maximum price in March 2016 of 722.80 MKW ($1.03) per litre (Malawi Energy Regulatory Authority 2016). However, with only limited fuel outlets and difficulty of transportation, there are still variations of the actual diesel price in different locations due to the cost of haulage.

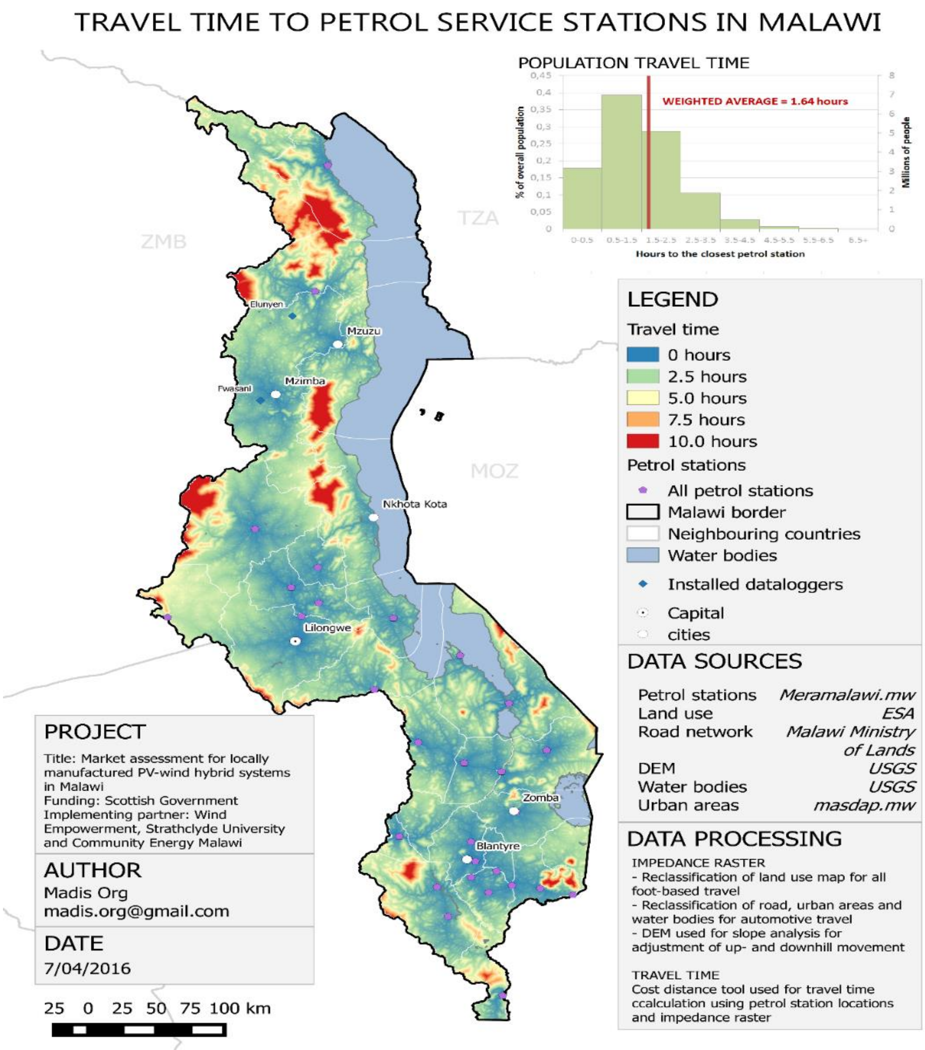
To deduce the map of diesel prices accounting for hauling, a map of travel time for Malawi needed to be constructed. To construct such a map an ArcGIS Desktop function CostDistance was used. Firstly, a raster map of travel times to cross each cell had to be created. As a base layer, the land use map was re-sampled based on the speeds for each individual land use. Then, the layer of roads was rasterized (into pixel size 100m) and each road cell was assigned the corresponding value based on the average speeds. Based on the methodology from Nelson (2008) an adjustment of travel time for slopes (slope layer deduced from DEM) was calculated as follows:

$$v = v_0 e^{-ks}$$

v = off road foot based velocity over the sloping terrain
v0 = the base speed of travel over flat terrain, 5km/hr in this case
s = slope in gradient (metres per metre) and,
k = a factor which defines the effect of slope on travel speed (3.0)

Finally, CostDistance function was used to calculate the lowest travel time from any point on a raster map to a given predefined set of points (in our case the locations of petrol stations). The function enables movement in 8 directions from each cell. Statistical analysis along with population data shows that on average people are about 100 minutes away from a petrol station in Malawi.

FIGURE 46: TRAVEL TIME TO PETROL STATIONS IN MALAWI. DATA SOURCES: MALAWI ENERGY REGULATORY AUTHORITY (2015) AND OPEN STREET MAPS (2016).



Given the travel time map, base price for diesel fuel cost and few extra assumptions, it was now possible to deduce a map of diesel fuel cost accounting for hauling. Haulage assumptions from Szabó et al. (2011) were adopted along with the following formula to arrive at transportation cost of diesel fuel:

$$P_t = 2P_d ct / V$$

P_d = the national market price for diesel (assumed to be 1.12 USD/l taken from Lilongwe pump price 25/1/2016)

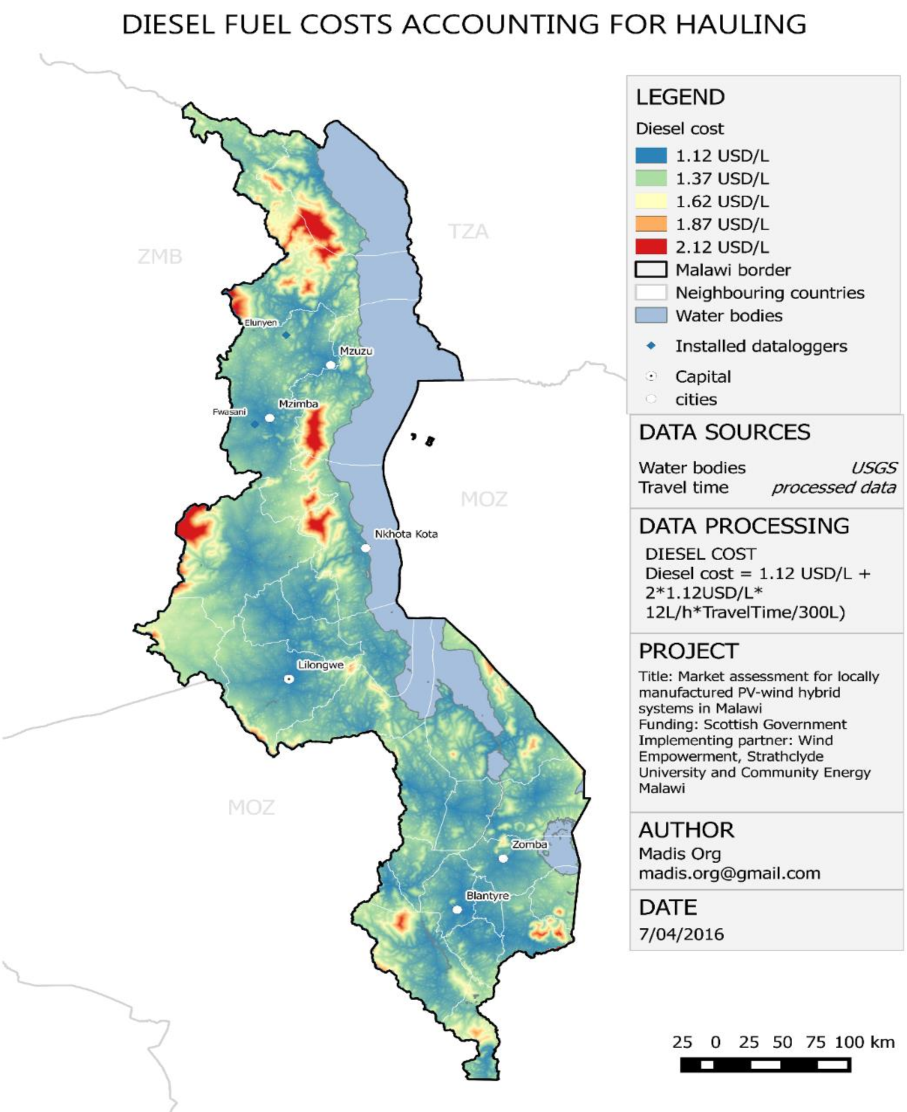
c = is the diesel consumption per hour (assumed to be 12 l/h based on Szabó et al. (2011))

t = the transport time

V = the volume of diesel transported (assumed to be 300 l based on Szabó et al. (2011))

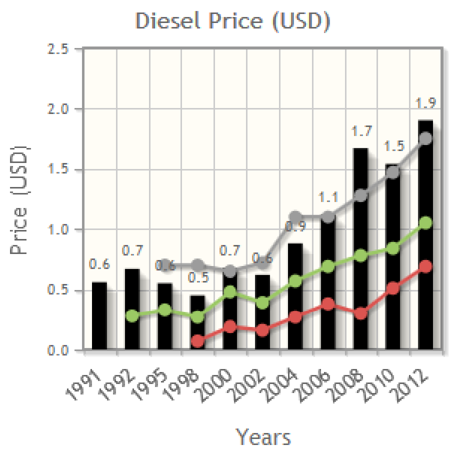
From the map it can be seen that final fuel cost accounting for hauling can have as big as two times difference (1.1 USD/l to about 2.1 USD/l) when comparing very remote areas with urban centres.

FIGURE 47: DIESEL PRICE IN MALAWI ACCOUNTING FOR HAULING. DATA SOURCES: MALAWI ENERGY REGULATORY AUTHORITY (2015) AND OPEN STREET MAPS (2016).



As with global prices, Figure 48 shows that the cost of diesel fuel in Malawi has been consistently rising over the past 30 years. It is expected that this trend will continue, so a doubling of the diesel price was included as a sensitivity in the HOMER modelling.

FIGURE 48: THE RISING DIESEL PRICE IN MALAWI (ENERGYPEDIA 2014).



6.2.8.2 Component costs

The investment cost of equipment required to define the energy system used by the HOMER-software has as far as possible been collected directly from suppliers in the main urban areas of Lilongwe and Blantyre. Some of the data has been gathered during a field visit in January 2016, whereas others have been extracted from implementation reports of SWTs conducted by Students for Malawi (Maclean & Friese 2015). Quite a few components required for the construction of a Locally Made SWT cannot be found in Malawi and in those cases UK prices have been used. Table 7 summarises the component costs detailed in the subsequent section.

TABLE 7: SUMMARY OF COMPONENT COSTS INCLUDED IN HOMER MODELLING.

Item	Cost	Replacement Cost	O&M Cost
480Wp PV array	$700	$700	$10/year
1kW SWT	$3000	$3000	£250/year
2.5kW Diesel Generator	$890	$890	$0.075/hr
2.5kW Converter	$900	$900	$70/year
4 x 260Ah Batteries	$1700	$1700	$100/year

Item	Value
Inflation	10%
Project Lifetime	15 years

There is an intrinsic uncertainty when it comes to cost estimates due to a local inflation rate of about 25% as well as a range of qualities to choose from. The research methodology and timeframe has made it impossible to get full real quotations for the large range of system designs that HOMER optimize on, and instead a specific component cost is used by HOMER as reference points for a linear extrapolation to smaller or larger components of the same type.

For example, the prices for generator sets showed an average cost of $890/kW, which is the number that HOMER scales linearly with the size of the generators to be evaluated. In a similar way, operation and maintenance costs are set as rough figures based on experiences from similar project or with reference to similar activities in Malawi. The cost estimates have been verified by a comparison to costs calculated in a similar study in Ethiopia (Eales 2015).

To test the impact of the costs on the final optimal system design, the HOMER model has been allowed sensitivity parameters that scale the various cost inputs. The practise helps to evaluate the stability of the simulated result, but can also serve to better understand where it makes sense to put efforts to cut expenses, or for example what impact a future higher diesel price would have.

During the field visit in January 2016, efforts were made to work out what it would cost to run a business with a workshop to build, install and maintain these kinds of energy systems. However, since the full business- and related delivery models are not within the scope of this study, it was decided to only look at the component costs alone.

6.2.8.3 Fixed system costs

These are costs associated with the installation of any stand-alone power supply system. This would be required for all types of system.

TABLE 8: FIXED SYSTEM COSTS, ESTIMATED FROM EALES (2015).

Item	Cost $	Quantity	Data	Date	Cost
Powerhouse	1000	1	Estimate	25/01/2016	1000
				Total:	1000

6.2.8.4 Wind Turbine costs

At present, with virtually no historical data on the cost reduction of locally built small wind turbines, we are only investigating systems with real costs obtainable on the market today. Wind turbine lifetime is set at 15 years, which is possible with a good operation and maintenance routine.

TABLE 9: COMPONENT COSTS FOR A UNIT ON A 12M TOWER.

Item	Cost $	Quantity	Data	Date	Cost
Generator	817.03	1	Local suppliers	25/01/2016	817.03
Electrical system	408.71	1	Local suppliers	25/01/2016	408.71
Tower cost (12m)	1504.3	1	Local suppliers	25/01/2016	1504.28
				Total:	2730.02

TABLE 10: COMPONENT COSTS FOR A UNIT ON AN 18M TOWER.

Item	Cost $	Quantity	Data	Date	Cost
Generator	817.03	1	Local suppliers	25/01/2016	817.03
Electrical system	408.71	1	Local suppliers	25/01/2016	408.71
Tower cost (18m)	1850	1	Local suppliers	25/01/2016	1850
				Total:	3075.74

TABLE 11: OPERATION AND MAINTENANCE COST ESTIMATES.

