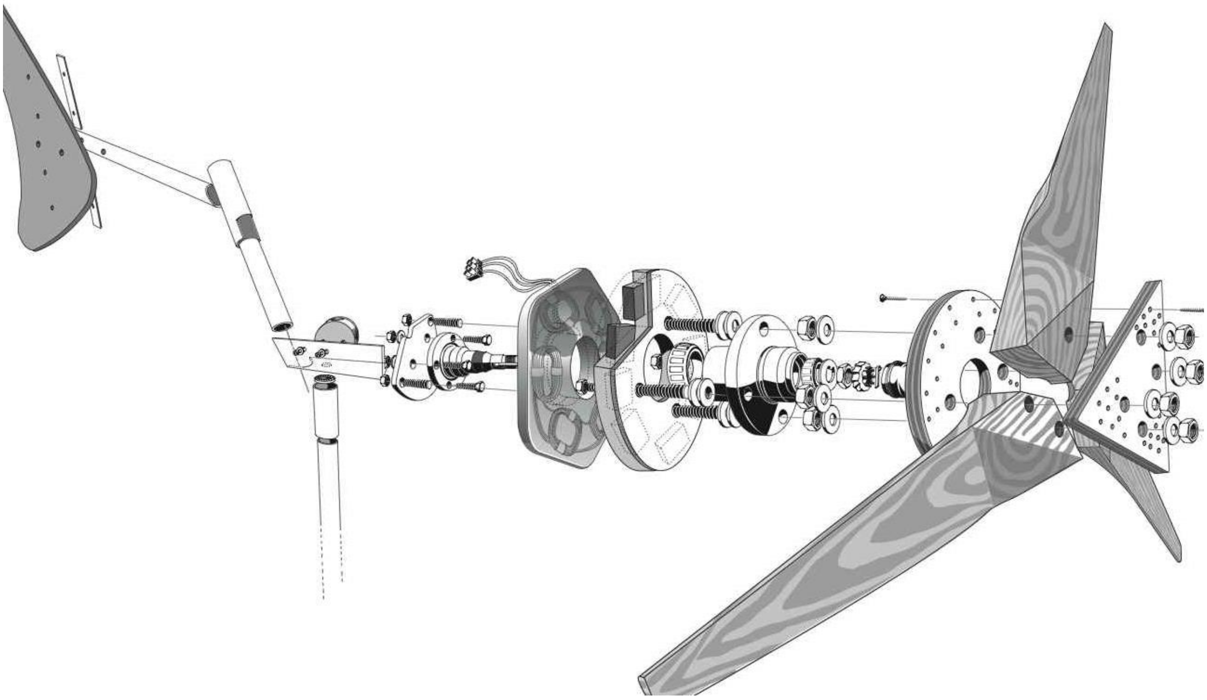
Market Assessment for Locally Manufactured Small Wind Turbines in Ethiopia



Wind Empowerment, January 2016

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Executive Summary

Ethiopia has one of the lowest rates of energy access in the world, as only 14% of its 82 million people have a direct supply of electricity in their homes. 83% of the population (66 million) live in rural areas, where the figure is below 1%. However, the Ethiopian government is aiming to achieve middle income status by 2025 and has a vision to become a regional hub for renewable energy in East Africa, as Ethiopia has significant hydro, geothermal, solar and wind resources. In fact, Ethiopia already generates 98% of its electricity from renewable sources and wind power is already being exploited at the utility scale, with three wind farms now feeding power into the Ethiopian electricity grid.

With the exception of a few key components, SWTs can be manufactured from materials that are available in urban centres around the world and as a result have the potential to enhance local economies, build local capacity for operation and maintenance, including a local supply chain for spare parts, along with trained mechanics and engineers who are able to perform repairs. This market assessment was commissioned by MercyCorps in order to answer the following research question:

What role (if any) could Small Wind Turbines (SWTs) play in the electrification of remote communities in the Somali, Afar and Southern Oromia regions of Ethiopia?

The market assessment was carried out by Wind Empowerment, an association for the development of locally manufactured small wind turbines for sustainable rural electrification. This report applies an open-source methodology currently under development by the association's Market Assessment Working Group and draws heavily on the collective experience of its 40+ members in over 25 different countries. The methodology uses a combination of techno-economic and spatial modelling, to compare SWTs with the other most viable off-grid power generation technologies using the Levelised Cost of Energy (LCoE) as the key metric. This study investigates the scalability of a 1kW SWT designed to meet the demands of a rural commercial centre by comparing four power generation system architectures:

1. Solar PV/Generator
2. Solar PV/SWT/Generator
3. SWT/Generator
4. Generator

The study is conducted on the basis that a micro-business would be established in the most viable region and the modelling takes into account the costs associated with local manufacture or importation of the various system components, as well as the installation and operation/maintenance of the energy systems. The model tests the sensitivity of the outcome to variations in the economic parameters in order to reflect the different scenarios in which the system could be employed (e.g. accessible vs. very remote sites) and future price trends (e.g. the falling global price of PV). The sensitivity of the outcome of the model with respect to the range of energy resources typically found across Ethiopia was also tested and plotted using Geographic Information Systems (GIS) in order to assess where SWTs are economically viable.

The LCoE/GIS analysis indicates that for the modelled 1kW scale commercial centre, PV systems with a generator backup are the most cost effective option for off-grid electrification throughout the majority of Ethiopia. However, in some regions, most notably the southeast of the country, PV/wind hybrids with a generator backup or even wind/generator systems are predicted to be the optimal system architectures. The study found 5.5m/s to be the threshold annual mean wind speed, above which, it becomes more cost effective to include a SWT in all systems, regardless of the solar resource. In the Somali region, where the solar resource is around 6kWh m^{-2} day^{-1}, SWTs are cost effective in locations with greater than 4.9m/s (increasing to 5.8m/s under a pessimistic scenario for SWTs).

In Ethiopia, the regions of high wind resource overlap significantly with the regions of high solar resource. In the East of the country (Somali region), both the wind and solar resources are high and the wind resources are relatively evenly distributed. In contrast, in the far South (Southern Oromia, close to the Kenyan border) the wind resources are high and the solar resources average, but the wind resource is much more variable meaning that individual wind resource assessments would be essential for all new SWT installations. This significantly slows down project implementation timelines, adds to their cost and increases risk (as there is no guarantee that the resource assessment will have a positive outcome). As a result, it is recommended that MercyCorps focus support for SWT-related activities in the Somali region, with the major target market in the southeast. Although hydropower was not formally assessed in this study, the potential for small scale hydro that would directly compete with SWTs is very low in this semi-arid region.

Land cover in the Somali region is predominantly grassland or sparsely vegetated, meaning that there are few obstacles to create shelter or turbulence. The viability of SWTs increases with eastward travel in the Somali region, as the average wind speed increases and altitude decreases, both of which increase the power available in the wind. In the west of the Somali region, there are locations with 2.5m/s (at 10m) annual mean wind speed at an altitude of 2,500m, which would be completely unviable for SWTs, meaning that wind resource assessments are considered essential for all new SWT installations in this region. In contrast, in the east, annual mean wind speeds range from 4.5-6m/s (at 10m) and altitude from 500-1,500m. As a result, after some preliminary on site measurements have been obtained from the region, it may be possible to install SWTs without having to perform in-situ wind resource measurements for each new site, making the technology much more attractive. Of course, a standard site assessment that locates the SWT upwind of any major obstacles will still be necessary. The solar resource increases with northward travel in the Somali region, from a minimum of 4.5kWh m^{-2} day^{-1} in the South to a maximum of 7kWh m^{-2} day^{-1} in the North. As a result, the most viable places for SWTs in Ethiopia are the East and South of the Somali region.

On a seasonal basis, the wind resource does peak in the months where the solar resource is at its lowest (Jun-Aug). The variation in the solar resource is not huge (+/-20%), whilst the variation in the wind resource is a little larger (+/-30%). This may seem insignificant, but when combined with the fact that SWT power production is proportional to the cube of the wind speed (PV panel production is directly proportional to solar insolation), this means that the energy available from a SWT varies considerably throughout the year (+/-40%), whist it is relatively stable from a PV panel (+/-10%). Unfortunately it was not possible to obtain data on the compatibility of these two resources over shorter timescales.

The most viable regions for SWTs in Ethiopia (south east) correspond to areas of low population density, no access to grid electricity, high levels of civil unrest and poor existing transportation infrastructure. These factors present both significant opportunities and challenges for the implementation of SWTs, in particular with regards to maintenance. The techno-economic modelling indicates that due to the fact that SWTs require significantly more maintenance than PV, the O&M costs for difficult to access sites (2 day round trip) are 3 times higher than those for accessible sites (half day round trip). As a result, sites selected for SWTs should be within one day's travel (round trip) from where maintenance services are available. In the short term, this will be the workshop where the SWT is fabricated, but in the longer term, a network of service centres could be established in order to offer maintenance services to a significant number of users in a particular region that is beyond this radius. These service centres would enable users to access the spare parts, tools and technical knowledge they need to maintain their equipment, without having to either make a lengthy/costly journey. What is more, such centres would create additional jobs and feed money back in to the local economy in even more rural parts of the country, where such benefits are likely to be valued even more highly. In addition to this, the training of on-site personnel (either those operating the commercial centre or suitable nearby businesses such as car mechanics), particularly with regards to the regular preventative maintenance check-ups, can greatly reduce these ongoing costs and is therefore highly recommended.

The main arguments to justify the implementation of this more challenging technology are the significant potential for local capacity building and economic development. The local manufacturing process presents an ideal practical learning opportunity that can raise awareness of the technology and build capacity for installation, operation and maintenance, as well as further manufacturing. The production of your own renewable energy system can also be an empowering experience for end-users themselves. This study estimates that a small business producing 10 turbines per year would create approximately 3 jobs (more if a rural service network is established). If a local SWT manufacturing hub is successfully established, it is expected to increase the proportion of the value chain that stays within Ethiopia to over 70% (from below 50% for a comparable PV-generator system).

Ultimately, in order to decide whether to support the further development of a local SWT manufacturing hub in the Somali region MercyCorps will have to make a judgement as to whether the comparative advantages of SWTs outweigh the disadvantages. In order to assist with this decision, Table 1 compares SWTs with the most viable alternatives, PV and diesel generators within the Ethiopian context. In fact, generators and PV should be seen as complementary rather than competing technologies, as the wind is a highly variable resource and therefore installing SWTs without one (or both) of these technologies is not recommended.

TABLE 1: COMPARISON OF THE POTENTIAL FOR PV, SWTS AND DIESEL GENERATORS IN ETHIOPIA.

	PV	SWTs	Diesel generators
Scalability	Scalable across the entire country. Modularity and simplicity make it suitable for a range of applications.	Limited to the southeast of the Somali region (with isolated, non-scalable pockets elsewhere). Maintenance requirements & reduced modularity make it most compatible with productive applications.	Scalable across the entire country as not site specific. Only really economic in combination with renewables.
Seasonal variation in resource	Relatively consistent. Lowest Jul-Aug.	Large variation. Highest Jul-Aug.	Dispatchable.

Value chain	Assembly of PV panels possible nationally, but cells must be imported.	Manufacture of entire SWT possible in basic workshops. Greater need for service centres & local technicians creates more job opportunities in rural areas. Participatory manufacture can be an empowering way to transfer knowledge and ownership.	Importation standard practice, but national assembly and potentially manufacture possible.
Price trends	Decreasing rapidly. Currently cheapest on all sites < 3.8m/s[1].	Small reduction expected as local manufacturing experience increases. Currently cheapest on all sites > 5.5m/s[1].	Fuel prices increasing.
Maintenance	Simple. Service network desirable and already exists in some places. Suitable for very remote sites.	Complex. Service network with highly trained personnel must be created. Not suitable for very remote sites.	Complex. Service network with highly trained personnel already exists in most places. Not suitable for very remote sites (also due to fuel distribution).