O&M Work Item	Hardware			
	Lifetime [years]	Frequency per year	Unit Cost [$]	Annual Cost [$]
Diversion controller	4	0.25	100	25
Bearing	10	0.1	47	4.7
Generator	20	0.05	648	32.4
Break switch	2	0.5	10	5
Tower guy cables	10	0.1	200	20
Fuses	5	0.2	40	8
Consumables	1	1	30	30
Travel cost	0	2	116	232
			Total:	***357.1***

6.2.8.5 Photovoltaic system

Local suppliers' quotations from Sonlite Solar and Powered by Nature, visited 25-28th Jan 2016 were used to inform the local prices of PV modules. An average 'cost per Wp' has been calculated and the cost for a 480Wp array has been extrapolated. PV array lifetime estimated at 20 years.

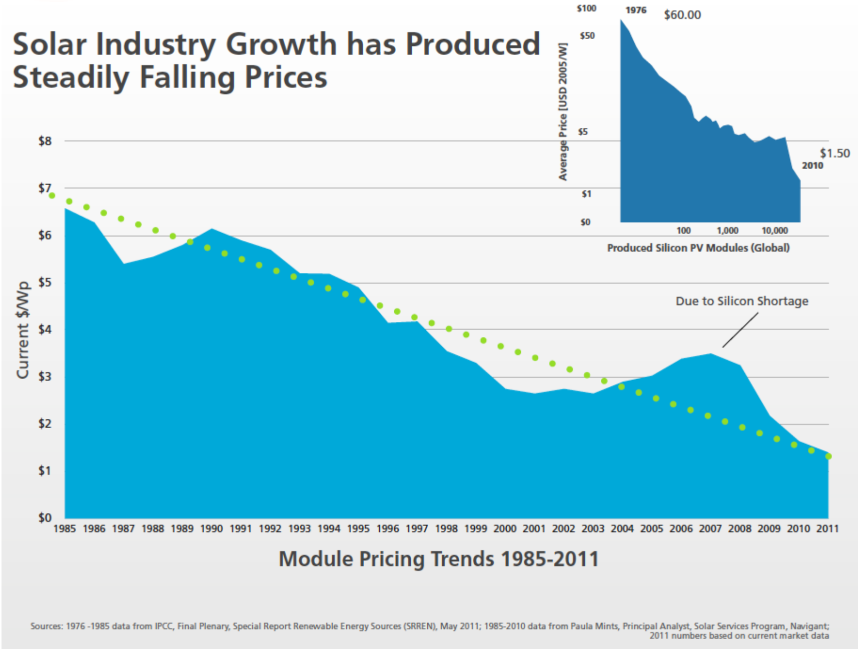
Array frame is an estimate, at 35% of the module cost (Jons Nicaragua Study).

TABLE 12: PV ARRAY COMPONENT COSTS.

Item	Cost $	Quantity	Data	Date	Cost
480Wp system	700	1	Local Supplier	25/01/2016	700
Array frame	245	1	Estimate		245
Electrical system (50A)	361	1	Local Supplier		361
				Total:	1306

The cost of solar PV modules has steadily fallen over the past 30 years by approximately 5% each year. However, it should be noted that Malawi does always not see the full cost reduction of PV that happens on the international market, because of the high inflation rate. With this trend the cost of solar PV looks set to fall to 63% of its price today by 2020 and to 37% by 2030. In the HOMER modelling, we have chosen a figure of a 50% cost reduction to investigate how this trend will affect the optimal system architecture.

FIGURE 49: FALLING GLOBAL PRICE OF PV (SHAHAN 2014).



6.2.8.6 Diesel generator

Diesel generator prices were from a local suppliers visited 25-28th Jan 2016. This data is linearly extrapolated for other sized diesel generators. Diesel generator lifetime is estimated at 15000 hours.

TABLE 13: DIESEL GENERATOR COMPONENT COSTS.

Item	Cost $	Quantity	Data	Date	Cost
Generator 2.5kW	890	1	Local supplier	25/01/2016	890
Electrical System	8.7	1	Estimate		8.7
				Total:	898.7

TABLE 14: DIESEL GENERATOR OPERATION AND MAINTENANCE COSTS:

O&M Work Item	Hardware			
	Lifetime [years]	Frequency per year	Unit Cost [$]	Annual Cost [$]
Bearings/Worn parts	1	1	100	100
Consumables	1	1	30	30
Overhaul	10	0,1	2500	250
Travel cost	0	2	116	232
			Total:	***612***

6.2.8.7 Batteries

Battery prices have been extrapolated from local supplier quotations visited 25-28th Jan 2016. Battery lifetime was estimated at 5 years.

TABLE 15: BATTERY BANK COSTS.

Item	Cost $	Quantity	Data	Date	Cost
Battery 260Ah	1700	1	Local Supplier	25/01/2016	1700
Electrical system	38.47	1	Local Supplier	25/01/2016	38.47
				Total:	1738.47

6.2.8.8 Converter

Power electronic converter prices have been extrapolated from local supplier quotations visited 25-28th Jan 2016. Inverter lifetime is estimated at 10 years.

TABLE 16: INVERTER COSTS.

Item	Cost $	Quantity	Data	Date	Cost
Inverter DC-AC 2.5kW	900	1	Local supplier	25/01/2016	900
Electrical system	8.7	1	Estimate		8.7
				Total:	908.7

6.2.8.9 Inflation and exchange rates

The US dollar to Malawian Kwacha is extremely variable due to the high and extremely variable inflation rate. Simulations were run to investigate the effect of the inflation rate on the optimal system design. A high inflation rate adversely affects long term costs, such as replacement parts and diesel price. Due to the complexity of this issue along with the fact that all prices are quoted in US dollars, we have decided upon using an inflation rate of 10% in our simulation models, in line with other similar international studies on renewable energy cost modelling (ESMAP 2007). Due to the rapidly changing context in Malawi, we are looking at system lifetime of 15 years.

FIGURE 50: MALAWI INFLATION RATE TRENDS (TRADING ECONOMICS 2016).

TABLE 17: INFLATION AND EXCHANGE RATES.

Parameter	Figure		Data	Date retrived
Malawi Inflation Rate	23.5	%	http://www.tradingeconomics.com/malawi/inflation-cpi	11/03/2016
International Standard Inflatio	10	%		
US Dollar [MWK/$]	685		http://coinmill.com/MWK_USD.html	13/01/2016
UK Pound [MWK/£]	996.47		http://www.xe.com/currency/mwk-malawian-kwacha	11/03/2016

6.2.9 Load profiles

In order to simulate the various systems designs within HOMER we need to use representative load sizes, both in terms of maximum power demand and maximum energy requirements, and the variation of the load through the day, week and season.

In this analysis we are looking at productive uses of energy which will bring economic returns, such as energy for a business or a workshop and also micro-grids for multiple users. These load profiles arose from a mixture of real-world interview data, literature reviews and data from similar systems. This was analysed to create four typical load profiles.

6.2.9.1 Growth of system over time

Malawi has a high population growth rate of around 3% (The World Bank 2016). This will affect the design of rural community energy supplies with a lifetime of 10 years. If a community has 100 households, then at 3% annual growth rate, the community will be 134 households in 10 years. There are other factors which will affect this, such as increased movement of people from rural to urban areas. A design margin of 10% to 25% additional capacity design margin should be used to account for load growth (as per IEEE 1013 1562). We have chosen a 20% design margin.

6.2.9.2 Survey results

A standard questionnaire was performed within a number of different remote communities within Malawi by CEM. There were two versions of the questionnaire: one for households and one for businesses/entrepreneurs. The results of the household questionnaires can be found in Appendix F.

FIGURE 51: PRODUCTIVE USE "CHOOSE TOP 3" QUESTION FOR HOUSEHOLDS. SURVEY RESULTS FROM 115 HOUSEHOLDS.

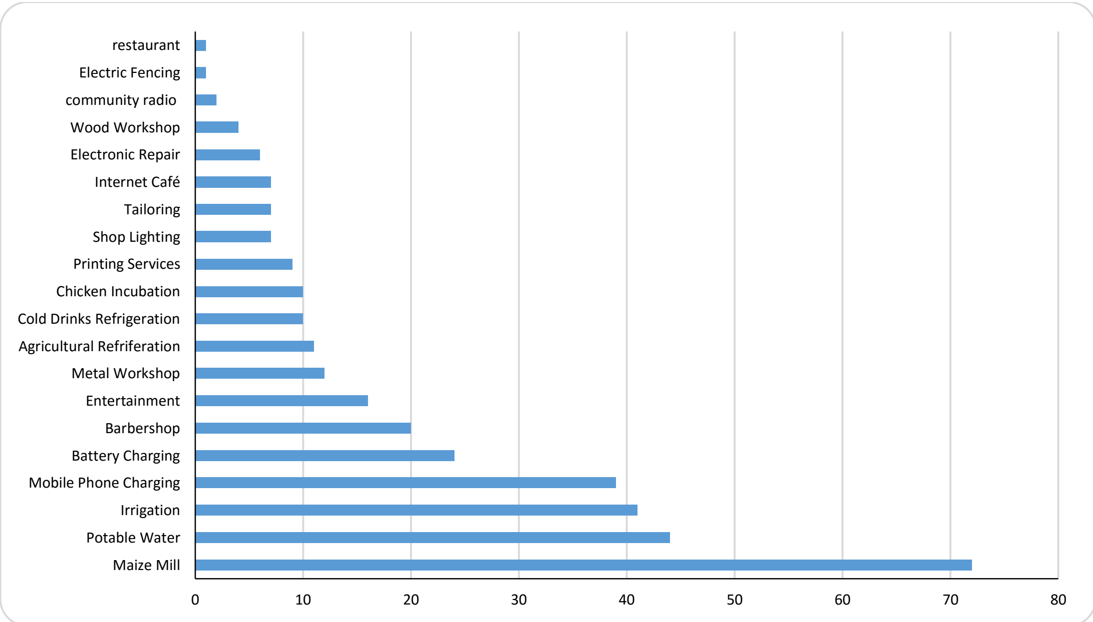
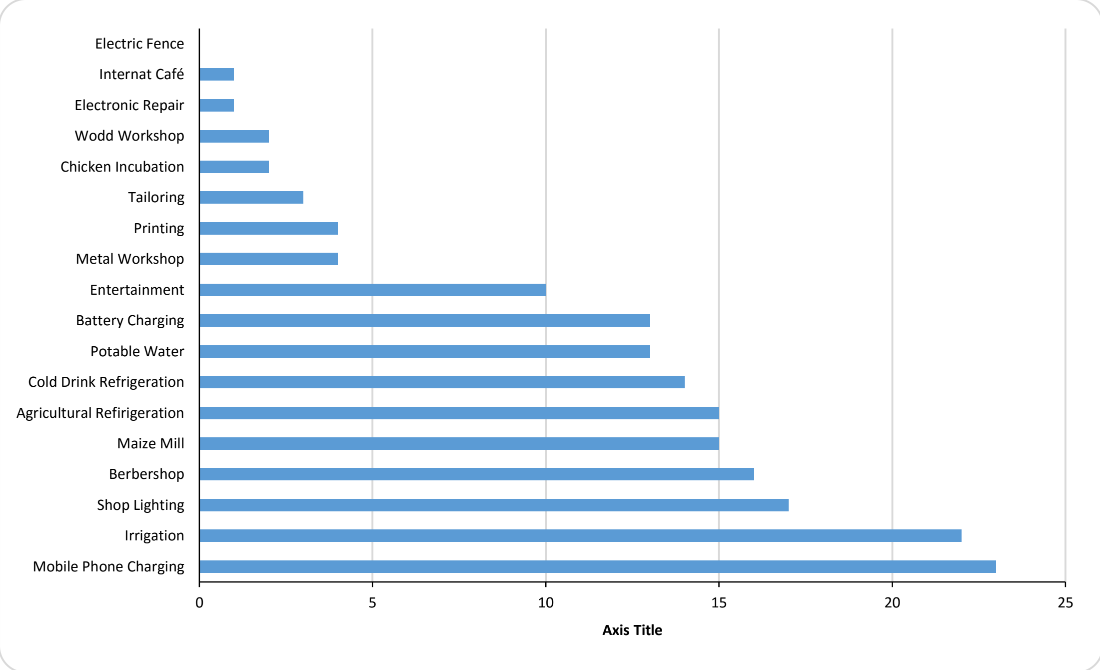


FIGURE 52: PRODUCTIVE USE "CHOOSE TOP 3" QUESTION FOR BUSINESSES. SURVEY RESULTS FROM 62 BUSINESSES.



6.2.9.3 Load Profiles

From these survey results we narrowed down the types of loads into four main loads to analyse. The load types analysed are:

- Maize Milling - Very popular with households.
- Egg Incubation - From initial data this was a popular load, although it is less popular as a business proposition. This type of load is very similar to a mobile phone charging system - basically a small consistent 24 hour load.
- Small workshop - Small workshops were seen all over Malawi during the site visits. These could be for many productive uses. The load profile is also similar to that of a barber shop or beauty parlour - loads used during the day with a mixture of load sizes.
- Mini-Grid - A mini-grid would provide refrigeration, lighting, mobile phone charging and entertainment to a small community.
- Irrigation/Water pumping - This type of load is very popular for farm irrigation and pumping potable water.

6.2.9.3.1 Load 1: Maize milling

Maize is a staple crop grown and eaten in Malawi and the main ingredient of Nsima. 96% of maize consumed in Malawi is grown in Malawi (Jaicaf 2008). Maize consumption in Malawi averages 130kg/person/year (Derlangen 2012). Maize is stored whole in woven basket silos. This allows the maize to be stored for longer periods of time than milled maize. Maize grains are hulled then milled into flour. Maize milling is a year-round activity, with maize planted in rainy season, Nov-April and harvested in July-September.

Different mill types have different power ratings (Appropedia 2014):

- Plate 0.4-4kW
- Hammer 2-150kW
- Stone: 0.4 – 15kW

A real community example of maize milling has come from data from Tanzania, which is a neighbouring country with a similar climate (Blennow & Bergman 2004). They found that the average mill size was 15kW, with a real power use of 7kW under no load and 12.5kW under milling load. They found that the milling process for each customer took 2-5mins with 50% of the time the mill was running without processing.

TABLE 18: MILLING DATA FROM TANZANIA (BLENNOW & BERGMAN 2004).

Season	No. Customers/Day	Hours open	Dates
Low	15	3	Nov-Feb
Medium	30	6	Oct-March
High	50	10	July-Sept

A number of milling machines are available within Malawi, in the range from 4kW up to 150kW (ABC Hansen Africa 2015). A mill of 7.5kW electrical power was chosen and this size mill is able to process about 180 Kgs/hour of raw maize into fine flour. An average community within the northern region of Malawi is 70 households per village with an average rural population of 5.1 members in each household (Digby 2000). So an average community is around 357 people and with a 30% design factor this will increase to around 464 within the 10 year lifetime.

So, at 130kg/person/year this is 60333kg maize to be milled each year, or 165kg per day per community. With the 7.5kW milling machine this would take around 1 hour of milling time, although the Tanzania data shows that 50% of the time the mill is running but idle, so we need to factor this in: 1 hour at 7.5kW and 1 hour at 3.75kW, which is 11.25kWh per day on average.

From the Tanzania data on average there are 31 customers per day, each for around 5mins, at 50% duty cycle of the mill. This is a run time of 2.5 hours, with around 1.25 hours at 50% (idle) and 1.25 hours at 100% (milling). This backs up the other example and gives an energy requirement is around 14kWh/day.

TABLE 19: INFORMATION FROM THE RURAL VILLAGE OF HARESSAW, ATSBI, ETHIOPIA (NIELSEN & FIEDLER 2012).

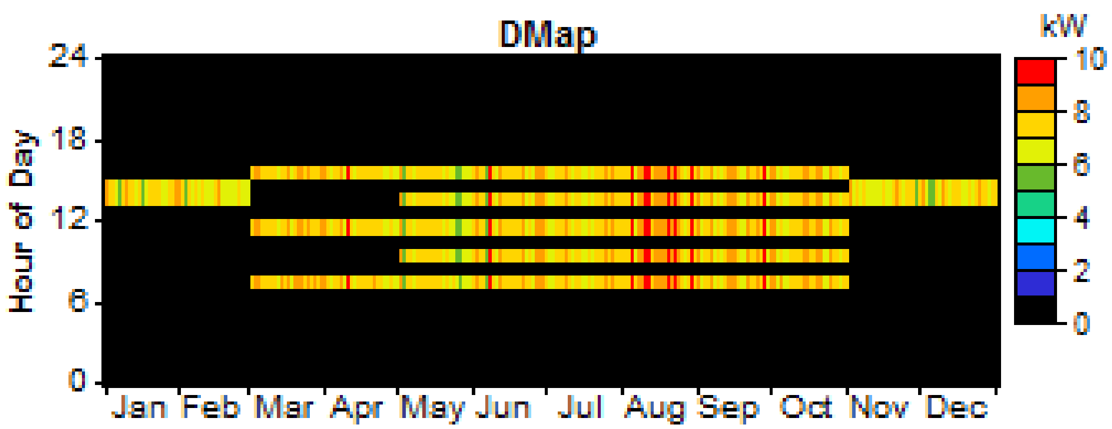
Equipment	Quantity	Capacity (KW)	Run-time (hours/day)	KWh/day
Flour milling	1	12.5	5	44.6428

TABLE 20: MILLING INFORMATION WAS FOUND FOR LIKOMA ISLAND IN MALAWI (ZALENGERA 2015).

Energy need	Number	Assumed unit power (W)	Operating times
Milling machines	9.[38]	7500	07:00 – 10:00.[39]; 13:00 – 17:00
Indoor lighting	7	15	n/a
Outdoor Lighting	14	15	18:00 – 06:00

This shows that 7.5kW milling machines are in use in typical community systems, operating for around 7 hours per day. The maize mill energy requirement varies from 15kWh/day to 38kWh/day.

FIGURE 53: LOAD 1: MAIZE MILLING FINAL LOAD PROFILE.



6.2.9.3.2 Load 2: Egg incubation

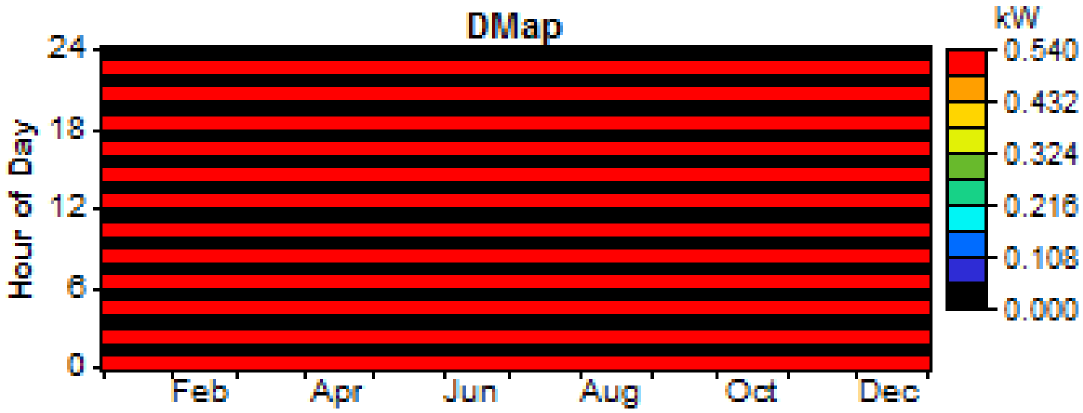
Chicken egg incubation was seen from the community interviews as a productive load.

Typical small egg incubators have a heater power consumption of around 200-750W for around 200-1000 eggs. Correct incubation temperature is from 29.5C to 36.5C (Jusof Khadidi & Hamid 2013).

A unit available from a South Africa distributer was chosen as the typical unit. This can hold 360 chicken eggs for setting or 200 eggs for hatching and has a heater power consumption of 500W (Surehatch 2016).

The heater on time is assumed to be 50%. This load is 6.16kWh/day.

FIGURE 54: LOAD 2: EGG INCUBATION FINAL LOAD PROFILE.



6.2.9.3.3 Load 3: Small metal/wood workshop

A productive use raised in the community interviews was for power for a wood or metalworking shop. Again, useful data has come from Tanzania, where two community carpentry shops were visited (Blennow & Bergman 2004). Typical opening hours were from 8am until 6pm, with a peak season between August and September.

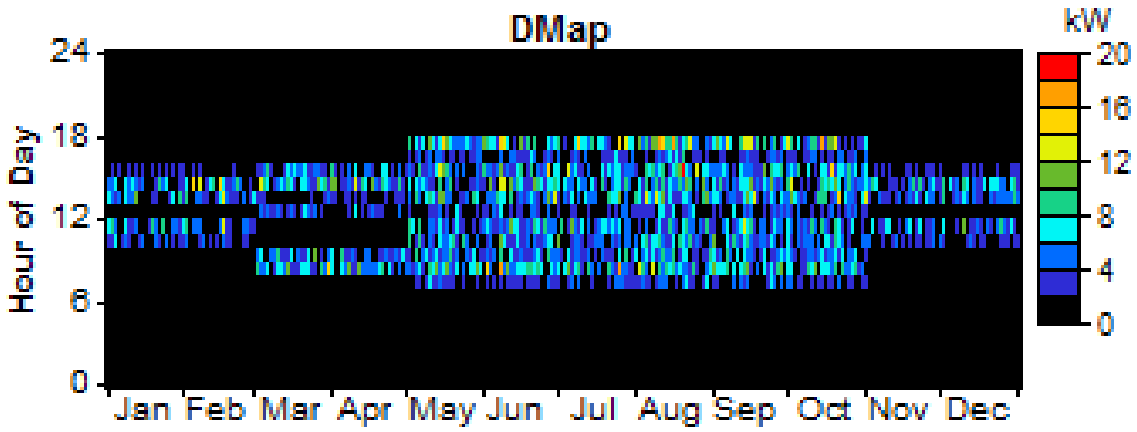
TABLE 21: WORKSHOP WORKING HOURS AND TYPICAL LOADS AND SIZES FROM TANZANIA (BLENNOW & BERGMAN 2004).

Season	Hours working	Dates
Low	3	Nov-Feb
Medium	5	Mar-Apr
High	10	May-Nov

Item	Load Type	Equipment Rating (W)	Peak-power multiplier	AC or DC	Hourly Noise [%]	Day-Day Noise [%]
#1	Drill press	2200	2	AC	80	40
#2	Table saw	2200	2	AC	80	40
#3	Thickness planer	2500	2	AC	80	40
#4	Band saw	1500	2	AC	80	40
#5	Grinder	1350	2	AC	80	40
#6	Lighting	20	1	AC	10	10

This load will vary from 16kWh/day in low season to 44kWh/day in high season - similar range to maize milling, but with lower peaks due to different equipment used.

FIGURE 55: LOAD 3: SMALL WORKSHOP FINAL LOAD PROFILE.

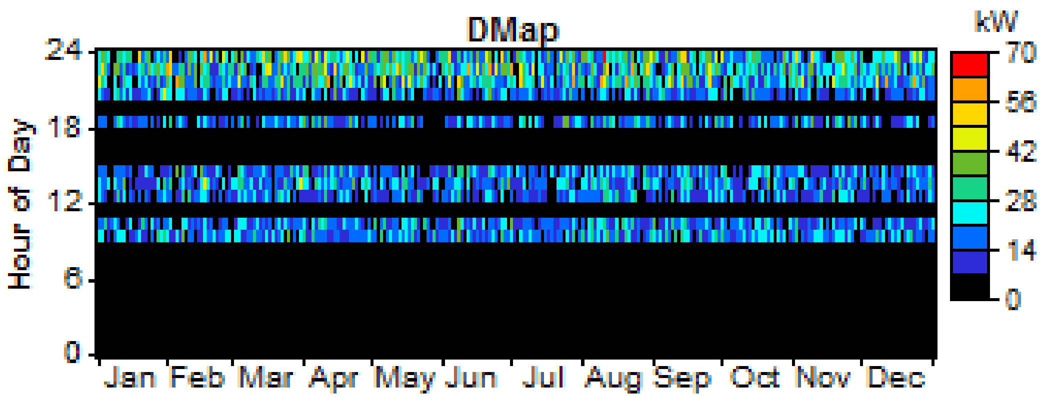


6.2.9.3.4 Load 4: Mini-grid

Mini-grids are distributed level energy systems which include all the necessary components to operate in isolation of the grid, including generation, storage and loads. Typically they are used to provide power to a community which includes a diverse range of loads, including domestic, school, medical and productive uses. Typical sizes are from 10kW up to a few MW (Thomson 2016). This type of load would include phone charging, lighting and refrigeration, as highlighted in the productive uses interviews. An average community within the northern region of Malawi contains around 70 households per village with an average rural population of 5.1 members in each household (Digby 2000). So an average community is around 357 people and with a 30% design factor this will increase to around 464 within the 10 year lifetime. A number of mini-grids within Malawi were used as the basis for this load profile, these are described in the following subsections.

The final mini-grid load will provide around 1.25kWh/day per household (for 164 households). This is a 205kWh/day load.

FIGURE 56: LOAD 4: MINI GRID FINAL LOAD PROFILE.



6.2.9.3.4.1 Wind/Solar hybrid system design

This is a provision of 0.38kWh/day for each household.

TABLE 22: DATA FROM DOCUMENTATION AT ELUNYENI INSTALLATION, FROM SITE VISIT JAN 2016.

	Number of Households:			**150**
Item	Power (W)	Quantity	Use Time (h/day)	Energy (Wh/day)
	Household loads			
Light	11	5	4	33000
Socket	40	1	3	18000
	Community Loads			
Street Light	55	3	8	1320
Fridge	250	2	12	6000
	Total Energy:			58,320Wh/day

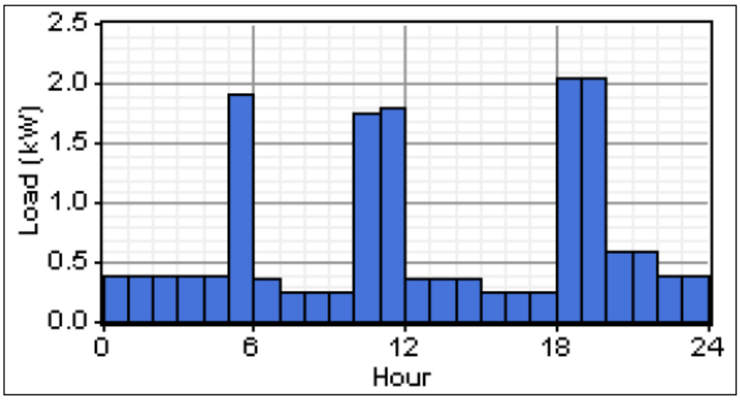
6.2.9.3.4.2 Lower Bondo power grid analysis

Power measurements were taken for Lower Bondo, a hydro-powered mini-grid in the south of Malawi[15]. This system was installed by MEGA - Mulanje Electricity Generation Agency. Three days of 1 hour average power demand were recorded. The peak for the community was 28kW, average was 9.6kW and the minimum was 5kW. This is for approximately 127 households. Per house the consumption was 1.8kWh/day on average. This is a provision of 1.8kWh/day for each household.

6.2.9.3.4.3 Likoma Island, Malawi

A load profile for an island mini-grid was developed (Zalengera 2015). With 650 households on the island. Houses had: 9 x Light bulb, 15 W; refrigerator, 225 W; television, 70 W; hotplate for cooking, 1,500 W; radio, 30 W; and satellite decoder for use together with TV, 30 W. This was an average of 4.68kWh per household per day. Typical household comprised of 7 people.

FIGURE 57: MODELLED ELECTRICITY DEMAND FOR A SINGLE HOUSEHOLD ON LIKOMA ISLAND.



6.2.9.3.4.4 Ikem village, Nigeria

This is a provision of 2.5kWh/day for each household. The analysis in the report also states that the daily energy demand of each household is around 2kWh/day, for a grid-connected community.