The report concludes with a series of recommendations for MercyCorps if they do decide to support the development of a local SWT manufacturing hub in Ethiopia:

- Build local capacity in the region where SWTs are most viable and most scalable:
  - Mix those with practical SWT experience with those with rural electrification experience.
  - Focus further SWT pilot projects in the Eastern and Southern regions of Ethiopia, principally the southeast Somali region.
  - Quantify scalability of delivery model by counting number of rural commercial centres in viable SWT regions
- Deepen understanding of locally available renewable resources:
  - Conduct site specific wind resource assessments.
  - Investigate solar/wind compatibility on shorter timescales.
- Find a locally appropriate delivery model:
  - Develop a full business plan.
  - Learn from previous experiences.
- Install hybrid systems
  - Generators and PV are complementary rather than competing technologies.
- Create a positive enabling environment:
  - Map the market.
  - Inform policy actors.
  - Tap into existing or create new knowledge sharing networks.
  - Develop higher education opportunities.

[1] Assuming minimum cost sensitivities, i.e. most favourable scenario for SWTs.

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1 Introduction

1.1 Background and Scope of Study

Wind Empowerment is an association for the development of locally manufactured small wind turbines for sustainable rural electrification. It serves its members by providing information and collaborating on key research to implement small wind turbines efficiently and effectively. Wind Empowerment offers consultancy and training for organisations already using or planning to implement small wind technology in rural areas.

MercyCorps is an international development organization that helps people around the world survive and thrive after conflict, crisis and natural disaster. The PRIME initiative is a 5-year, $52 million USAID-funded project designed to increase household incomes and enhance resilience to climate change through market linkages in Ethiopia's dryland areas. MercyCorps are working with the PRIME initiative in collaboration with Wind Empowerment with a focus on creating employment and developing local economies in their target regions.

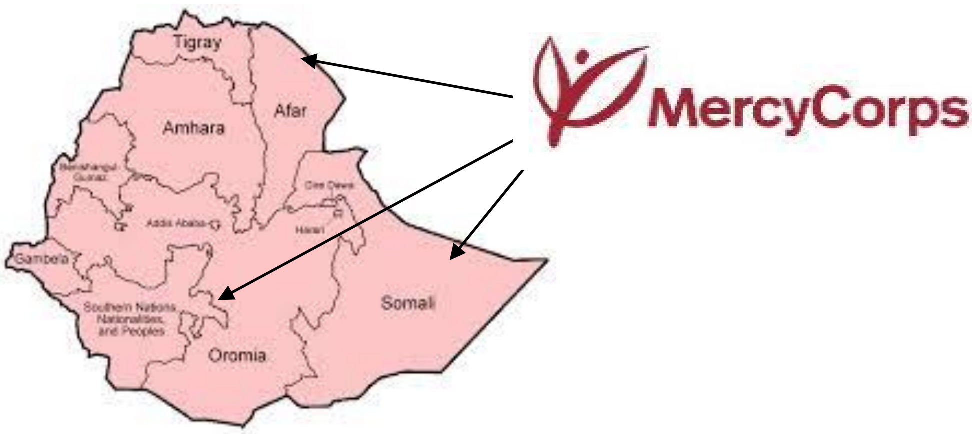
During the UN Global Conference on Rural Energy Access: A Nexus Approach to Sustainable Development and Poverty Eradication, which took place in Addis Ababa in December 2013, Wind Empowerment were introduced to MercyCorps Ethiopia and discussed the potential for small wind as a potential solution for rural electrification and local economic development in Ethiopia. Following the development of a detailed proposal, Wind Empowerment ran two pilot training courses constructing small wind turbines using mostly locally sourced materials. The courses were run as part of course with students from Jijiga and Semera University respectively, and the turbines installed in remote villages in the Somali and Afar regions.

Part of the proposal was to conduct a full market assessment to determine the viability of locally manufactured small wind turbines in an Ethiopian context. Prices for local components were found during the pilot courses and other data sources are describes in the body of this report. For a full description of the project see the document “Proposal to Implement Locally Manufactured Small Wind Turbines in Ethiopia”, available on request from windempowerment.group@gmail.com.

This report is intended to inform the locations and best practice for initial pilot installations of small wind turbines in Ethiopia.

The geographical scope of this report is focussed on the three areas of operation currently in place for the MercyCorps PRIME project: Somali, Afar and Southern Oromia, as identified on Figure 1. The market assessment will specifically focus on these areas.

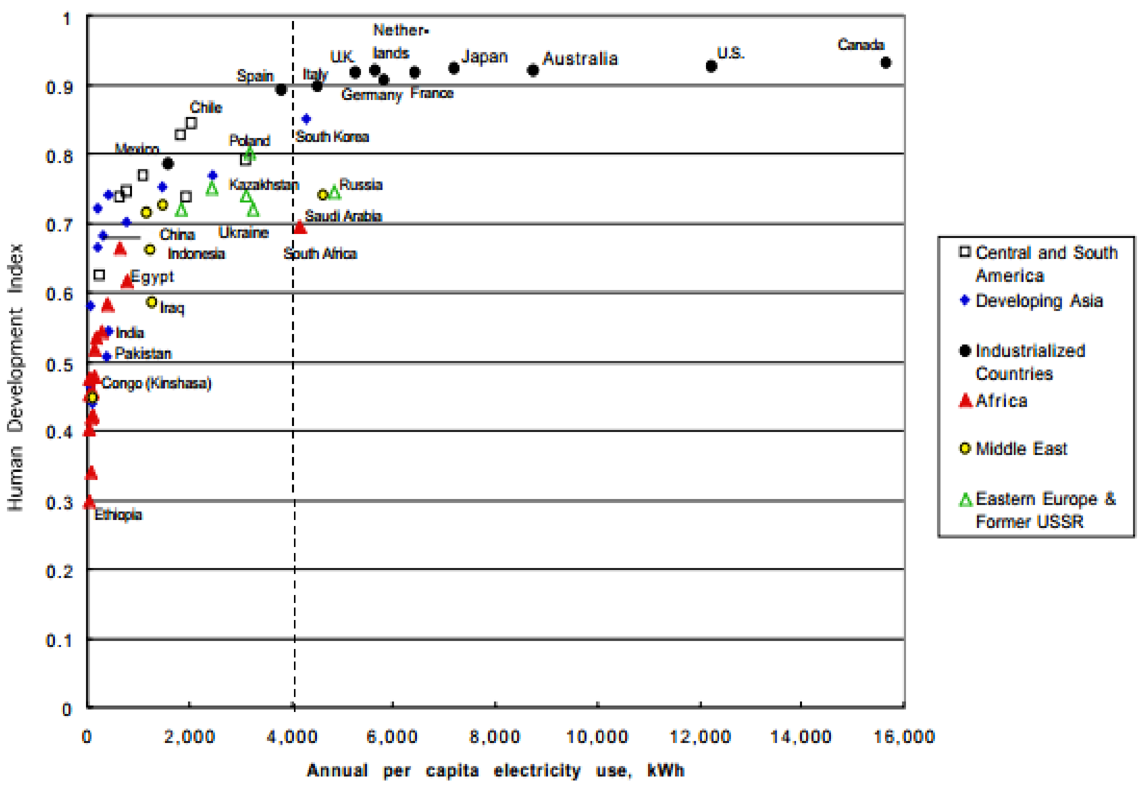
FIGURE 1: OPERATIONAL AREAS OF MERCYCORPS PRIME



1.2 Energy Access in Ethiopia

The United Nations Development Programme's (UNDP's) Human Development Index (HDI) is a multidimensional measurement of quality of life that takes into account factors of life expectancy, educational attainment and income. Figure 2 demonstrates that there is a clear correlation between access to electricity and quality of life, although it does not prove cause and effect (UNDP 2013).

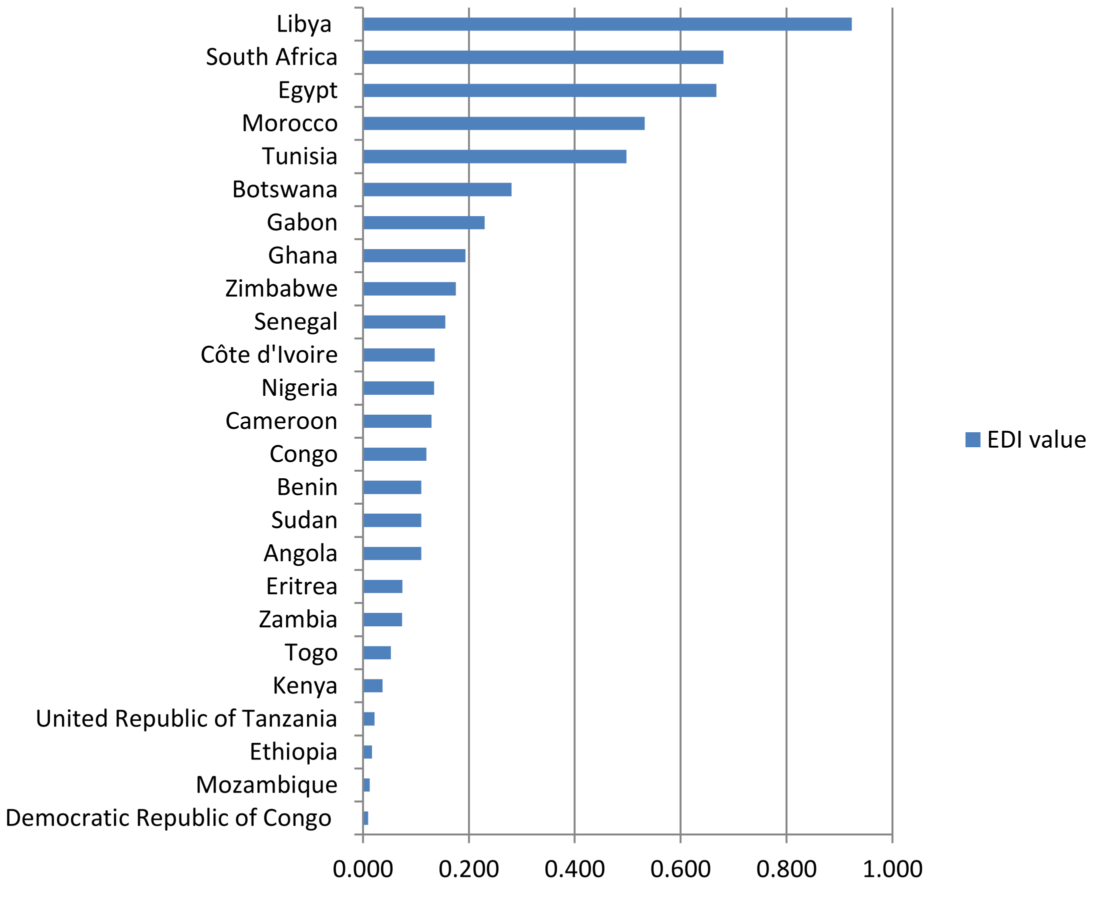
FIGURE 2: HDI AND ELECTRICITY CONSUMPTION FOR COUNTRIES OF THE WORLD *(PASTERNAK 2000)*.



Ethiopia has one of the lowest rates of energy access in the world, with only 14 % of its 82 million people having a direct supply of electricity in their homes and 83.2% of the population (66 million) live in rural areas (UNPD 2011), where the figure is below one per cent (GIZ n.d.). This is a major limitation on development and due to the cost and distances involved, the majority of the rural population is unlikely to gain grid access in the near future (Mulugetta 1999). Even after connection to the grid, electricity supply is often intermittent, with frequent black outs.

Ethiopia is already affected by climate change, with frequent droughts and unpredictable rains, which have severe consequences on the majority of the country, who rely on agriculture for subsistence (Ministry of Federal Democratic Republic of Ethiopia 2011). The IEA has recently presented an Energy Development Index (EDI) which measures a country's energy development at the household and community level (International Energy Agency 2012). In this study, Ethiopia received an index of 0.017 and ranked 62 out of the 64 countries studied.

FIGURE 3: ENERGY DEVELOPMENT INDEX FOR A SELECTION OF AFRICAN COUNTRIES *(INTERNATIONAL ENERGY AGENCY 2012)*.