TABLE 23: ESTIMATED POWER AND ENERGY REQUIREMENTS FROM A VILLAGE IN NIGERIA (MUNTHE 2009).

Quantity	Description	Power (kW)		Average duration (h)	Energy demand (kWh)
		Unit demand	Total demand		
2	Secondary schools	3	6	7	42
6	Primary schools	2	12	6	72
1	Local govt. secretariat	3	3	8	24
10	Street lights	0.1	1	12	12
1	District hospital	10	10	15	150
200	Households	0.5	100	5	500
1	Rice milling industry	100	100	10	1000

6.2.9.3.4.5 PV-diesel system in Mwanza, Tanzania

Average AC energy consumption was 1.47kWh/day.

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[15] Data from Lower Bondo Power Grid Analysis report – Daniel Kloser, 20/9/2014

FIGURE 58: PV-DIESEL HYBRID SYSTEM IN TANZANIA (NIELSEN & FIEDLER 2012)

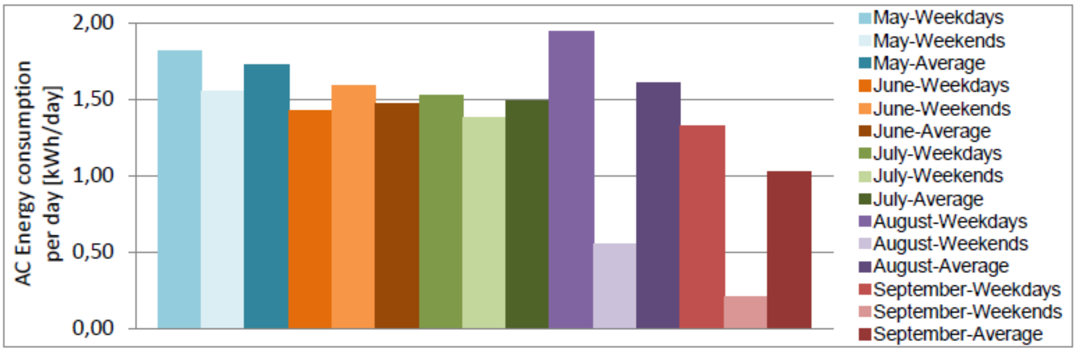


TABLE 24: INFORMATION FROM 1100 HOUSEHOLDS (5500 PEOPLE) IN THE RURAL VILLAGE OF HARESSAW, ATSBI, ETHIOPIA (BAHTA 2013).

Appliances	Quantity	Capacity (Watts)	Run-time (hours/day)	Peak load (kW)	KWh/day
Low-energy lights	3	13	6	0.039	0.234
Television	1	65	6	0.065	0.390
Radio	1	5	3	0.005	0.015
Baking machine	1	2850	1	2.85	0.40714
Total		2959		0.51614	1.04614

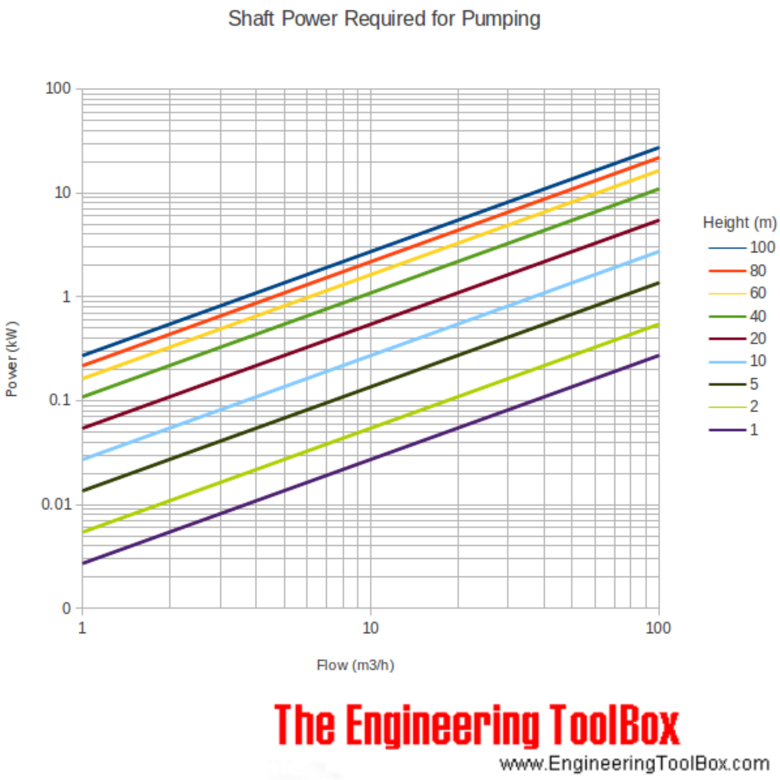
6.2.9.3.5 Irrigation/Water Pumping systems

The supply of water for drinking, washing and crop irrigation is very important to remote communities within Malawi. A dedicated renewable-energy powered water pumping system would not usually include a battery, as the pumped water acts as the energy store.

There are many solar and wind water pumping systems available. Pumping water with wind usually does not use an electrical wind turbine and their design is out of scope of this document. Water pumping systems could be a very useful addition to off-grid systems based upon renewable energy and with a battery bank. The battery bank needs to be protected from over-charging. Usually this is in the form of a charge controller which could divert the excess energy when the batteries are full but there is still renewable energy available (wind or solar).

The charge controller can be used to divert this (usually wasted) energy to an electrical water pump. The power requirement of the water pump load depends upon the total head to pump (including any friction) and the water flow rate required. There are many different types of pump to perform different tasks (such as surface (low head) and submersible (high head) pumps).

FIGURE 59: APPROXIMATE SHAFT POWER REQUIRED TO PUMP DIFFERENT AMOUNTS OF WATER FROM DIFFERENT HEAD HEIGHTS (ENGINEERING TOOLBOX 2016).



In the case of the Mini-grid load example (later in this document) around 10% of the electrical energy from the PV and wind turbine is wasted as the batteries could not accept any more charge, but the resource was available. This is equivalent to 6,284kWh per year (in this particular example of a mini-grid for around 150 people). A 60% efficient, 2.27kW electrical power pump could pump 50m^3 of water per hour from a depth of 10m (Engineering Toolbox 2016). With the excess energy from the Mini-grid system, this would give 2768 hours of pump run time pre year, which is equivalent to 138414m^3/year. This is 379m^3/day or 2.5 m^3/day/household. This would be a useful amount, especially if this is potable water.

Note: There will be inefficiencies in this system so these numbers are just for demonstration of concept.

6.3 Appendix C – Expert interview questions

Introductory questions

- What does your organisation do?
- What is your role within the organisation?

Energy access

- What are the main drivers for rural access to energy in Malawi?
- How do these compare to other development priorities?
- Which business models have been successful in the rural energy access sector in Malawi? (operation and maintenance, value chain aspects)

SWTs

- How much do you know about SWTs?
- What problems have you seen with solar PV initiatives in Malawi? Can SWTs address any of these?
- What are the key barriers/drivers for SWTs in Malawi?
- What do you think the potential for SWTs is in Malawi?
- If SWTs were to be manufactured in Malawi, where would be the best location and which organisation could do it?

Productive use of energy

- Which productive uses of energy are likely to be most successful in Malawi?
- In which months of the year do these normally occur?

Mini-grids

- How do you define a mini-grid?
- What is the potential for mini-grids in Malawi?
- What are the key drivers/barriers for mini-grids in Malawi?

Further info

- Is there anyone else we should speak to?

6.4 Appendix D - Experts' experience with small wind

The team interviewed had varied experiences in SWTs with relatively few with actual hands on experiences with the technology but mostly good appreciation of the energy sector in general and the key trends thereof. Some of the key experiences of the experts include:

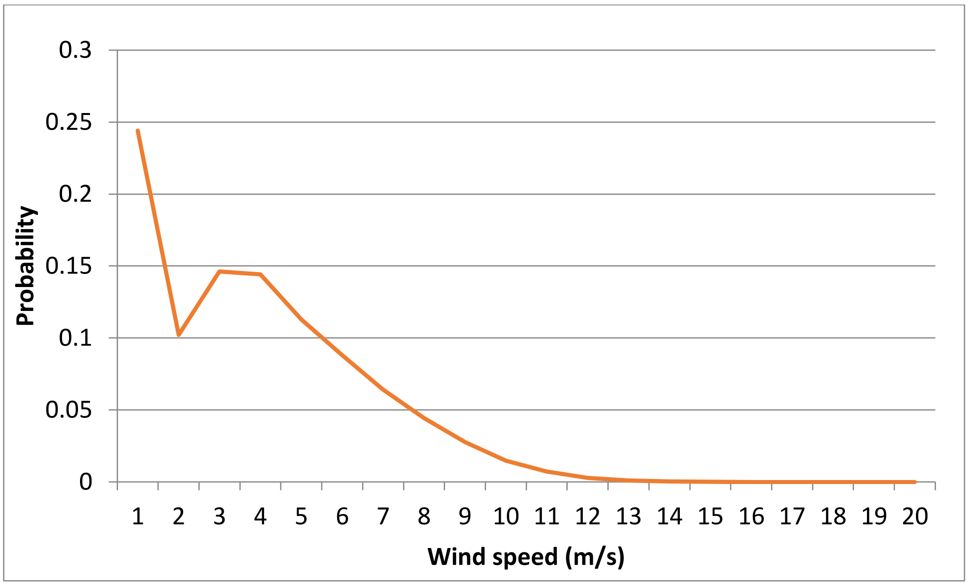
- One expert did a masters project on design and installation of a wind and solar hybrid system in the UK (Nottingham University). Other experiences include work on wind turbines, solar home systems and solar water heating systems. Installed data loggers for data collections for the master's project.
- MEET has supported, through a number of grants, the construction and installation of windmills for the purpose of pumping water for irrigation.
- In Lilongwe, the current Minister of Natural Resources and Energy, Hon Bright Msaka has used a solar wind hybrid at his residence since 2005.
- The expert from MERA was involved in the training of technicians at the Mzuzu university and certification of wind energy projects whilst working for the barrier removal to renewable energy in Malawi project in the ministry of energy for four years
- DFID expert has limited technical knowledge about SWTs because as DFID they do not implement but facilitate funding mechanisms and the improvements of the enabling environment. But personally the expert has been part of pico-solar projects in his past roles with other agencies including Concern Universal and generally appreciates energy technology mix and energy issues in Malawi.
- Tawanda Madovi (the private sector expert) has cumulative experience working in the energy sector in Malawi since 1996. Apart from working in the private sector Tawanda worked in wider development sector through a GEF funded project in Zimbabwe. He later joined private sector with a role in the manufacturing and designing of electronic systems. Tawanda has been a steering committee member for Renewable Energy and Energy Efficiency Partner (REEEP) southern Africa and global boards (1996 – 2009). Tawanda is also a historian and has written on tribes of Malawi. He is a founding member of the Renewable Energy Industry Association of Malawi (REIAMA) and has participated in almost all major energy policy processes in Malawi. Mr Madovi participated in setting up the Renewable Energy centre at Mzuzu University. Experiences mostly around solar energy and other electronic systems less on wind.
- Practical Action expert has experience with MEGA social enterprise, now operational. Complex system of financial and engineering systems. Donor support still required. Strategy and structures in place for potential sustainability. Associated with Students for Malawi – couple of students were VIP (Vertically Integrated Project) students. Tried to make them focus on sustainability of the systems

6.5 Appendix E – Preliminary datalogging results

TABLE 25: PRELIMINARY DATALOGGING RESULTS FROM KAMILAZA (FWASANI CBO) AND ELUNYENI.

	Kamilaza (Fwasani CBO)		Elunyeni	
	Simulated	Measured	Simulated	Measured
Jan	3.12	1.617	3.53	1.439
Feb	2.87	1.39	3.00	1.446
Mar	3.67	2.431	3.50	1.791
Apr	4.74		5.03	
Maj	4.63		4.73	
Jun	5.13		5.22	
Jul	5.52		5.74	
Aug	5.83		6.01	
Sep	5.87		6.18	
Oct.	6.14		6.50	
Nov	6.07		6.67	
Dec	4.32		4.67	

FIGURE 60: KAMILAZA (FWASANI CBO) WIND SPEED PROBABILITY DISTRIBUTION (<3 MONTHS OF DATA).



Kamilaza (Fwasani CBO) Average Wind Speeds Measured @9.7m hub height

26/01/2016 – 31/01/2016: 1.373 m/s

01/02/2016 – 29/02/2016: 1.477 m/s

01/03/2016 – 17/03/2016: 2.064 m/s

Kamilaza (Fwasani CBO) Average Wind Speeds Adjusted to 18m hub height. Surface Roughness 0.3m

26/01/2016 – 31/01/2016: 1.617 m/s

01/02/2016 – 29/02/2016: 1.739 m/s

01/03/2016 – 17/03/2016: 2.431 m/s

FIGURE 61: ELUNYENI WIND SPEED PROBABILITY DISTRIBUTION (<3 MONTHS OF DATA).

Elunyeni Average Wind Speeds Measured @9.7m hub height

26/01/2016 – 31/01/2016: 1.222 m/s

01/02/2016 – 29/02/2016: 1.228 m/s

01/03/2016 – 02/03/2016 & 12/03/2016-17/03/2016 (Missing data due to battery issue): 1.521 m/s

Elunyeni Average Wind Speeds Adjusted to 18m hub height. Surface Roughness 0.3m

26/01/2016 – 31/01/2016: 1.439 m/s

01/02/2016 – 29/02/2016: 1.446 m/s

01/03/2016 – 02/03/2016 & 12/03/2016-17/03/2016 (Missing data due to battery issue): 1.791 m/s

6.6 Appendix F – Survey Results

6.6.1 Overview

Surveys were conducted with households and businesses to determine current energy use, income levels and ability to pay for energy services. The purpose of the research is to determine the energy demand in the CBOs that CEM are active with, and whether the systems investigated in this study are feasible in terms of the social-economic factors present on the ground.

6.6.1.1 Data Collection Platform: Kobo Collect

KoBoToolbox is a suite of tools for field data collection for use in challenging environments, and was used as the data collection source for this study. The software, developed by the Harvard Humanitarian Initiative, is an open source suite of tools for data collection and analysis. Smart Phones were used to conduct surveys with the information being stored digitally, and then uploaded to a server which can then be accessed anywhere in the world through a web portal.

4 surveys were designed and conducted in the 12 CBOs visited by CEM staff during January and February 2016. A summary of the surveys is outlined below and the results of the surveys are presented following the table.

Name of Survey	Target Participant	Purpose	No. of Surveys
Household	Householders	Household social-economic and energy use	94
Business	Owners or Employees of rural businesses	Business social-economic and energy used day	62
Productive Use of Energy	Householders and businesses	Willingness to pay for productive uses of energy	115
Willingness to Pay	Householders	Willingness to pay for solar system	60

6.6.2 Household Survey

94 household surveys were conducted asking questions relating to energy use. The first questions relate to their income and what type of job. The above graph shows the maximum, minimum and average annual income.

Figure 61: Monthly Household Income

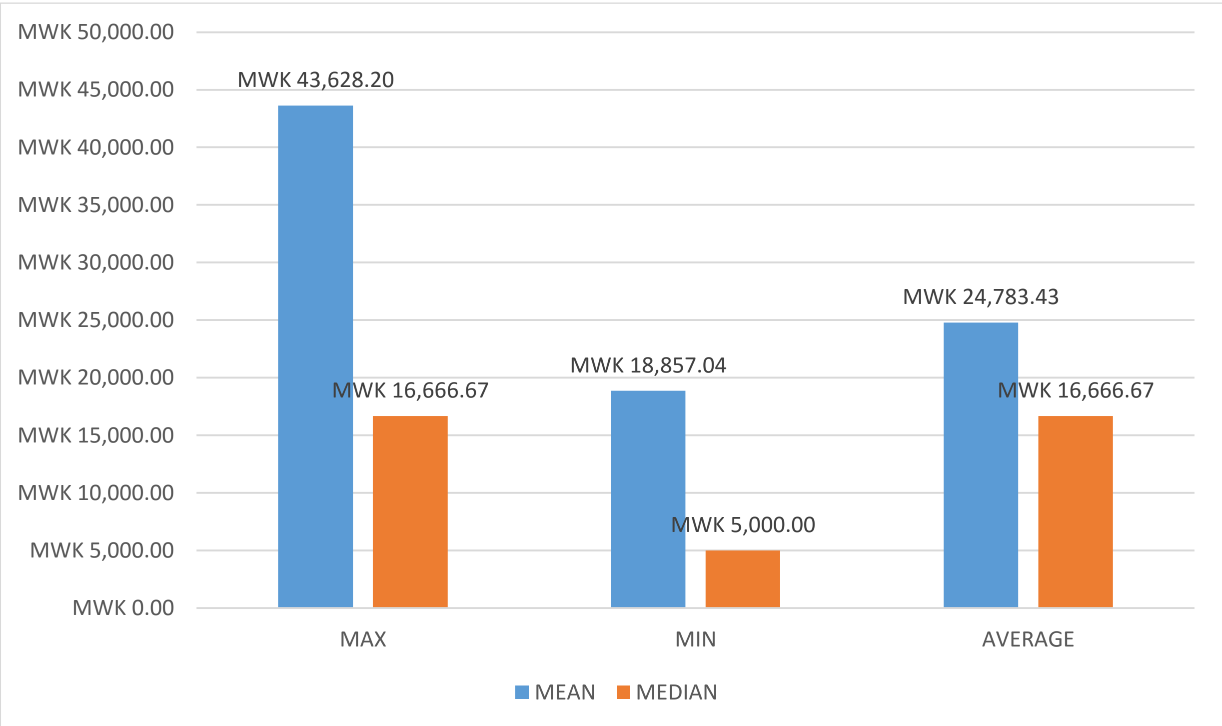


Figure 62: Income by job category

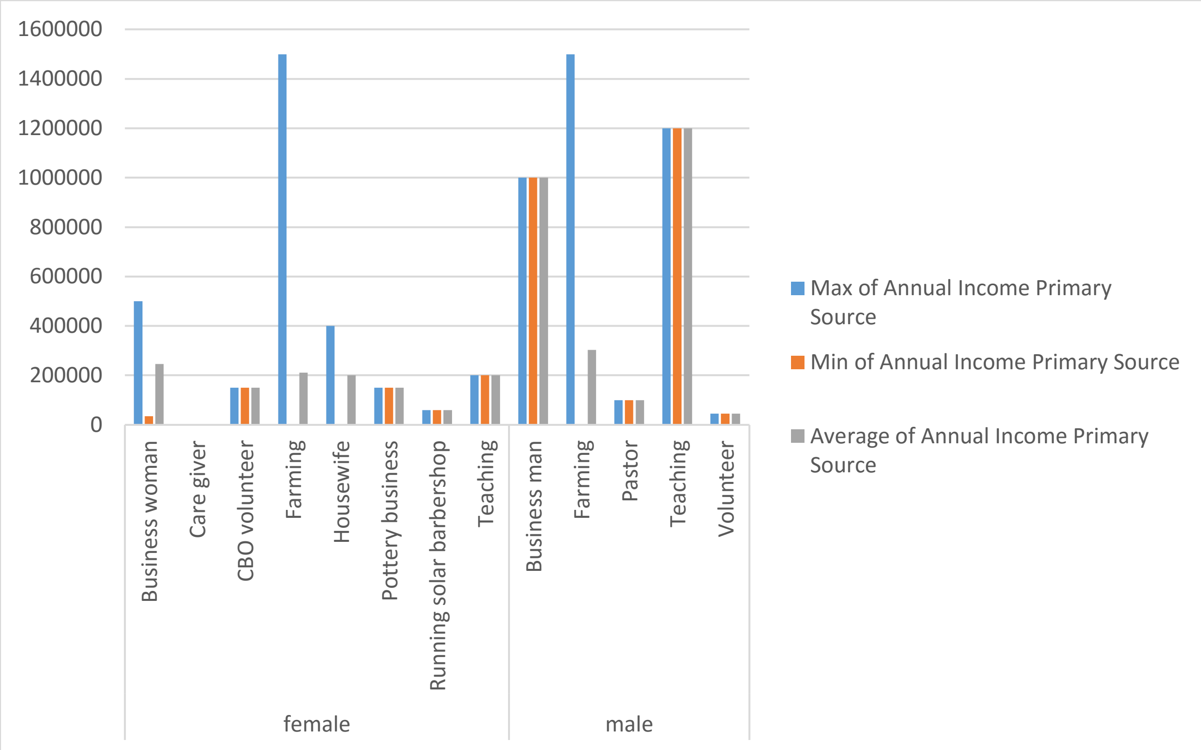
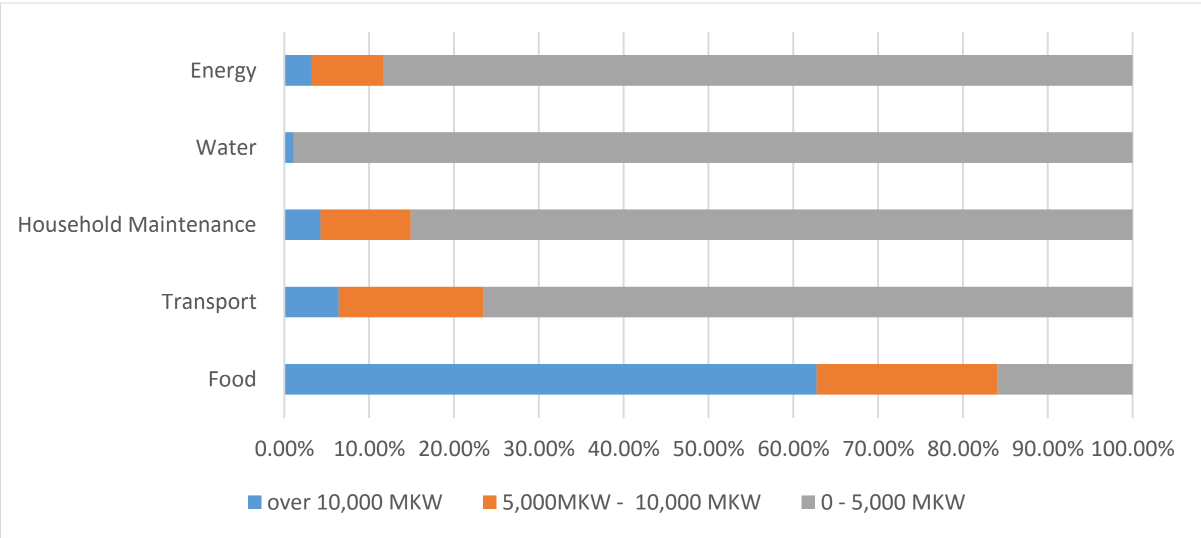


Figure 63: Percentage of respondents monthly spending categories

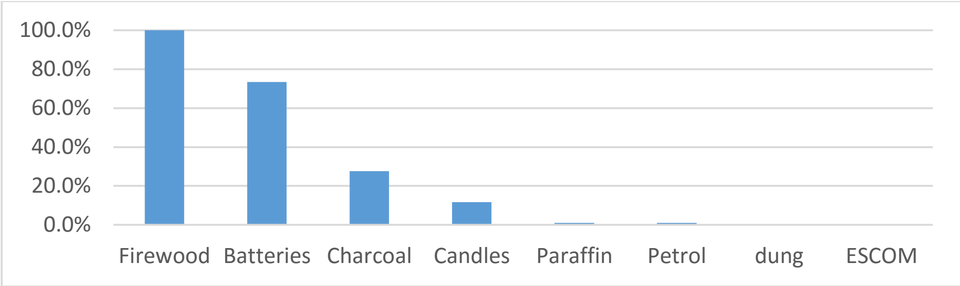


It can be seen that the majority of respondents spend 0 – 5000 MKW on energy, water, household maintenance and transport. Food is the only noticeable difference with the others, which is that over 60% of respondents spend over 10,000 MKW on food. The graph ultimately shows that food is the highest expense for the respondents interviewed.

6.6.2.1 Energy Use

It can be seen that all the respondents use firewood, and a large majority (over 70% use dry cell batteries. Charcoal is the next highest, followed by candles. Paraffin and petrol use were used by very few of the respondents. No respondents use dung and none are connected to the ESCOM grid.

Figure 64: Percentage of Respondents using a particular type of energy



6.6.2.2 Batteries

Although data on cost and collection time for firewood and charcoal was collected, it is not presented here as it has less relevance for energy provided by wind and solar power. The following graphs show the frequency of purchasing, the monthly spend, and the travel time to collect batteries. The costs give a good indication of how much people would be willing to spend on a renewable energy service to provide lighting to replace the current costs of batteries.

Figure 65: Frequency of Buying Batteries

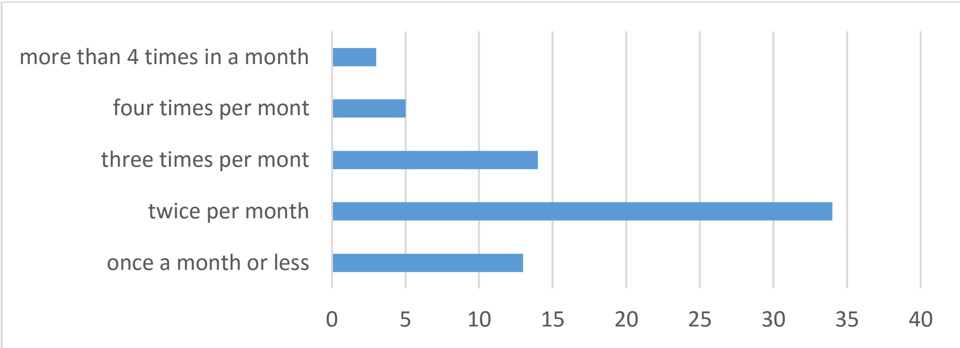


Figure 66: Monthly spend on Batteries (MKW)

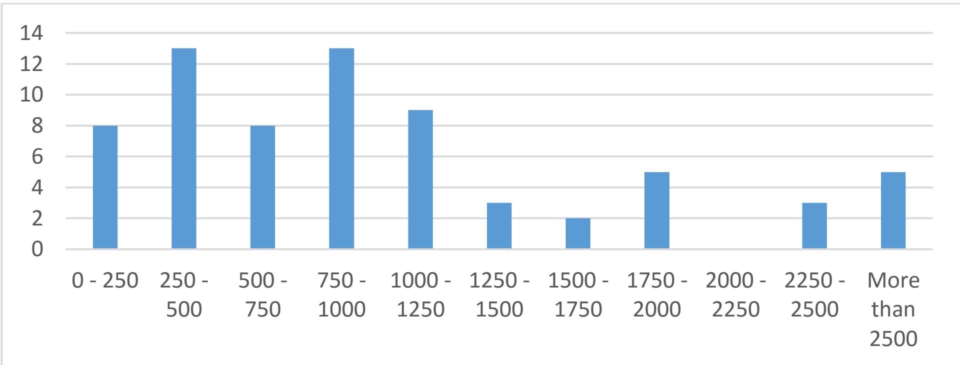


Figure 67: Monthly cost of Batteries (MKW)