1.2.1 National Strategy for Increasing Energy Access in Ethiopia

The Ethiopian government is aiming to achieve middle income status by 2025 and has a vision to become a regional hub for renewable energy in Eastern Africa. According to the government owned Ethiopian Electric Power Corporation (EEPCO), 48.3% of towns and villages were connected to the grid as of July 2012 (Ethiopian Electric Power Corporation 2014). The current 5 year growth and transformation plan aims to increase GDP by 11 – 15% per year from 2010 to 2015 and energy is included in this plan (Ministry of Federal Democratic Republic of Ethiopia 2011). The document states that Ethiopia is endowed with ample natural resources (hydro, geothermal, solar and wind) to meet demands for a green economy. In fact, Ethiopia already generates 98% of its electricity from renewable sources (Ministry of Water and Energy 2013). The country seeks to ensure that the use of renewable energy plays a significant role in the country's socio-economic development and transformation through the provision of sustainable, reliable, affordable and quality energy services to all sectors of the economy in an environmentally benign manner. To achieve this, the government has set robust targets in its Growth and Transformation Plan (GTP), which are further elaborated in the Climate Resilient Green Economy (CRGE) strategy. The CRGE has 4 pillars focusing on agriculture, forestry, energy production and energy efficient technologies. It clearly identifies electricity as a priority by stating their intention to:

"…expand electric power generation from renewable sources of energy fivefold over the next five years for markets at home and in neighbouring countries."

(Ministry of Federal Democratic Republic of Ethiopia 2011)

After achieving this fivefold increase in supply, the government plans to then further double its generation capacity, to 67 TWh, by 2030, and achieve zero emissions even sooner (Ministry of Federal Democratic Republic of Ethiopia 2011).

To date, the government's off-grid program has focussed on PV in remote areas, with 26,928 solar home systems (SHS) installed. Other achievements include the electrification of 821 institutions, such as health centres and schools with solar PV off grid systems, as well as the installation of an additional ten thousand solar panels nationwide. The goal is to be net zero carbon by 2025, which seems feasible as they are currently 95% renewable due to the large scale hydro program (Ministry of Water and Energy 2013).

1.2.2 Viability of Wind Power in Ethiopia

Figure 4 shows that Ethiopia is endowed with abundant renewable energy resources, with a potential 1,350 GW of wind power identified (Ministry of Water and Energy, 2013). In fact, wind power is already being exploited at the utility scale, with three wind farms now feeding power into the Ethiopian electricity grid. Ashegoda wind farm (Figure 5) consists of 84 turbines and generates 120MW electricity, which at the time of writing is the largest in Africa (Smith 2013) which is soon be superseded by the 300MW Aysha wind farm currently under construction near the border with Djibuti/Somaliland (Capital 2013).

FIGURE 4: RENEWABLE RESOURCE POTENTIAL IN ETHIOPIA (MINISTRY OF WATER AND ENERGY 2013).

Resource	Unit	Exploitable Reserve	Exploited	
			Amount	Percent
Hydropower	MW	45,000	~2100	<5%
Solar/day	kWh/m^2	4 – 6		<1%
Wind: Power Speed	GW m/s	1350 > 7	171MW Under construction	<1%
Geothermal	MW	7000	7.3 MW	<1%
Wood	Million tons	1120	560	50%
Agricultural waste	Million tons	15-20	~6	30%

FIGURE 5: THE 120MW ASHEGODA WIND FARM AT MEKELEE IN NORTHERN ETHIOPIA (SMITH 2013).

1.3 *Locally Manufactured Small Wind Turbines*

Mass-produced SWTs can be purchased from abroad or manufactured locally. This is in contrast to solar PV, for which there is only one choice, as there are currently very few solar PV manufacturing plants in Africa, and none in Ethiopia (ENF Company Directory 2014). The importation of equipment requires foreign exchange, building the economies of countries other than Ethiopia. With the exception of a few key components, SWTs can be manufactured from materials that are available in urban centres around the world and as a result have the potential to enhance local economies, build local capacity for operation and maintenance, including a local supply chain for spare parts, along with trained mechanics and engineers who are able to perform repairs (Sumanik-Leary, While, et al. 2013).

What is more, Locally Manufactured SWTs (LMSWTs) offer flexibility to adapt the technology to local conditions, such as the wind resource, skills, materials and financing models.

The maintenance requirements of LMSWTs are significantly higher than for solar PV (Sumanik-Leary, While, et al. 2013). However the local manufacturing process can increase the availability of skills to perform maintenance, build end-user commitment (if directly involved with the manufacturing) and create a strong local supply chain for spare parts, all of which are essential components for the long term sustainability of GMG (DfID-IED 2013). What is more, it presents a further opportunity for job creation in rural areas, as these maintenance services must be available locally.

The risk with local manufacture is that the end user requirements will not be met due to low quality unreliable equipment, unlike a mass produced turbine which generally comes with a guarantee of quality. Experiences from Kenya have shown that this can undermine the reputation of the technology as a whole, seriously limiting consumer confidence and creating a negative perception of the technology at all levels of society (Kamp & Vanheule 2015).

FIGURE 6: PROS AND CONS OF LOCALLY MANUFACTURED VS. MASS PRODUCED WIND TURBINES (DEEP EA N.D.).

	Advantages	**Disadvantages**
Locally Manufactured	Relatively cheap Can be repaired locally	Can be less efficient Can have a crude appearance
Prefabricated/Mass Produced	Well tested and reliable systems Often more efficient	Relatively expensive Spare parts may not be available

1.3.1 The "Piggott" Wind Turbine

The SWT described in this study is designed by Hugh Piggott of Scoraig Wind Electric, who has been developing robust low-cost wind turbine technology for the last 30 years in order to electrify his own community of Scoraig on the Northwest coast of Scotland. Piggott describes his open-source design and the manufacturing process in "*A Wind Turbine Recipe Book*" (Piggott 2013).

The turbine is a Horizontal Axis Wind Turbine (HAWT) designed to be robust and easy to manufacture from locally available materials anywhere in the world. With regular maintenance, the turbine can last for up to 20 years. The design incorporates recycled materials where possible and generally the magnets are the only component that requires importation into a developing country, such as Ethiopia. A description of the turbine components and electrical system is outlined in *Appendix 17 Description of the Hugh Piggott turbine* and a schematic of one of the turbine designs is shown in Figure 8, and layout of a common electrical system in Figure 7. The recipe book includes designs for several sizes of turbine, ranging from 200W to 1kW. Table 2 is the estimated monthly output for each turbine at a range of typical wind speeds.

FIGURE 7: TYPICAL ELECTRICAL SYSTEM LAYOUT FOR AN OFF-GRID SMALL WIND POWER SYSTEM (PIGGOTT 2000).

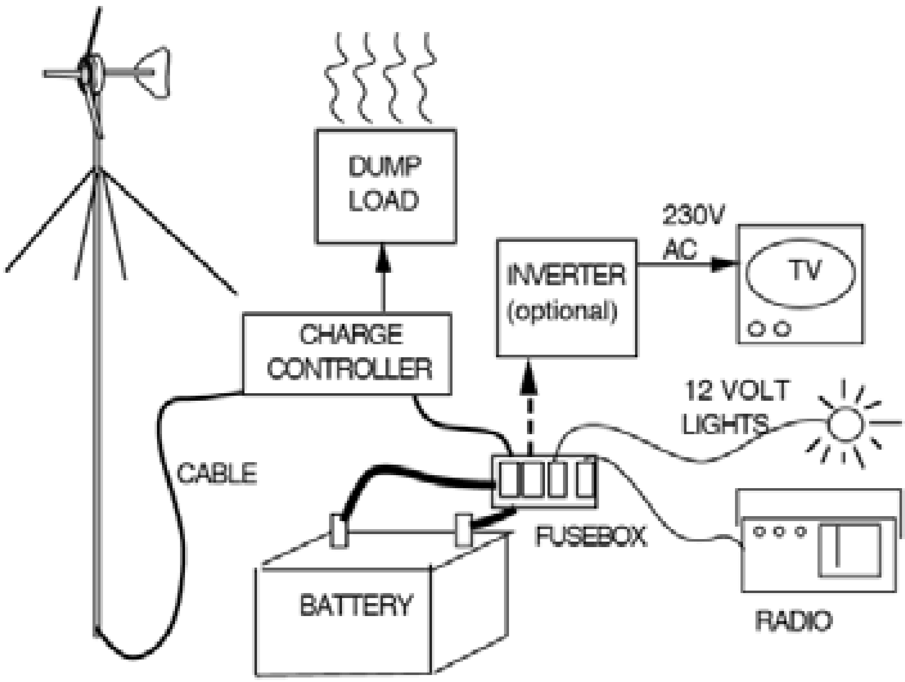
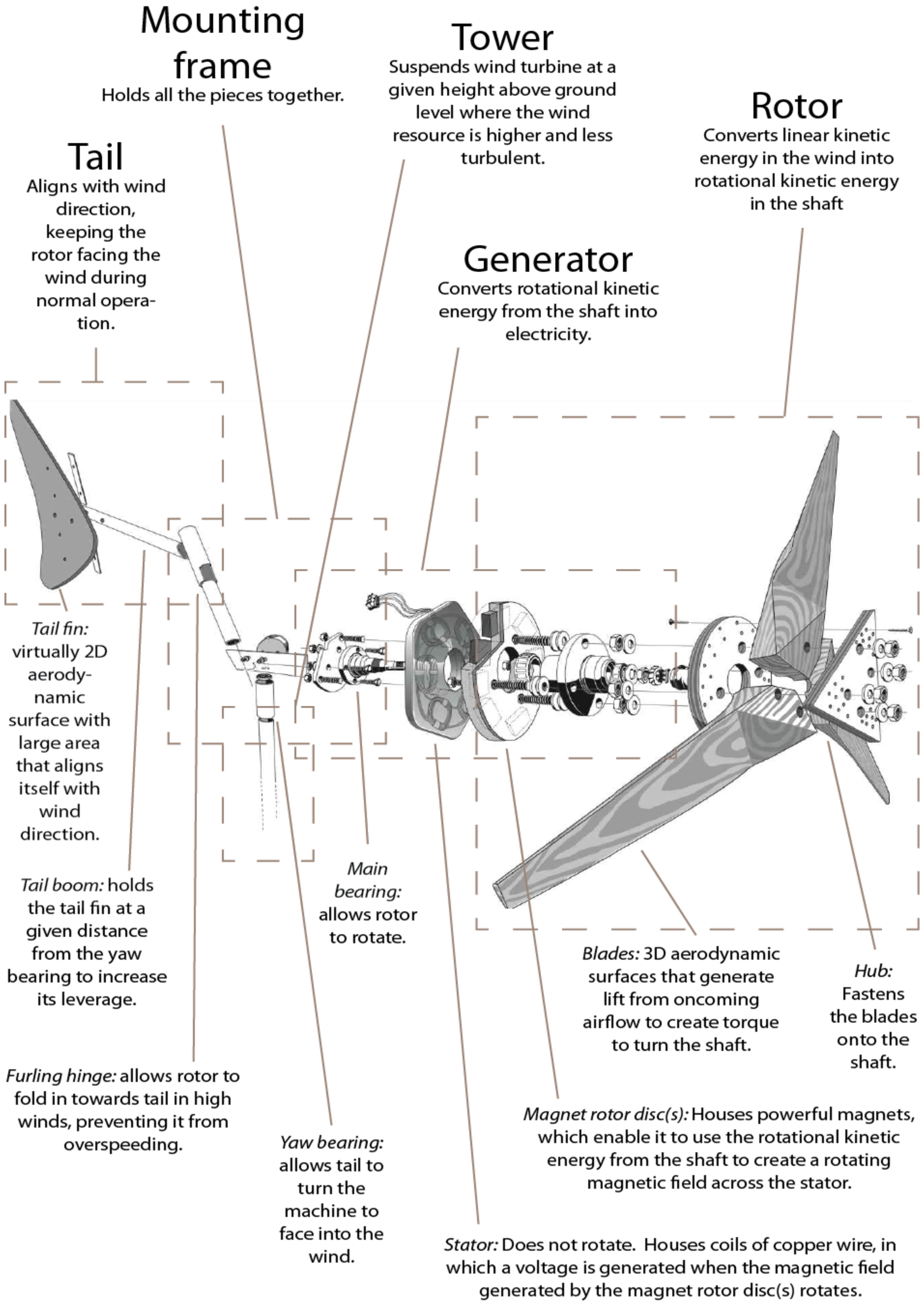


TABLE 2: PIGGOTT TURBINE SIZES AND MONTHLY PRODUCTION (PIGGOTT 2013).