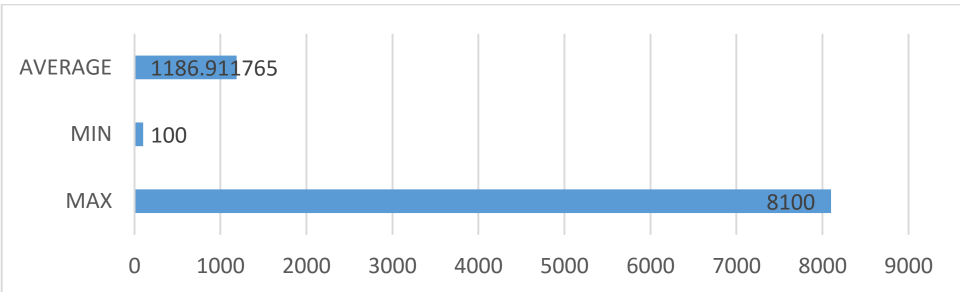
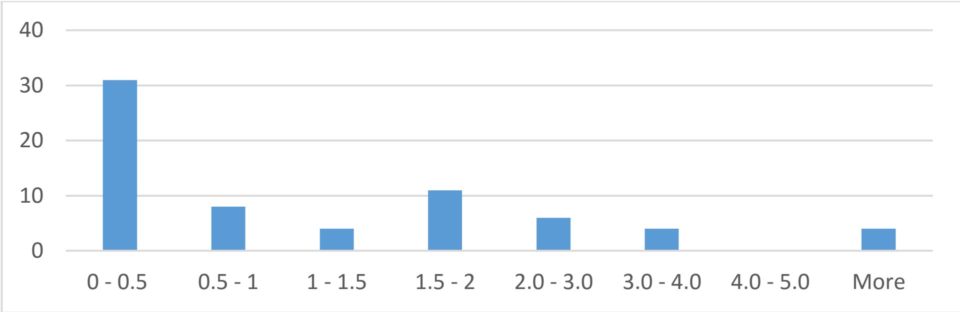


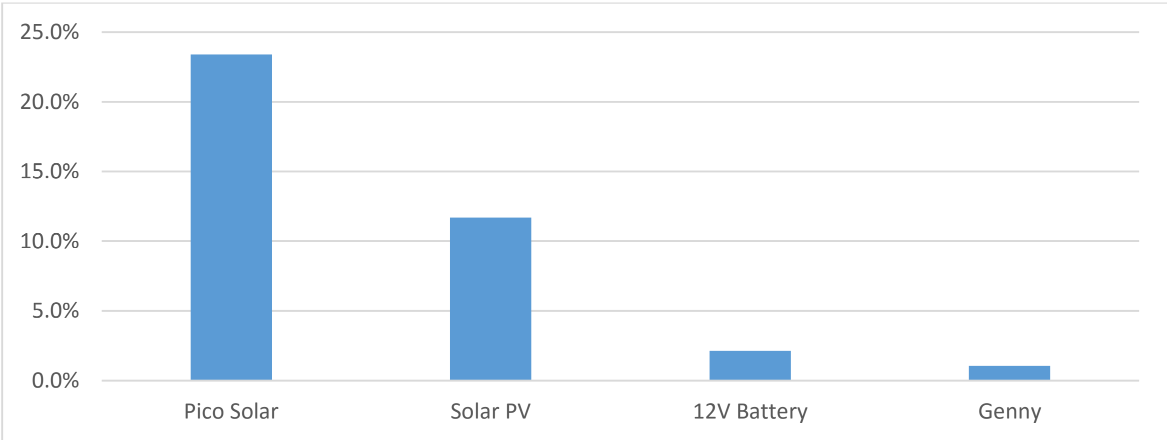
FIGURE 68: ROUND TRIP TRAVEL TIME (HOURS) TO COLLECT BATTERIES



6.6.2.3 Ownership of Energy Generators

Respondents were asked if they own energy generators. Most did not, for the respondents that did own, it was mostly pico solar products, (22%) followed by Solar Home Systems (12%), with few respondents owning 12V batteries and generators

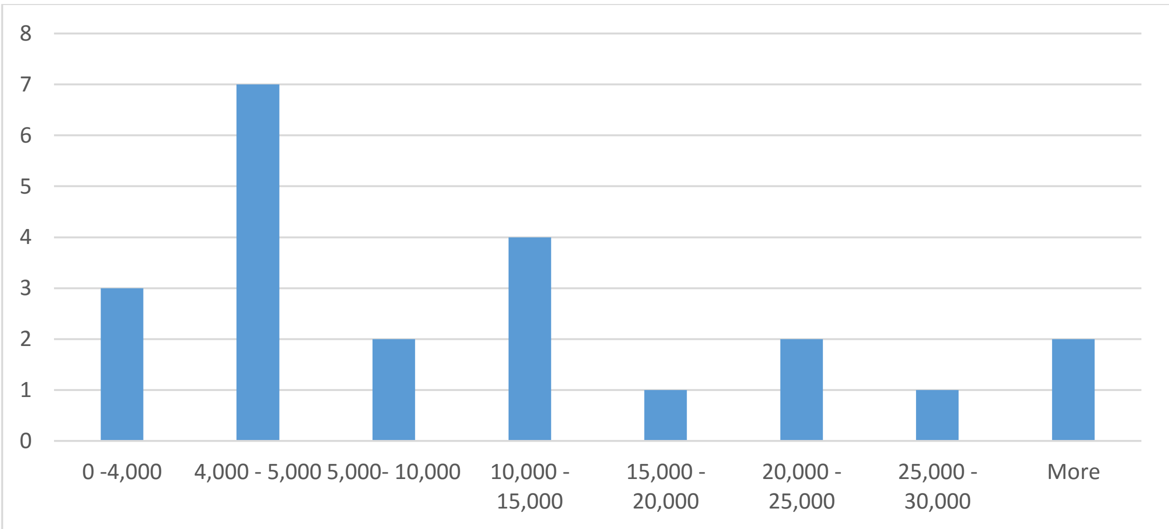
FIGURE 69:: % OF RESPONDENTS OWNING A PARTICULAR ENERGY GENERATOR



6.6.2.4 Pico Solar Cost

A Histogram of the costs of the pico solar products is shown below. Most are in the region of 4,000 – 5,000 MWK. The most expensive system cost 36,000 MWK, the cheapest was 3,500 MKW and the average cost of all the systems was 11,985 MWK.

FIGURE 70: COST OF PICO SOLAR SYSTEMS



6.6.2.5 Comments about Pico Solar

Respondents were asked about their opinions of pico solar products, which are outlined below in categories with the number of repeated comments in brackets. Most respondents were positive about the technology.

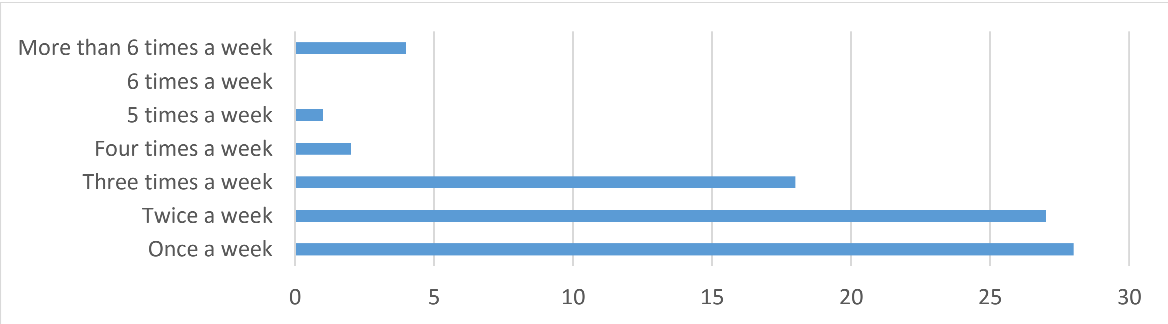
Good	Bad
• Performs better than battery torches (4) • Very reliable (4) • it is cheap to use/more cost effective than buying batteries (6) • High performance (4) • easy to charge • generally these products are good (4) • durable (2) • has made life simple (2)	• not reliable • It is also expensive to buy (3) • It is not functioning anymore (3)

6.6.2.6 Mobile Phone Use

Respondents were asked how many phones were in their household, what the cost of charging it was, and what the travel time was to charge their phones. Also asked was how often a phone is charged in their household. The results are shown below:

	Max	Min	Average
Number of Phones in household	4	0	1.5
Cost of charging (MKW)	300	0	43
Distance to travel (hours)	12	0	2

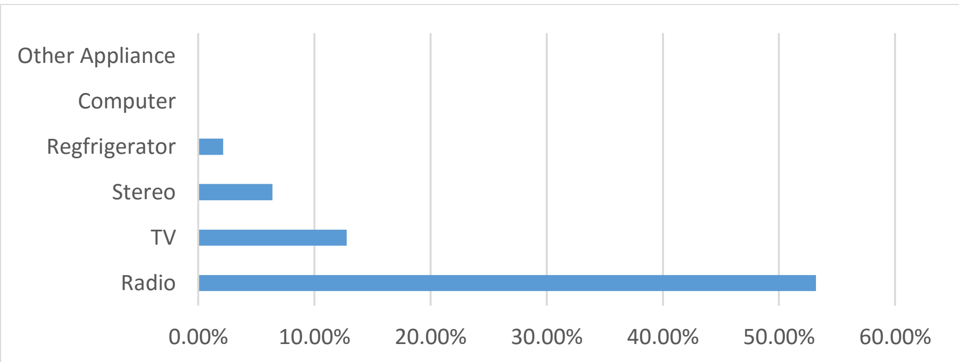
FIGURE 71: HOUSEHOLD PHONE CHARGE FREQUENCY



6.6.2.7 Appliances

Respondents were asked what appliances they own, and what the source of power is for these appliances. Just over half of the respondents owned a radio. 13% owned a TV, whereas 6% owned a stereo. Results are shown below

FIGURE 72: OWNERSHIP OF APPLIANCES



6.6.2.8 Source of Power for Appliances

Most people (63%) are using dry cells for the radio with the remaining using solar power. The majority of respondents do not use their TV because they don't have a power source for it, although 34% use solar.

FIGURE 73: SOURCE OF POWER FOR RADIO

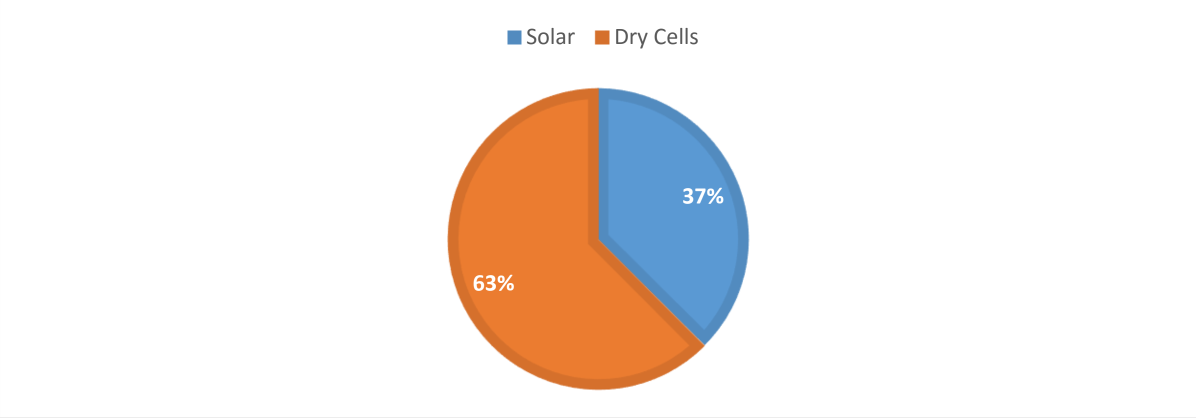


FIGURE 74: SOURCE OF POWER FOR TV

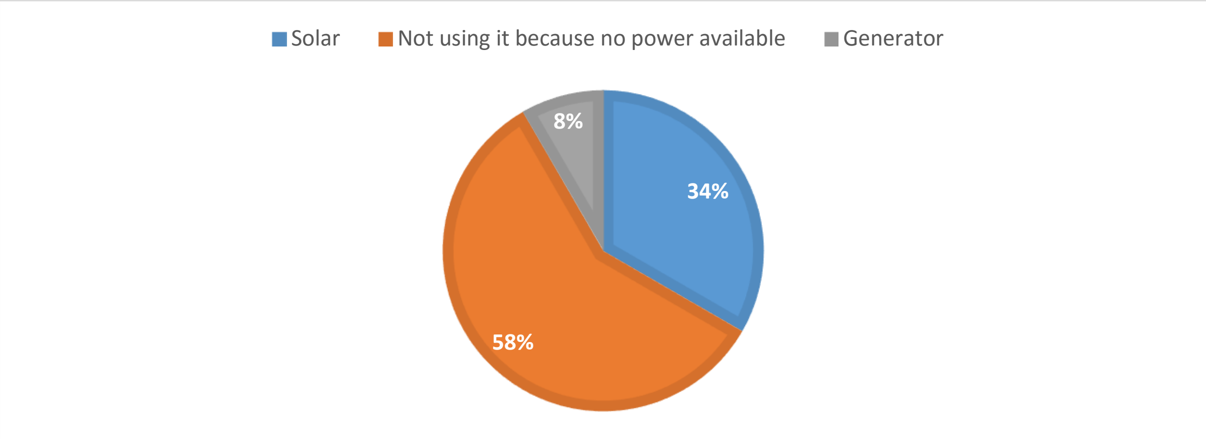
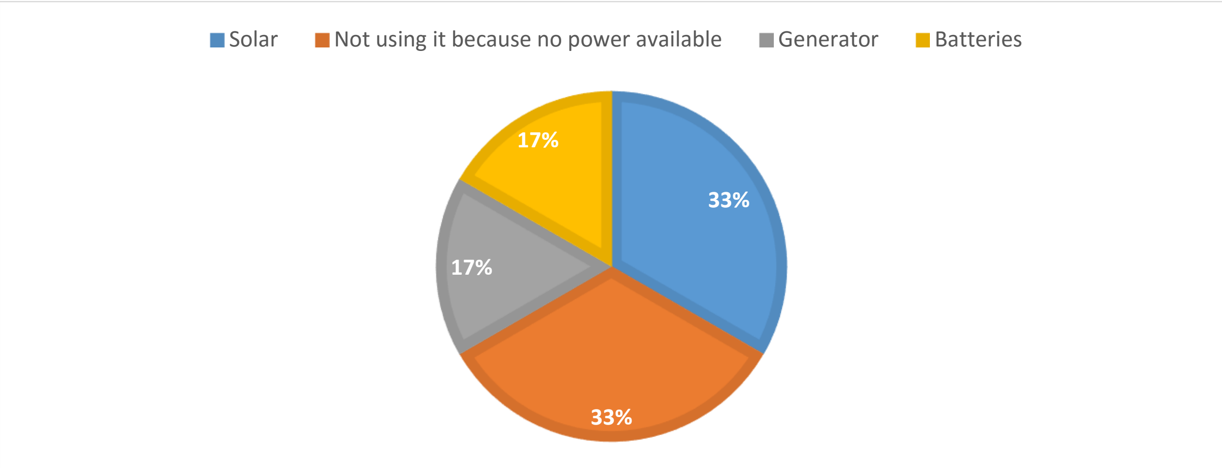


FIGURE 75: SOURCE OF POWER FOR STEREO

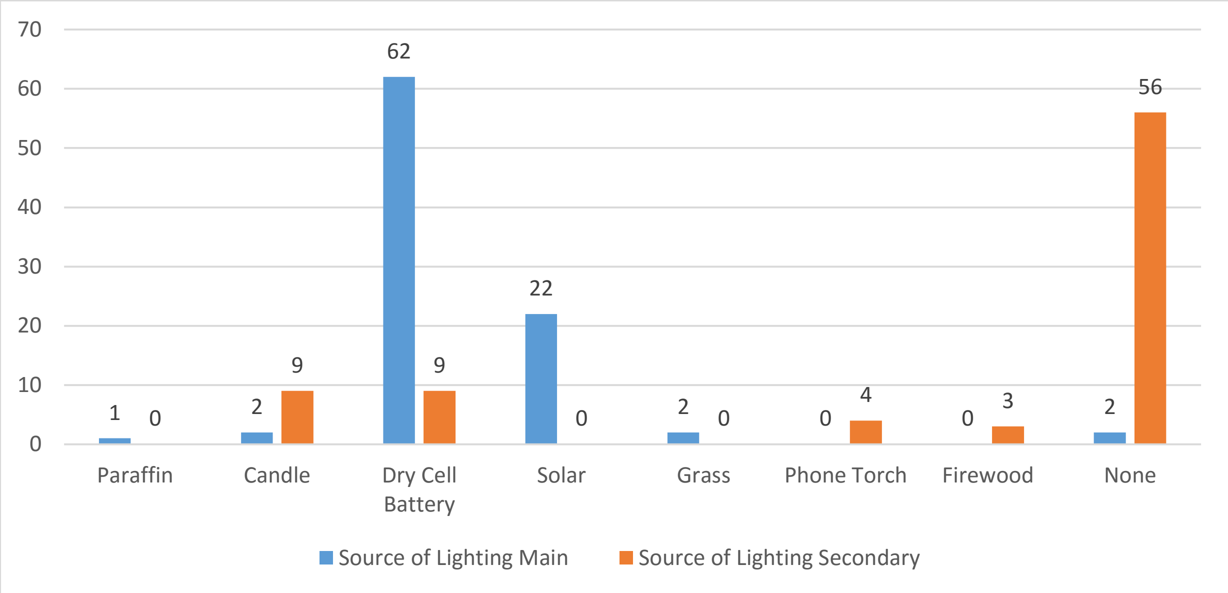


The two respondents that owned a refrigerator did not have a power source for it. It is interesting to see that many respondents own appliances but do not have a power source for them.

6.6.2.9 Lighting

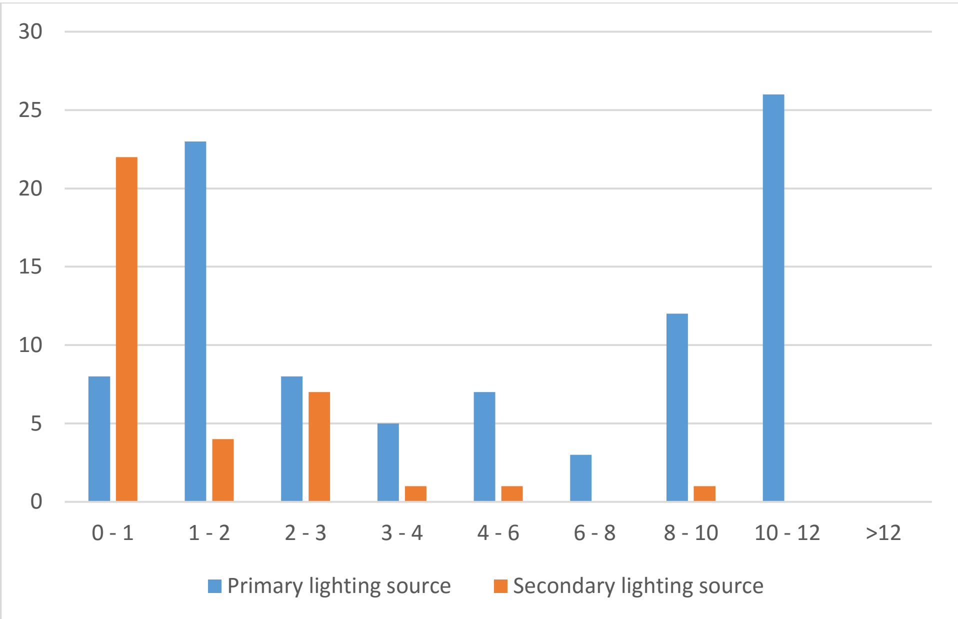
Respondents were asked what their primary and secondary lighting source is, and results are shown below

FIGURE 76: SOURCE OF LIGHTING FOR HOUSEHOLDS



It can be seen that the most popular primary source of lighting is dry cell batteries, followed by solar, with a few respondents using elephant grass or candles. 2 respondents had no source of lighting. The majority of the respondents had no source of secondary lighting, however the ones that did mostly used dry cell batteries and candles, which some using the torch on their phone or firewood.

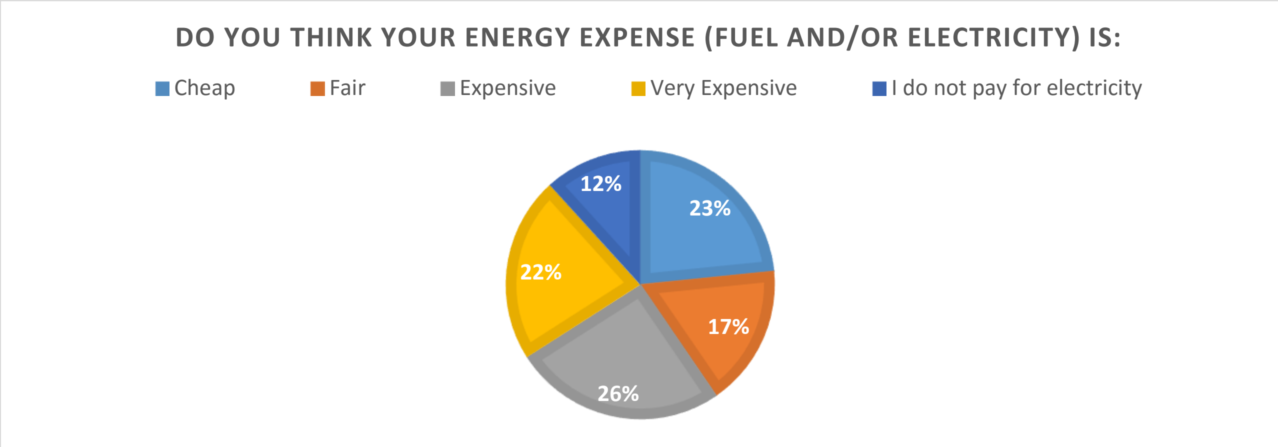
FIGURE 77: HOW MANY HOURS PER NIGHT EACH SOURCE OF LIGHTING IS USED

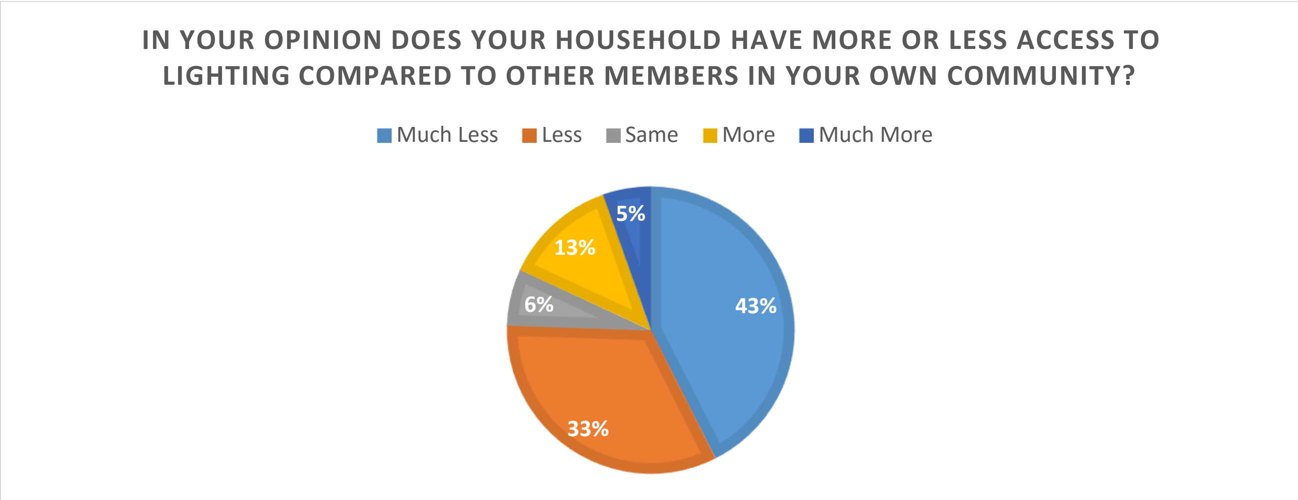


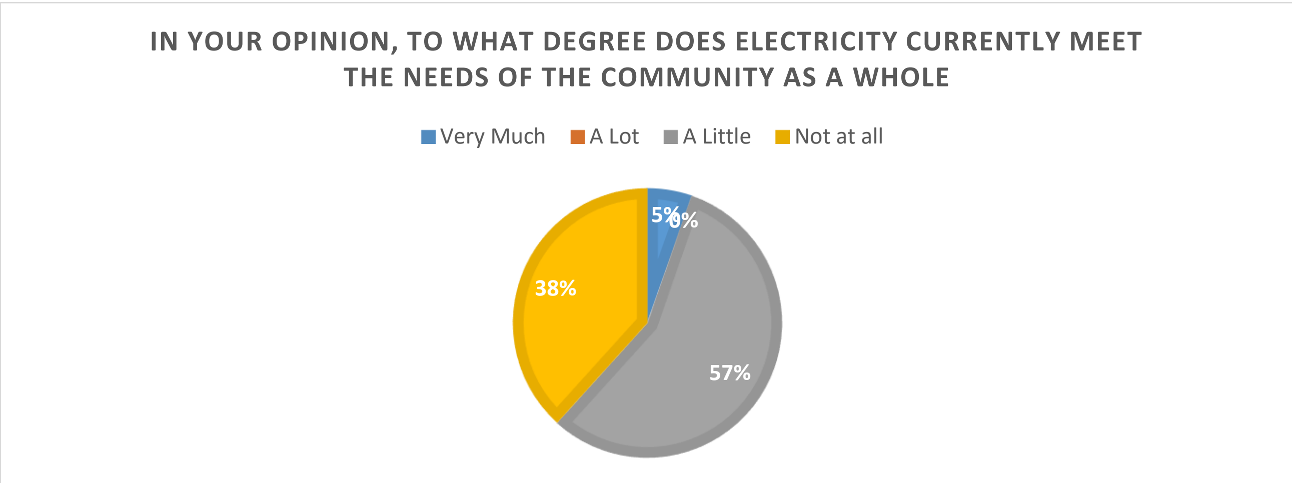
In terms of length of time used for each source of lighting, most respondents stated that they used the light for 10 – 12 hours. As the most used source of lighting is dry cells, it may be that they meant that the light was available for a longer time. The next most common length of time is 1 – 2 hours which is more believable. The secondary source of lighting is mostly used very briefly (0-1hours) with respondents saying for example that firewood or elephant grass is only used while cooking.

6.6.3 Energy Use Options

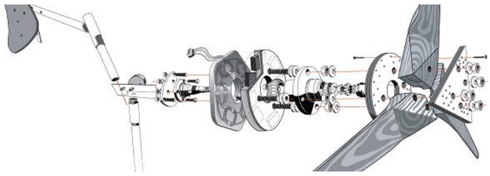
Respondents were asked various questions regarding their energy use, responses are shown below for each question.







Most of the respondents indicated that they thought their energy is expensive or very expensive (48% in total), whereas 40% thought their energy is cheap or fair. A clearer response is found in the next question, where 76% of respondents stated that their household has less or much less access to lighting than other households. The clearest response is in the final question, where 95% of respondents indicated that electricity meets the needs of the community a little or not at all.



6.6.4 Willingness to pay for energy services

Respondents were shown a variety of pico solar products, a picture of a solar home system, and a picture of a minigrid. Each product or system was described to them, including the main features and how it worked. Respondent were then asked to state what a fair price would be for rental for once month of the product, and then a fair price to purchase the product.