Blade Diameter	**1.2m**	**1.8m**	**2.4m**	**3m**	**3.6m**	**4.2m**
Power Rating	200W	350W	700W	800W	1000W	1000W
3 m/s	5kWh	12 kWh	22 kWh	34 kWh	49 kWh	67 kWh
4 m/s	14 kWh	30 kWh	54 kWh	85 kWh	122 kWh	166 kWh
5 m/s	23 kWh	53 kWh	93 kWh	146 kWh	210 kWh	286 kWh
6 m/s	33 kWh	74 kWh	131 kWh	205 kWh	296 kWh	402 kWh
7 m/s	41 kWh	92 kWh	164 kWh	256 kWh	369 kWh	502 kWh

The open source nature of the turbine design means that product testing and feedback is shared throughout a global user network comprised of universities, NGO's and hobbyists. This makes the design resilient and development costs inexpensive (HEDON, 2013). Similarly, due to the accessibility of Piggott's plans, many organisations have been established across the world in order to utilise the design to provide rural electricity, create jobs and develop the economy in their local area. Currently there are over 40 organizations and hundreds of individuals around the world using variants of Piggott's proven design for rural electrification. These practitioners are organized through the global association Wind Empowerment (2014).

FIGURE 8: EXPLODED CAD ILLUSTRATION OF AN LMSWT, IDENTIFYING AND CLASSIFYING THE KEY COMPONENTS AND THE INTERACTIONS BETWEEN THEM (ROLAND, 2013).



1.3.2 Case Studies of LMSWT initiatives

The purpose of this section is to describe organisations around the world that are currently using the open source wind turbine design proposed for this project (Piggott 2013), in order to give examples of how the technology can be implemented. Where applicable business and ownership models are outlined, including the merits and problems with each. In addition to the four examples given below, the Wind Empowerment association has over 40 member organisations, all of which have different delivery models. Wind Empowerment (2015) has recently launched a database of projects implemented by its member organisations, which compares the technical, social and economic dimensions of each delivery model.

1.3.2.1 COMET-ME, Palestine

Web site: Comet-me.org

Comet-ME is an Israeli-Palestinian organization providing green energy and clean water services to off-grid communities using environmentally and socially sustainable methods. Wind turbines are installed in hybrid systems with solar panels to provide domestic power for off grid communities in Area C of the occupied Palestinian Territories. Energy provided by the system is metered and communities pay a monthly bill for the energy they use. COMET-ME build, install and perform maintenance on the turbines, which are all located relatively close to their workshop.

FIGURE 9: INSTALLATION OF A PIGGOT TURBINE IN THE OCCUPIED PALISTINAN TERRITORIES BY COMET-ME.

1.3.2.2 Wind Aid, Peru

Web site: WindAid.org

The WindAid Institute is supplies electricity to impoverished rural Peruvian communities by leveraging the participation of volunteers from around the world, who learn about, construct, and then install wind turbines in a participatory construction course. The main financial income for Wind Aid comes from volunteers in USA and America paying to partake in a 6 week placement where they build a wind turbine and install it in a remote community in Peru. The volunteers benefit from engineering experience in a development context and the rural communities receive access to electricity with only the maintenance costs to cover. Community members are involved in the construction process and are trained in the maintenance of the turbines. WindAid commonly install a 2.5kW turbine at a school, heath post or other community building. Community members are often allowed to charge their mobile phones or domestic batteries for a fee. They have recently begun producing smaller (500w) systems for household lighting and phone charging at a household level.

FIGURE 10: INSTALLATION OF A PIGGOTT TURBINE IN THE PERUVIAN ANDES BY WINDAID.

1.3.2.3 Wind Gen, Kenya

Web site: WindGenPower.com

WindGen are a commercial company in Kenya that locally produce and sell wind turbines for the off grid market in East Africa. They locally manufacture wind turbines from 200W to 1kW but also import mass produced wind turbines from abroad up to 10kw in power rating. Their customers include tourist resorts, households, schools or hospitals, generally paid for by clients who are currently using diesel generators and can afford the upfront cost. Prices range from $2300 for a small hybrid system (200w wind turbine and 140w solar panel with batteries and control systems) up to $9900 for a deluxe system with a 1kW wind Turbine and 700w solar PV.

FIGURE 11: LMSWT AND ACCOMPANYING ELECTRICAL SYSTEM INSTALLTED BY WINDGEN IN KENYA.

1.3.2.4 I Love Wind Power, Tanzania/Mali/Mexico/Brazil

ILWP's mission is to "Encourage small-scale wind energy in developing countries through local activity." It supports local enterprises in each of the countries in which it operates by offering access to an extensive international network on small-scale wind energy which can provide technical and financial support for local projects.

FIGURE 12: LMSWT INSTALLED BY I LOVE WIND POWER IN TANZANIA

1.4 General Trends in Rural Electrification with Renewable Energy

Extending the grid is usually the cheapest option for households close to existing grid infrastructure and is generally favoured for urban areas, due to the higher population density. What is more, it is generally also a more desirable option, as its virtually limitless capacity offers a much greater range of energy services to the end use, particularly with regards to productive uses of energy.

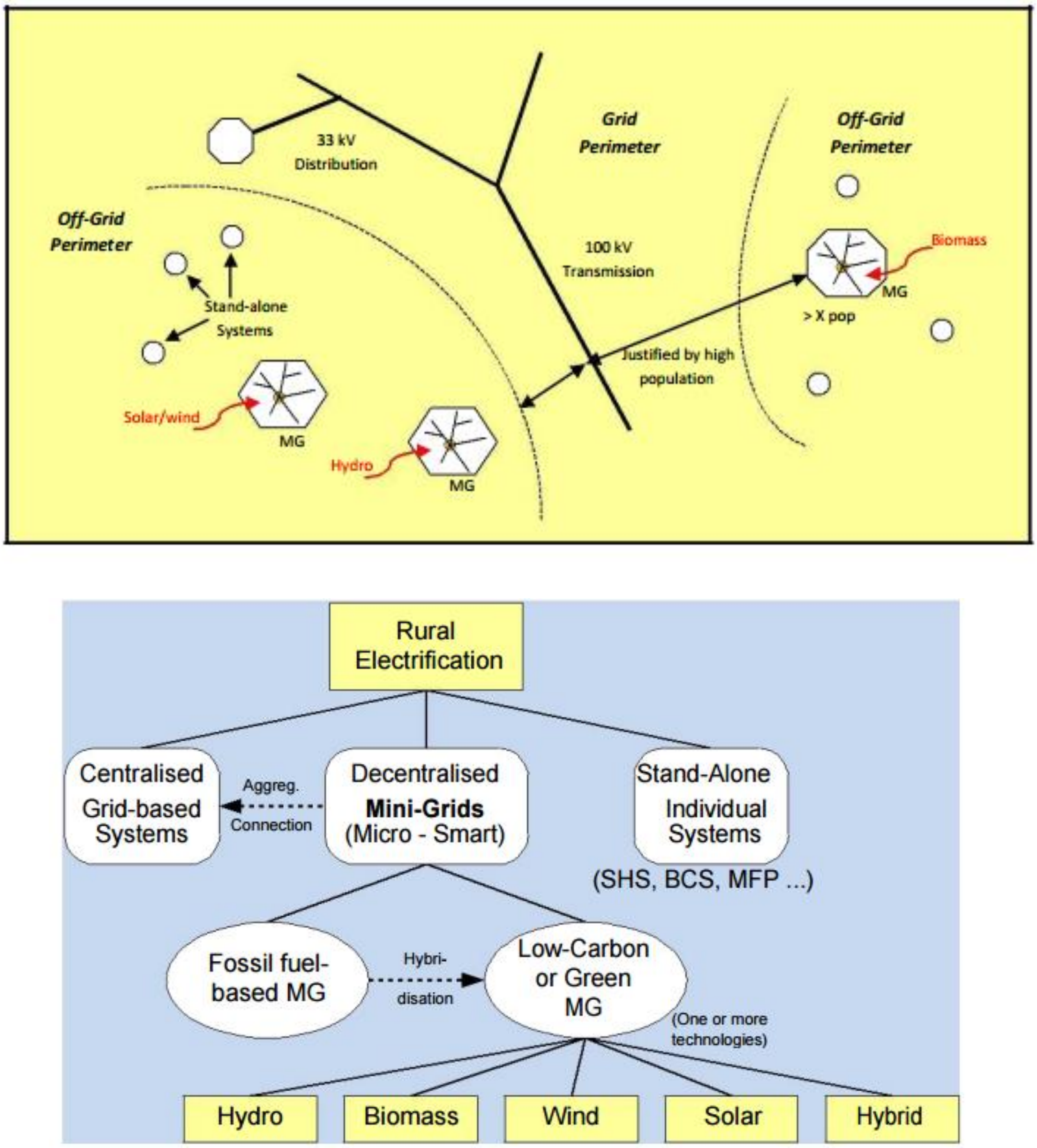
However there are challenges with grid extension, especially in SSA. A major hurdle is the sheer distances involved between households, which makes connections to many rural areas uneconomic (Yadoo 2012). What is more, GIZ (2011) identified the following challenges with implementing grid connections:

- corruption in tendering contracts
- low quality of in-house-installations
- high number of secondary connections
- high levels of technical and non-technical losses
- time/resource consuming tendering and procurement procedures
- lengthy construction contracts

AS AN ALTERNATIVE TO A CENTRALISED GRID, THERE HAS BEEN A RECENT PARADIGM
(MULTI USER) OR “OFF-GRID” (HOUSEHOLD OR SINGLE USER) SYSTEMS (DFID-IED 2013).
DEFINITION OF MINI-GRID (DFID-IED 2013), HOWEVER THEY ARE GENERALLY
SMALLER IN SCALE THAN A NATIONAL NETWORK. ONE DEFINITION IS A “LOCAL POWER
DISTRIBUTED ENERGY RESOURCES AND MANAGES LOCAL ENERGY SUPPLY AND *DEMAND*”
(LILIENTHAL 2014).

Figure 13 shows that cost is a key factor in choosing between these three options and is based on distance and number of users with mini grids and stand-alone systems falling in the off grid perimeter.

FIGURE 13: REPRESENTATION OF GRID, MINI GRIDS AND STAND ALONE SYSTEMS (DFID-IED 2013).



Each method presents specific advantages and challenges and is appropriate for different geographic, social and economic contexts. Table 3 shows GIZ's predictions for how the 650 million people in SSA could potentially be electrified.

TABLE 3: PREDICTIONS FOR METHOD OF ELECTRICITY SUPPLY IN SSA (HELLPAP 2013).

Method of Electrification	Grid extension/ densification	Mini-grids (multi-user systems)	Household systems (one user systems)
Example	3MW Hydro Power Plant	100kW Wind-Diesel Hybrid	Solar Home System
Predicted Number of People in SSA	550 million	225 Million	225 million

Although minigrids are often powered by diesel generators, renewable energy technologies (RET) have matured over recent years and there is a strong and increasing interest from the private sector to invest in so called "Green Mini Grids" (GMG). Decentralised renewable energy mini-grids also offer potential social benefits, including increased participation of local people in the planning of energy services, equity in distribution and consumption and empowerment through local management (Ministry of Federal Democratic Republic of Ethiopia 2011).

However, the unpredictability and intermittency of renewable sources of energy present a significant drawback for GMGs, which leads to additional costs for energy storage, especially with wind and solar GMGs, and hybrid systems or those utilising multiple sources (hybrid systems) are now perceived a promising alternatives (DfID-IED 2013).

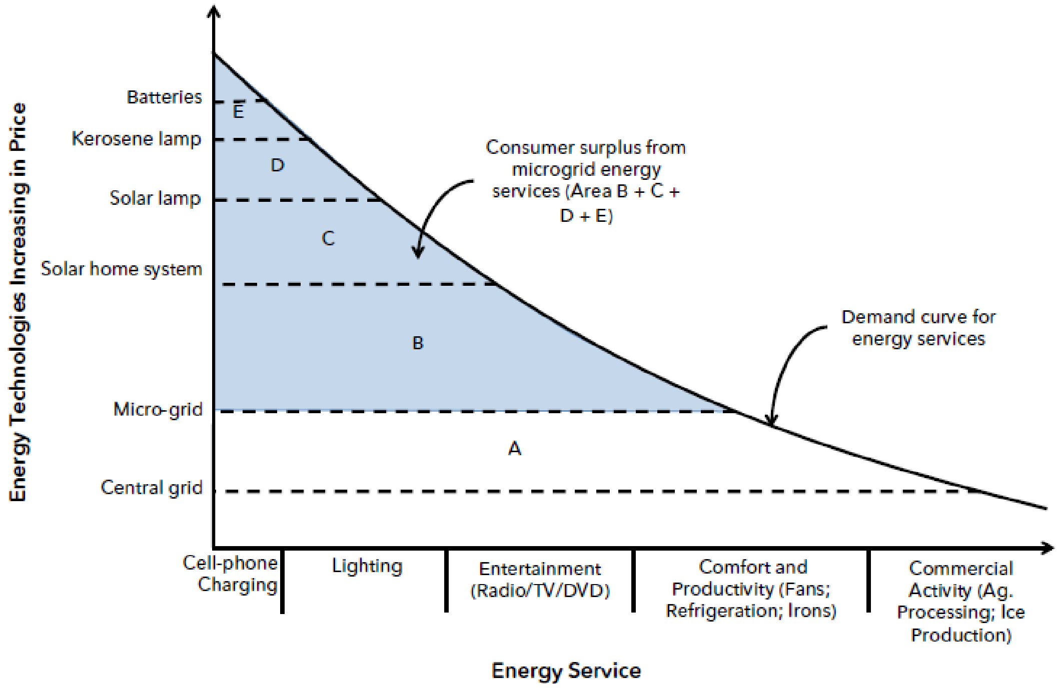
1.4.1 Productive Use of Energy verses Communication and Education

Figure 14 shows how GMG can extend energy services up to "comfort and productivity", which sits at a lower point on the demand curve and offers increased potential for economic and human development than solar home systems, solar lamps or kerosene lamps. The definition of Productive Use of Energy (PUE) given by GIZ is:

"Agricultural, commercial and industrial activities involving energy services as a direct input to the production of goods or provision of services" (GIZ 2011)

Although stand alone systems such as Solar Home Systems (SHS) increase quality of life and can allow activities such as study to be carried out after dark and also provide enhance means of communication through phone charging, their potential for income generation is limited and as a result, they are generally seen as an intermediate step before more versatile systems arrive (Jacobson 2007; Lemaire 2011).

FIGURE 14: PRICE OF ENERGY SERVICES PROVIDED BY ENERGY FUELS AND TECHNOLOGIES (DFID-IED 2013).



2 Methodology

2.1 Market assessment for LMSWTs

Table 4 list the ideal conditions for LMSWTs and is used as a check list of factors to evaluate during this study in order to assess whether LMSWTs are a viable technology for the regions where the MercyCorps PRIME project is operating (Somali, Afar and Southern Oromia, as identified on Figure 1.

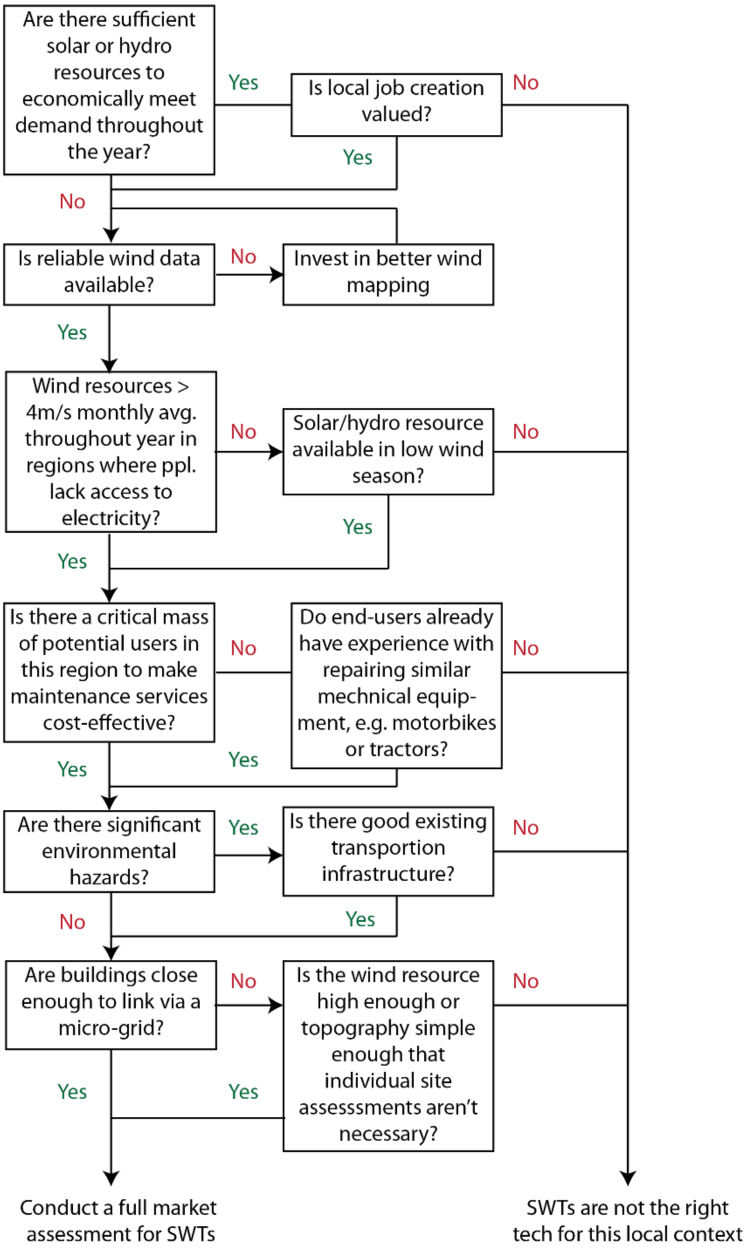
Figure 15 shows the interrelationship between these factors and a thought process that can be used to conduct a quick and easy preliminary evaluation of a new place. Both these tools are based on case study work conducted in Peru, Nicaragua and Scotland (Sumanik-Leary, While, et al. 2013) and the collective experience of the Wind Empowerment association. Marandin et al. (2013) details a similar market assessment for SWTs that was conducted in Nicaragua in 2012/13 and on which the methodology employed in this study is based.

TABLE 4: IDEAL CONDITIONS FOR SWTS - THE MOST CRITICAL FACTORS ARE SHOWN IN BOLD/ITALIC.

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.
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 15: DECISION SUPPORT TREE FOR THE IDENTIFICATION OF VIABLE REGIONS FOR SWTS (SUMANIK-LEARY, WHILE, ET AL. 2013).



Interview data was obtained from the following sources:

Source	Description	Data capture	Reason
Thomas Koepkpe	Local manufacture of solar PV products. Experience in RE in Ethiopia	Informal Interview	Staff costs in Ethiopia
Wubishet Asrat	Head of Adama Institute for Sustainable Energy	Informal Interview	Travel Estimates
V3 Power	DIY Renewable energy cooperative based in the UK, Wind Empowerment members	Company documents	Manufacturing times and cost
Blue Energy	RE Practitioner in Nicaragua	Technical Report	Maintenance Assumptions
Lydetco	Supplier of RE equipment in Ethiopia	Quote	Component Costs

2.2 LCoE/GIS modelling

Eales (2014) conducted an analysis of the Levelised Cost of Energy (LCoE) of LMSWTs and compared it to the most viable alternative power generation technologies for remote communities using data relevant to the Ethiopian context. This study draws heavily from Eales' work, presenting the most relevant parts of the analysis and extending it to the regions of interest to MercyCorps PRIME project: Somali, Oromia and Afar. The LCoE compares the total costs across the lifetime of a project with the total energy it generates across its lifetime. A net present value of costs is calculated by using a discount rate to discount future costs to their present net value. This takes into account that you could earn interest on money over the projects lifetime. The following equation is used in this study to calculate LCoE:

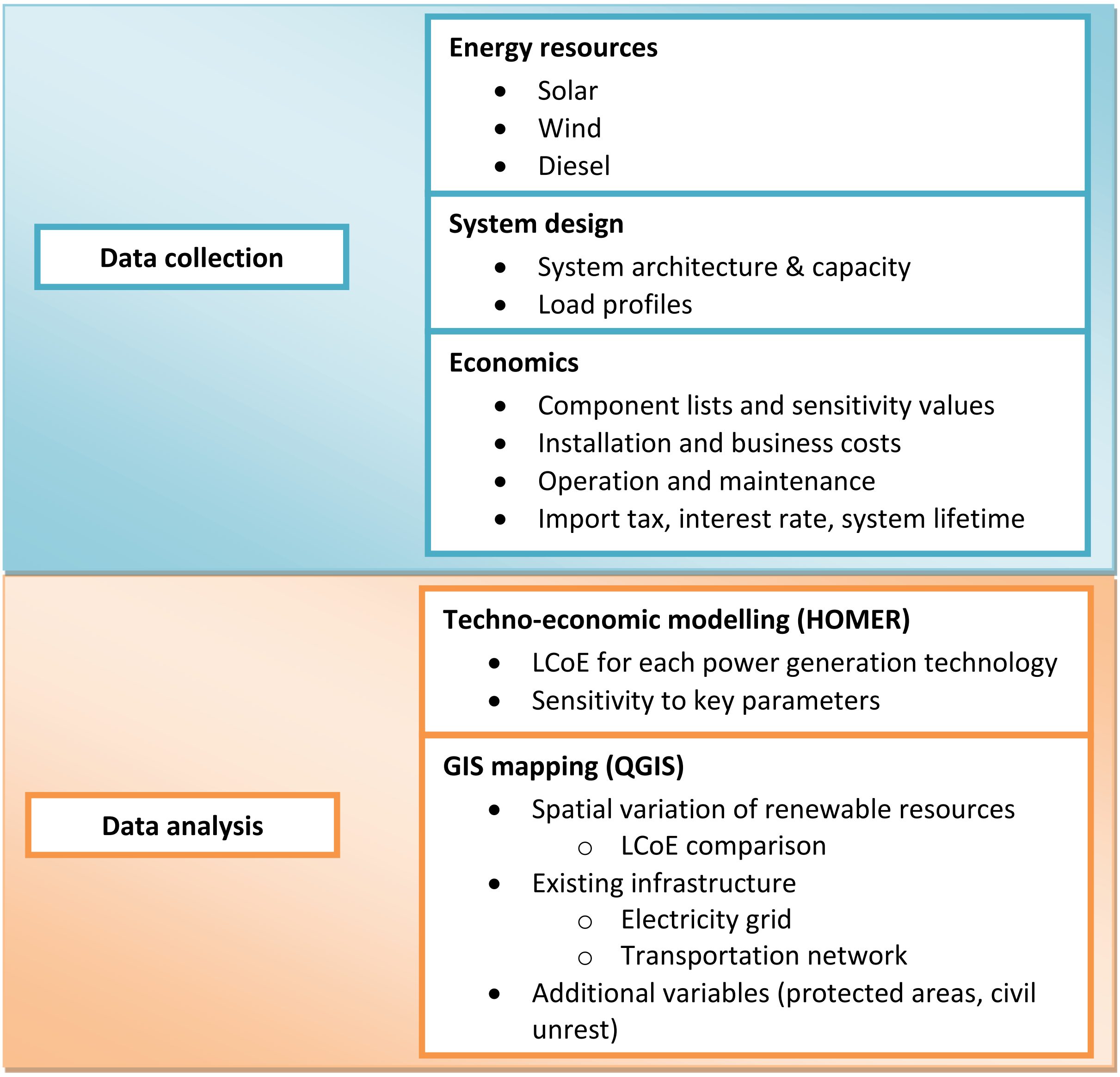
$$LCoE = \frac{\sum_{t=1}^{n} \frac{C_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{D_t}{(1+r)^t}}$$

$\boldsymbol{n}$	System lifetime (years)
$\boldsymbol{C_t}$	Capital costs in year 't' (US$)
$\boldsymbol{M_t}$	Operation and maintenance costs in year 't' (US$)
$\boldsymbol{F_t}$	Fuel expenditures in the year 't' (US$)
$\boldsymbol{D_t}$	Electricity demand in year 't' (kWh)
$\boldsymbol{r}$	Discount rate (set as 10% (ESMAP, 2007))

Figure 16 presents an overview of the techniques employed during this market assessment. Firstly, data on energy resources, technical system specifications, component costs and economics was obtained first hand in Ethiopia during a series of practical wind turbine construction courses carried out by Wind Empowerment in Arba Minch and Jijiga from 2013-2015[2]. This was used as input data for the micro-grid optimisation tool, HOMER, which enabled the construction of a techno-economic model of the wind, solar, diesel and hybrid energy systems of interest. LCoEs relevant to the Ethiopian context were then calculated for each configuration and their sensitivity to varying levels of wind and solar resources was established. This information was then used as an input into Geographical Information System (GIS) software (QGIS) in order to incorporate the spatial variation of wind and solar resources across Ethiopia and identify where LMSWT-based rural electrification might be appropriate. Additional spatial data on existing infrastructure (electricity grid and transportation networks), protected areas and civil unrest was also obtained.