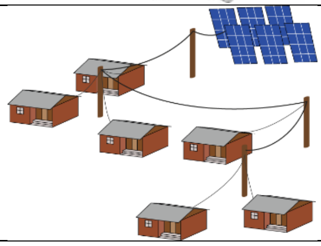
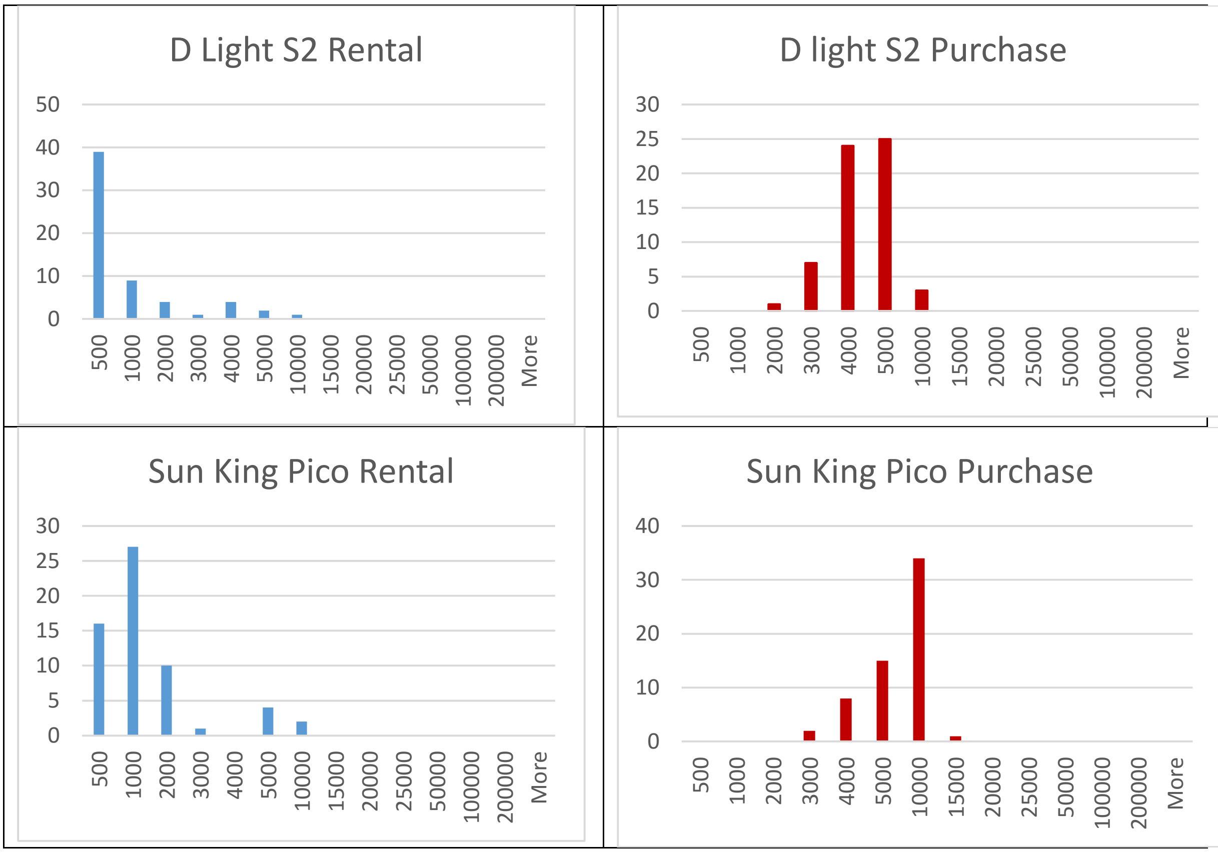
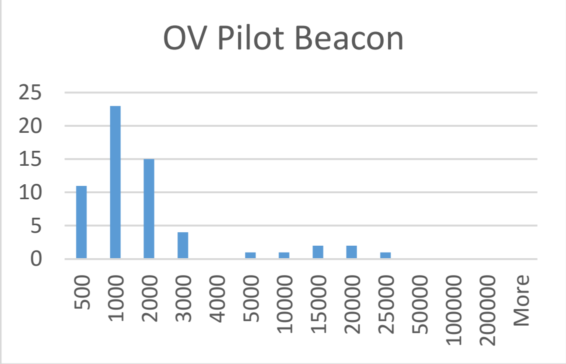
Dlight S2	only lights, no phone charging
Sunking pico	Only lights
OV Pilot	Light stand, phone charging 1.8
Marathon beacon 380	3 lamps, phone charger, 5.5Wp panel, remote control
Solar Home System	
Minigrid	

FIGURE 78: WILLINGNESS TO PAY FOR ENERGY SERVICES




OV Pilot Beacon
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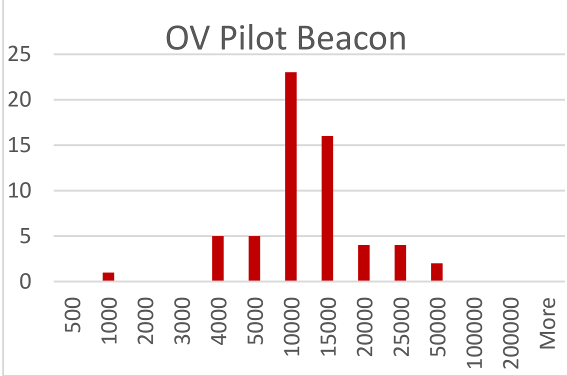
5000
10000
15000
20000
25000
50000
100000
200000
More


OV Pilot Beacon
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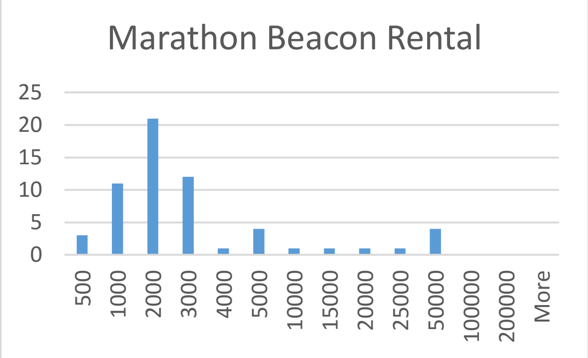
20000
25000
50000
100000
200000
More


Marathon Beacon Rental
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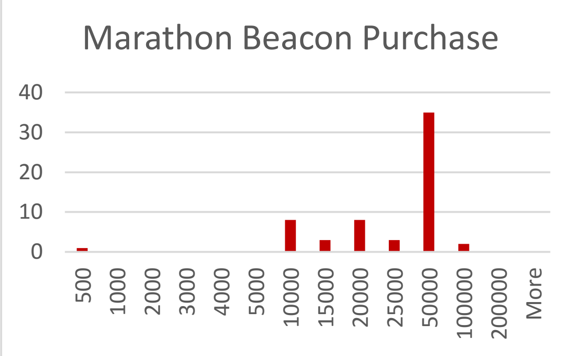
Marathon Beacon Purchase
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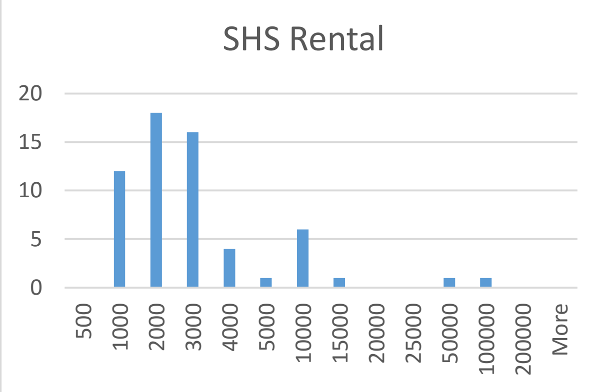
SHS Rental
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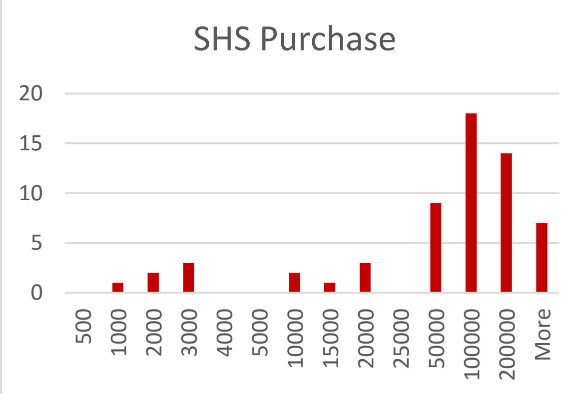
SHS Purchase
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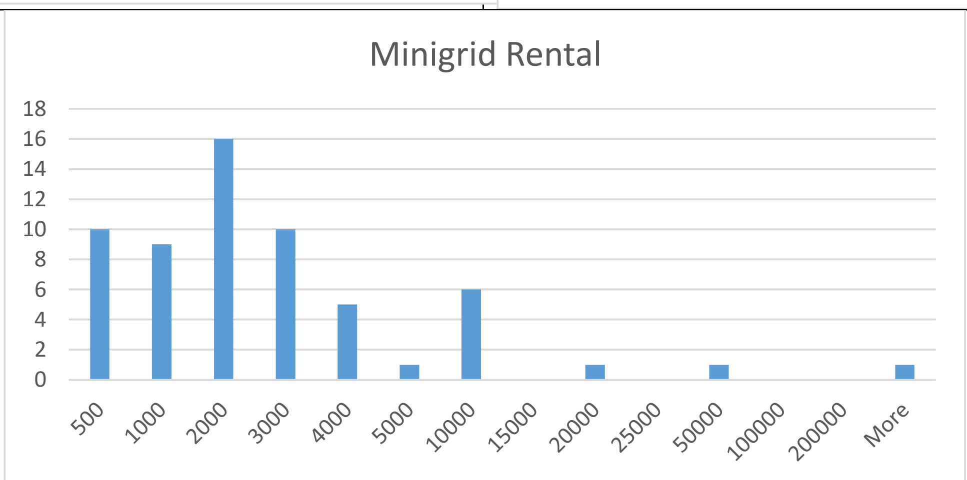
Minigrid Rental
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14
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18
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25000
50000
100000
200000
More

6.7 Appendix G – Full list of Wind Empowerment members

TABLE 26: FULL LIST OF WIND EMPOWERMENT MEMBERS.

Member organisation	Country	E-mail	Website
500 RPM	Argentina	esteban.vandam@gmail.com	www.500rpm.org
aee.tec	France	aee.tec@voila.fr	aee.tec@voila.fr
AJA Mali	Mali	ajamali@datatech.net.ml	www.ajamali.org/
Association pour le development de l'autosuffisance alimentaire et economique		gavinelli.olivier@wanadoo.fr	www.adaa-ase.com
ATcenter	South Korea	atcenter@live.co.kr	http://www.altecenter.blogspot.fr/p/about-us.html
blue energy	Nicaragua	media@blueenergygroup.org	www.blueenergygroup.org
Comet-ME	Area C, Israel	elad@comet-me.org	www.comet-me.org
Craftskills East Africa	Kenya	simon@craftskillseastafrica.com	http://craftskillseastafrica.com/
Ecoshpere	India	vivek.mundkur@gmail.com	www.spitiecosphere.com
Eirbyte	Ireland	eirbyte@gmail.com	
Energizar	Argentina	info@energizar.org.ar	http://www.energizar.org.ar/
eolocal	Argentina	esteban.vandam@gmail.com	http://www.eolocal.com.ar/
EolSenegal	Senegal	cmkebe@gmail.com	http://eolsenegal.sn/
EWB - UK	UK	Broad list - several contacts	www.ewb-uk.org
Green-step	Germany	info@green-step.org	http://www.green-step.org/
Green Empowerment	US, Nicaragua Peru, Philippines	aaron@greenempowerment.org	www.greenempowerment.org
Hettigoda Energy Technologies	Sri Lanka	udayahettigoda@yahoo.com	
I Love Windpower Mali	Mali	isabel@i-love-windpower.com	www.i-love-windpower.com
I love Windpower Tanzania	Tanzania	isabel@i-love-windpower.com	http://i-love-windpower.com/projects/tanzania/
Imecofarm	Ireland	eddieconnors@me.com	http://www.imecofarm.com/index.htm
Instituto Denuar	Mexico	johnrick.garcia@gmail.com	No website
Kapeg	Nepal	kapeg@kapeg.com.np	www.kapeg.com.np
Kartong project	Gambia	a.schiffer@gmx.net	http://web.me.com/anneschiffer/design_for_appropriate_technology_blog/Volunteering/Entries/2010/5/6_Leeds_Met_Volunteering_-_wind_power_for_Kartong.html
MinVayu	India	jorge.ayarza@gmail.com	http://www.minvayu.org/
Nea Guinea	Greece	neaguinea@riseup.net	www.neaguinea.org
NTUA RurERG	Greece	latoufis@power.ece.ntua.gr	
oh mayumi	Japan / Korea	noama1999@hotmail.com	
Otherpower	USA	info74@otherpower.com	www.otherpower.com
Renewable Energy Innovation	UK	matt@re-innovation.co.uk	
Renewable world	UK	Jo.Kelly@renewable-world.org	
RIWIK	Kenya	info@riwikeastafrica.com	http://www.riwik.nl/
SamSaara	Estonia	madis.org@gmail.com	http://www.samsaara.ee/

Scoraig Wind Electric	Scotland	hugh@scoraigwind.co.uk	http://scoraigwind.co.uk/
Sibat	Philippines	sibat@sibat.org	http://www.sibat.org/
Solar Energy for West Africa	Burkina Faso	jens.brand@solar-afrika.de	
Solarmad	Madagascar	lionel@solarmad.biz	www.solarmad-nrj.com
Soluciones Practicas	Peru	info@solucionespracticas.org.pe	http://www.solucionespracticas.org.pe/
TaTedo	Tanzania	energy@tatedo.org	www.tatedo.org
The Clean Energy Company	Mozambique	jason_morenikeji@hotmail.com	
Ti'Eole	France	jay@tieole.com	www.tieole.com
Tripalium	France	gael@tripalium.org	www.tripalium.org
Universitat Politècnica de Catalunya	Catalunya (Spain)	laia.ferrer@upc.edu	
V3 Power	UK	info@v3power.co.uk	http://v3power.co.uk/
WindAid Institute	Peru	jessica@windaid.org	www.windaid.org
WindEnergy4Ever	Netherlands		www.windenergy.nl
WindGen Power	Kenya	info@powergen-re.com	http://powergen-renewable-energy.com/
WISIONS	Germany	info@wisions.net	www.wisions.net