[2] It was not possible to obtain some components at short notice for the practical wind turbine construction courses, so for these items, suitable online sources were used to estimate a local price.

FIGURE 16: METHODOLOGY OVERVIEW.



The Geographical Information System (GIS) software, QGIS, was used to evaluate spatial data in the form of individual layers representing key variables such as the electricity grid, solar/wind resources in order to ascertain which system configurations are most optimal in different areas of Ethiopia. Figure 17 shows an arbitrary grid overlay superimposed onto each layer representing spatially varying data across Ethiopia. This grid was used to discretise the wind and solar resource maps in order to compare system architectures within each unit. As the resolution of the wind and solar maps is higher than the grid system, a visual assessment was made to determine the majority colour within the square. Figure 17 and Figure 18 below show this grid superimposed onto the wind and solar resource maps used in this study. For the wind resource map, an adjusted legend was used in order to take into account an increased hub height of 12m (as opposed to the map's reference height of 10m). The process used to calculate this adjustment is detailed in Appendix 18 Wind speed height corrections.

FIGURE 17: SOLAR RESOURCE (KWH M^{-2} DAY $^{-1}$)WITH GRID OVERLAY AND EXAMPLE SQUARE HIGHLIGHTED. ORIGINAL DATA FROM NREL (2014).

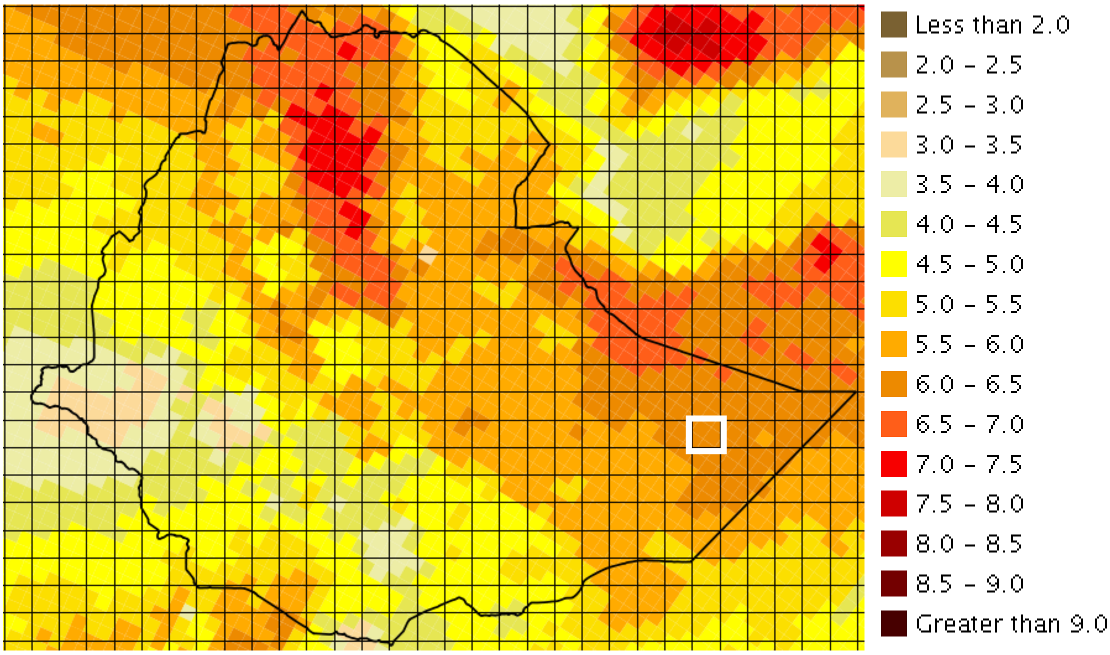
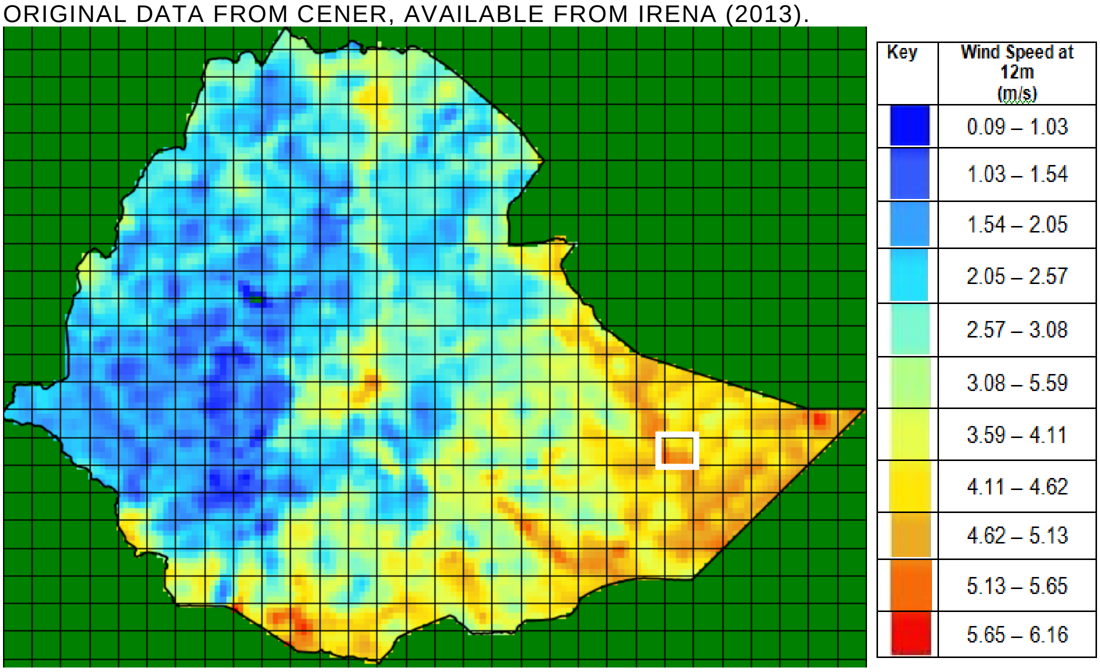


FIGURE 18: WIND RESOURCE WITH GRID OVERLAY AND EXAMPLE SQUARE HIGHLIGHTED. ORIGINAL DATA FROM CENER, AVAILABLE FROM IRENA (2013).



For solar and wind resource parameters, the midpoint of the predominant colour within each square was taken from the ranges presented in the legend. An example square is highlighted in the above figures. For the solar resource map it corresponds to the 6.0 – 6.5 kWh m^{-2} day^{-1} band, so the value of 6.25 was selected. For the wind resource map, the majority of the square is in the 5.13 – 5.65 m/s band so the value of 5.39 m/s was selected. These values for solar and wind resources were then used to look up the optimal system architecture for that region on the output plots from the techno-economic modelling in HOMER. A final graphic was produced indicating the optimal system architectures for each unit on the discretised map of Ethiopia.

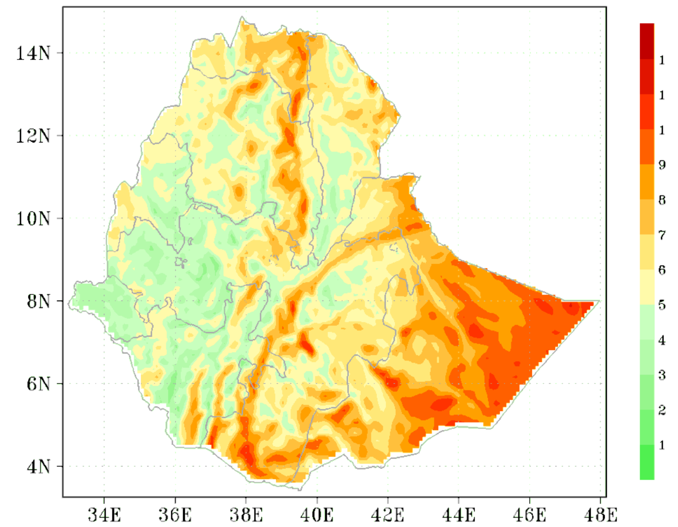
3 Input data

3.1 Energy resources

3.1.1 Wind resource

Although the National Meteorological Service Agency (NMSA) has been logging wind speeds at 39 stations based around Ethiopia, the quality of data is limited, due to the stations being positioned at 2m above ground level and therefore subject to turbulence and shelter effects (Lakew 2013). Figure 19 and Figure 20 show the wind resource maps of Ethiopia considered in this study. The maps are at different heights and use different datasets and algorithms to extrapolate this data across the whole country. Overlaid are the administrative districts of Ethiopia. Further information on each of these wind resource datasets can be found in *Appendix 1 Wind resource datasets* .

FIGURE 19: WIND RESOURCE MAP OF ETHIOPIA (MINISTRY OF WATER AND ENERGY 2013).

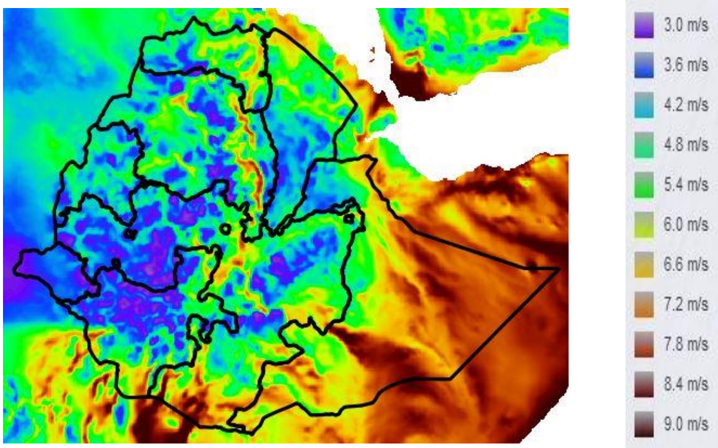


Map created by: **Ministry of Water & Energy**

Height: 50m

Notes: No details given.

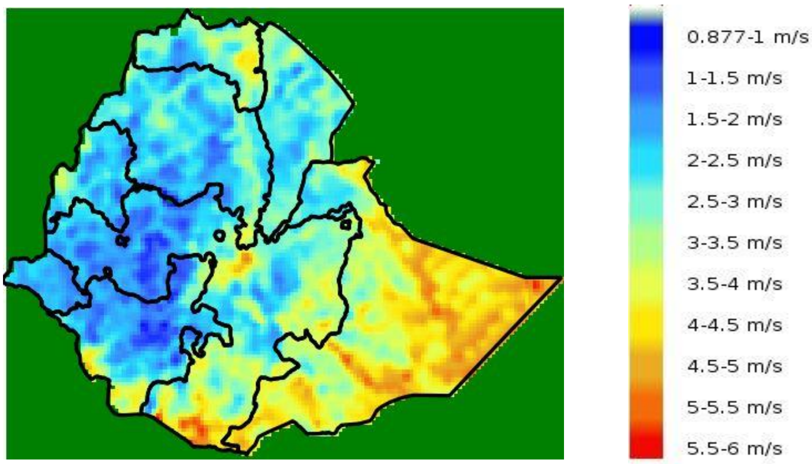
FIGURE 20: WIND RESOURCE MAPS OF ETHIOPIA COSIDERED IN THIS STUDY. SEE IRENA (2014) FOR MORE INFORMATION ON EACH WIND DATASET.



Map created by: **3Tier**

Height: 80m

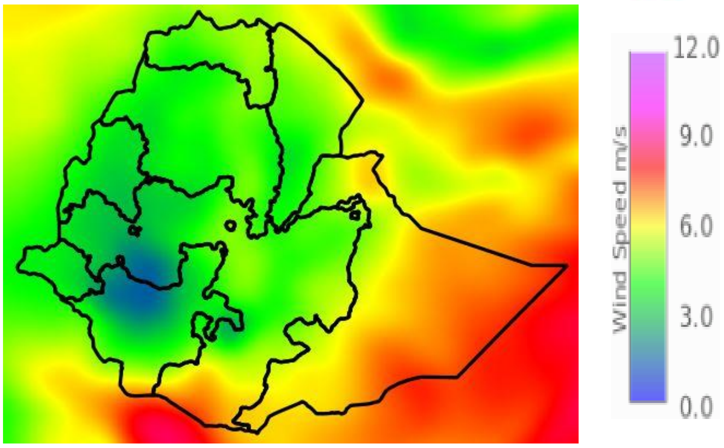
Notes: World Wind map, useful for general overview



Map created by: **CENER**

Height: 10m

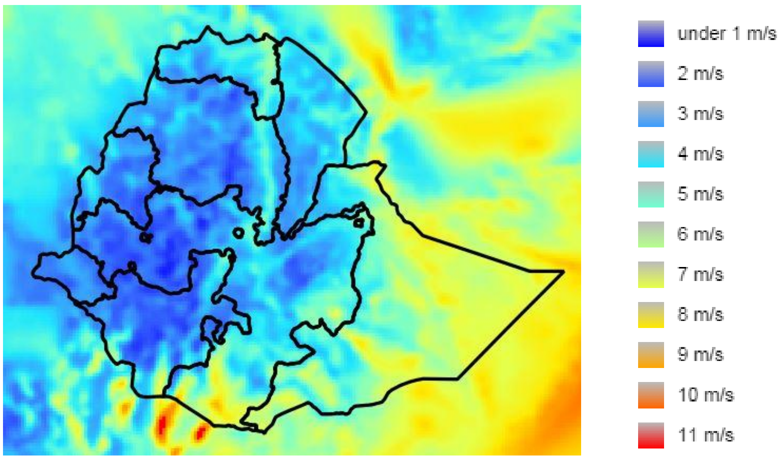
Notes: 10km resolution, 2008 - 2010



Map created by: **MERRA**

Height: 50m

Notes: Mean wind speeds for each hour from 1980 – 2011



Map created by: **Vortex**

Height: 80m

Notes: Created at 9km resolution, useful for prospecting purposes only.

The CENER data set was selected for use in the GIS analysis of wind speeds at a national level because it offered high resolution coverage at a height that most closely resembles SWT hub height, 10m. However, it should be noted that the 3 year measurement period on which it is based is lower than the other options. The 3Tier, Vortex and MERRA atlases are all global datasets based on longer measurement periods, however their resolution was deemed too low for this national study. The wind resource map shown in Figure 19 was presented by the Ethiopian Ministry for Water and Energy, however it was not possible to obtain further details on how this map was produced or to obtain a GIS layer containing this data. As a result, it was not possible to consider it within the study, however it should be noted that it shows very similar trends to the CENER data set that was selected. A Weibull K value of 2 was used in this study to represent the wind speed distribution throughout Ethiopia. Table 5 lists values calculated by Bekele & Palm (2009) for different locations across Ethiopia, validating this assumption.

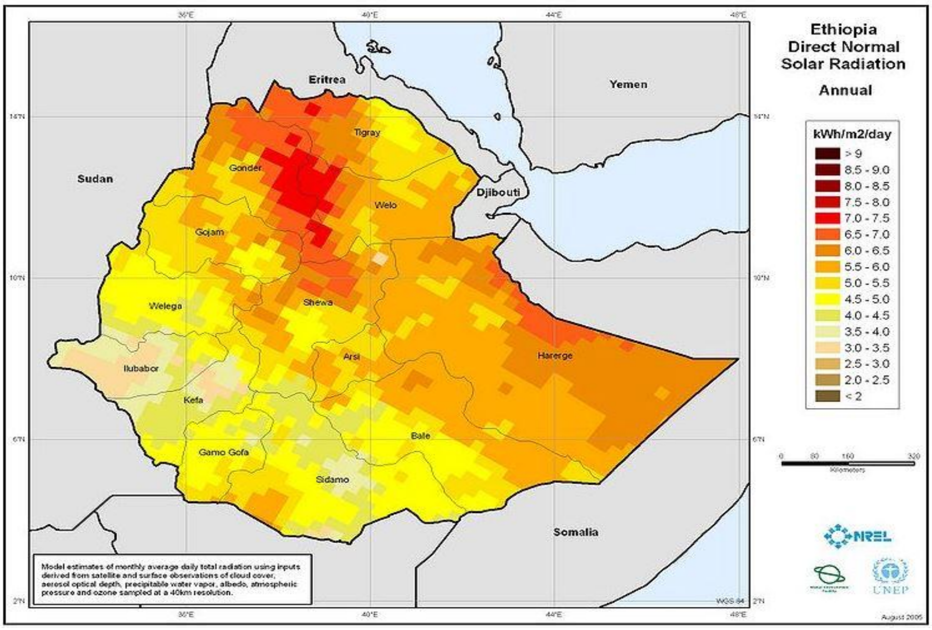
TABLE 5: CALCULATED WEIBULL "K" VALUES (BEKELE & PALM 2009).

Location	Addis Ababa	Mekele	Adama	Debrezeit
Weibull K	2.01	2.01	1.97	2.01

3.1.2 Solar Resource

Ethiopia's solar resource is also extremely varied, due to equatorial proximity as well as tropical cloudy weather systems in the southwest. The resource varies from 3 kWh m^{-2} day^{-1} in the extreme western lowlands to a high of 7 kWh m^{-2} day^{-1} in the Adigrat area, Northern Ethiopia.

FIGURE 21: SOLAR RESOURCE OF ETHIOPIA (NREL 2014)



3.1.3 Solar/wind complementarity

To investigate the effect of different seasonal wind and solar resource distributions on the model, monthly averages for 14 locations identified below in Figure 22 were obtained. The data (normalised to 5m/s or 5 kWh m^{-2} day^{-1}) is presented below in Figure 23 and Figure 24. Comparisons were then made visually for each of the 14 locations with normalised wind and solar resources to assess how complimentary the wind and solar resources are in each location.

FIGURE 22: LOCATIONS SELECTED FOR SEASONAL ANALYSIS.

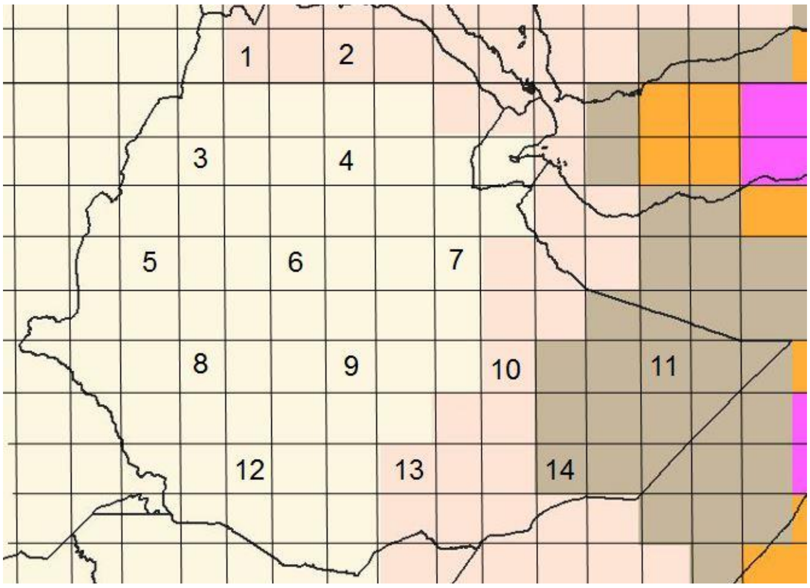


FIGURE 23: SEASONAL WIND PROFILES AT DIFFERENT LOCATIONS IN ETHIOPIA NORMALISED TO 5 M/S AVERAGE.

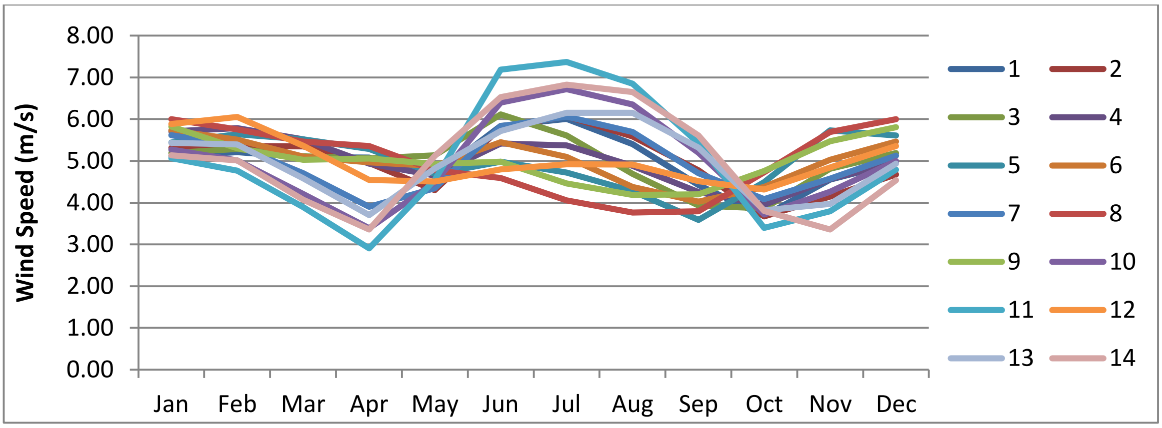
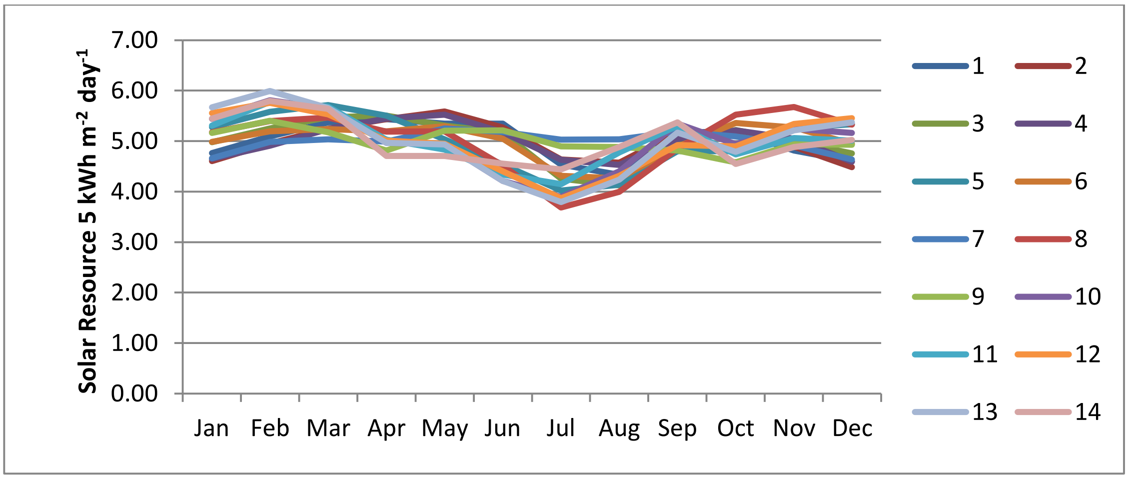


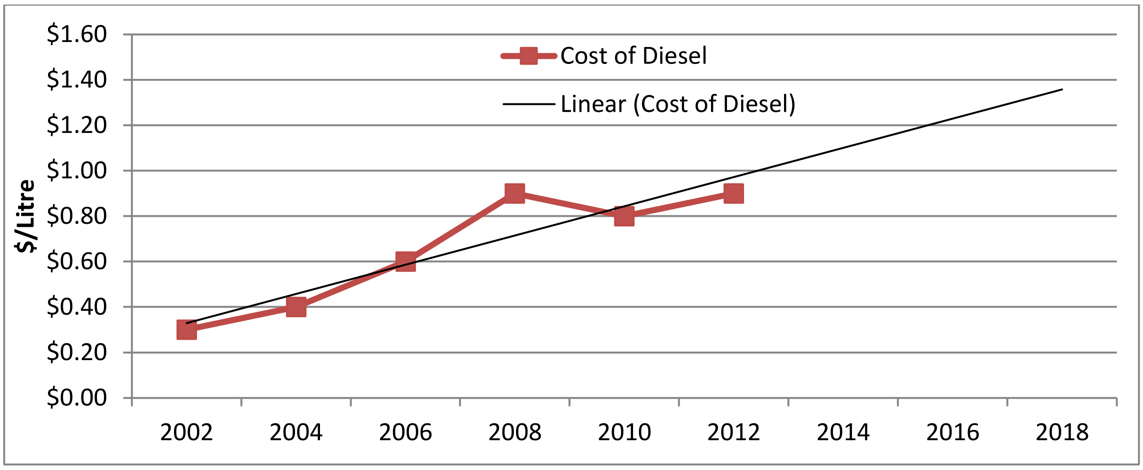
FIGURE 24: SEASONAL SOLAR PROFILES AT DIFFERENT LOCATIONS IN ETHIOPIA NORMALISED TO 5 KWH M^{-2} DAY^{-1} AVERAGE.



3.1.4 Diesel

Diesel prices in Ethiopia have been rising steadily over the past years due to international price increases, related to limited national fossil fuel supplies and dependency on imports. Up to 2008 the government was subsidising petroleum fuel but since that date has set domestic prices higher than import taxes (Kojima 2013). EEPCO (Ethiopian Electric Power Corporation 2014) has provided diesel generators to some remote communities in Ethiopia without access to the national grid, however the increasing cost of diesel has made these connections expensive to the consumer and these costs are expected to rise. Figure 25 shows 10 years of historical diesel price data plotted to obtain a linear trend line, which was then forecast 6 years into the future to give a predicted cost of diesel in 2018. $1.00 per litre was used as the current value and an upper value of $1.35 per litre for 2018 was used as the higher sensitivity value for the HOMER analysis.

FIGURE 25: HISTORICAL AND PREDICTED COST OF DIESEL IN ETHIOPIA (WORLD BANK, 2014).



3.2 System configurations

Currently, off grid electrical consumers in Ethiopia are supplied by solar photovoltaic (PV) modules, diesel generators or micro hydro plants, with no documented small wind projects as of yet. An assessment of hydro power for off-grid electrification is not within the scope of this study, as it is very site specific and therefore, there will always be some communities (even in rainy, mountainous regions) that don’t have a suitable water course nearby and must therefore consider alternatives. As a result, this study directly compares wind, solar and diesel generators, as well as hybrid systems (see Figure 26). A proposed schematic for a hybrid system incorporating wind, solar PV and a diesel generator is presented in Appendix 7.

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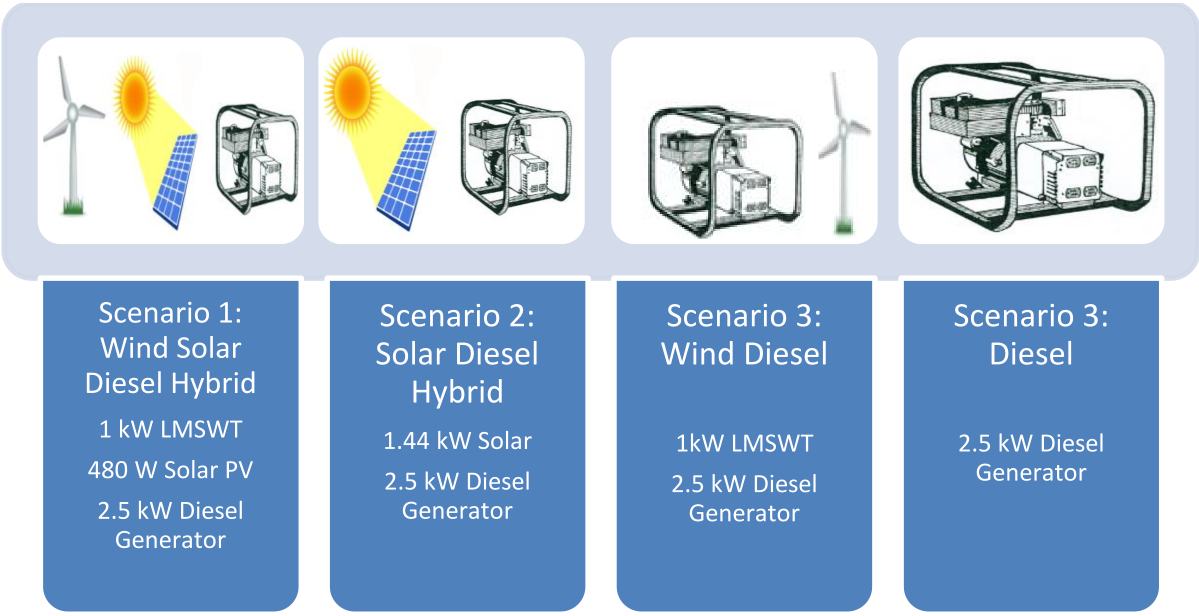
FIGURE 26: SYSTEM CONFIGURATIONS CONSIDERED IN THIS STUDY.



3.3 *Economics*

A summary of economic parameters relevant to the study are presented below. For all calculations in the following report, $ represents US Dollar (USD).

TABLE 6: GENERAL ECONOMIC PARAMETERS REQUIRED FOR NET PRESENT COST CALCULATIONS IN HOMER.

Parameter	Description	Value	Data source
Annual Real Interest Rate	The discount applied to future costs in order to calculate the net present cost.	10 %	(ESMAP, 2010)
Project Lifetime	The number of years over which the net present cost of the project is calculated.	20 Years	(Wind Empowerment, 2014)
Import Tax	Tax applied to materials brought into the country for the pilot projects	10%	(Wind Empowerment, 2014)
Shipping Costs	Not included, as imported items were brought in by pilot project practitioners	N/A	N/A
Exchange Rate	ETB – USD currency exchange rate	0.052	www.xe.com (21/03/14)

3.3.1 LMSWT

3.3.2 Turbine sub-component costs

A detailed cost breakdown of components and consumables required to manufacture a 1kW LMSWT in Ethiopia using components sourced from local suppliers in Mercato, Addis Ababa can be found in *Appendix 2 Wind Turbine Component Prices* . Electricity costs for turbine manufacture, including an energy audit of power tools used combined with EEPCO's price tariff are shown in *Appendix 3 Electricity Costs of Manufacturing 1 LMSWT*. Electricity costs in Ethiopia are low due to government subsidies and the high proportion of hydropower in the national generation mix, and as a result are a negligible proportion of manufacturing costs. Figure 8 shows an exploded CAD diagram of a Piggott turbine, clearly labelling the major sub-components. Figure 27 presents a summary of these costs, showing that the alternator makes up the majority of the $892. Table 7 shows the results of a sensitivity analysis, which predicted $1,441 as the upper limit for material costs.

FIGURE 27: SUMMARY OF LMSWT COMPONENT COSTS.

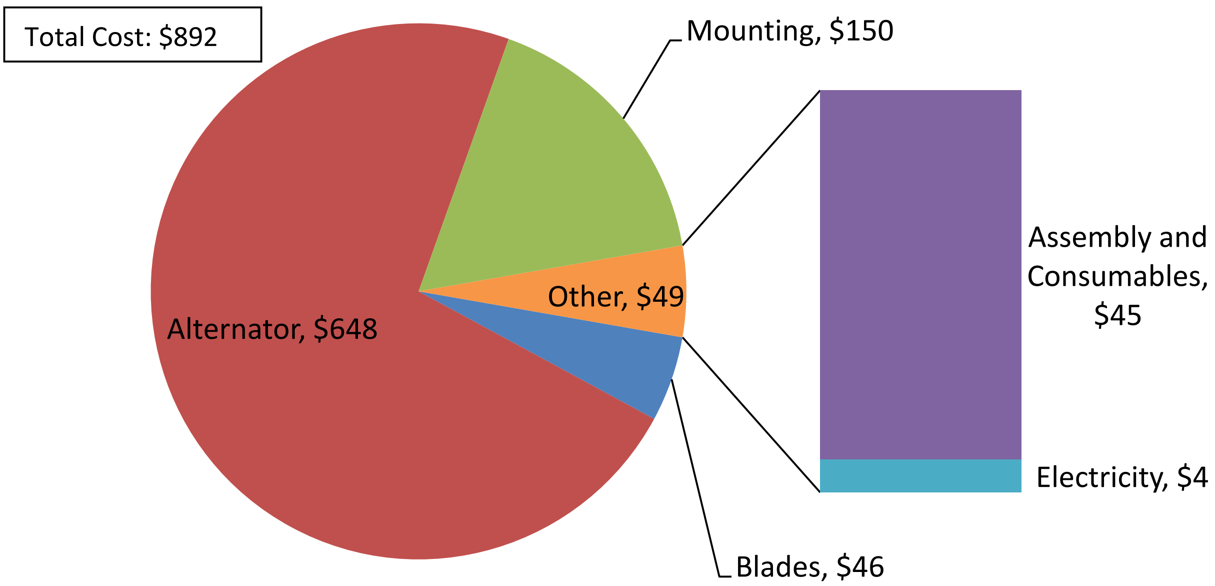


TABLE 7: SUMMARY SENSITIVITY VALUES FOR COMPONENT PRICE INCREASES.

Component	Sensitivity range	New Cost
Magnets	Increase to 250% of cost (Koepke, 2013)	$827
Other materials	General price increases 10%	$613
	TOTAL	$1,441

3.3.3 Tower

A 12m tower consisting of steel pipe sections and wire rope guys (see Figure 28 has been proposed with a gin pole to facilitate erection and anchors comprising cement and steel re-bar. The height of the tower has been chosen due to the common availability of 6m steel pipes in Ethiopia. A full cost breakdown of component materials required for such a tower is shown in

Appendix 4 Tower Costs . A sensitivity analysis was conducted for the tower to account for a taller tower (18m), which may be needed where the local terrain has obstacles (e.g. trees, hills or buildings) causing turbulence. A detailed calculation for the increased costs of a higher tower is shown in

Appendix 5 . Table 2 shows a summary of the 12m and 18m tower costs.

FIGURE 28: 3D DRAWING OF LMSWT AND 12M TOWER (CHEVALIER 2011).

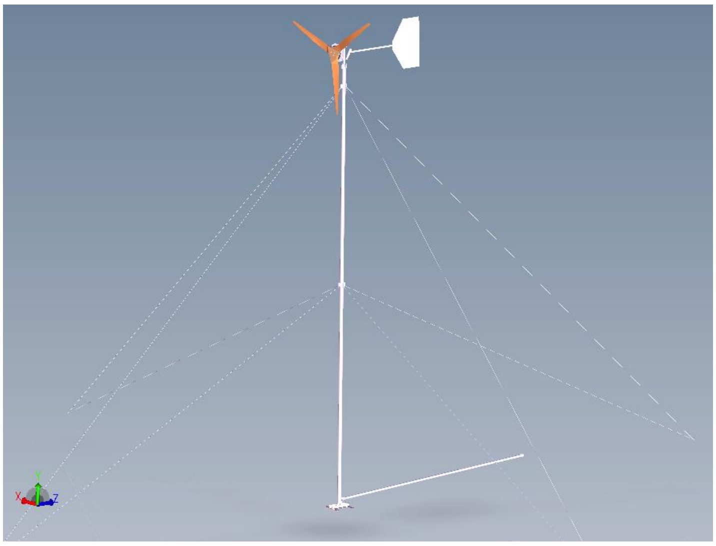


TABLE 8: SUMMARY OF COSTS FOR 12M AND 18M TOWER.

Height of Tower	Cost of Tower
12m	$979
18m	$1,211

3.3.4 Electrical System

Figure 7 shows a typical electrical system for an LMSWT. Prices for electrical components were found during primary field research in-country from local electrical contractors based in Addis Ababa, a list of which is outlined in *Appendix 6* . Currently charge control circuits are not available locally, so the price from a UK supplier was modelled bv adding an appropriate shipping fee and import tax.

Electrical system costs are summarised below in Table 9 and a schematic diagram and detailed breakdown of electrical system components (excluding batteries and inverter) can be found in Appendix 7. A limitation of HOMER when modelling hybrid systems is that the charge controller is used for both the PV and wind system, but can only be included in one set of economic parameters. In this instance the cost of the charge controller has been split equally between the LMSWT and PV parameters. Optional devices, such as a lightning protection unit and logging device were not included in the electrical system budget. The inclusion of such components is estimated by Wind Empowerment members to increase the cost by around $300. Sensitivity values have been set to take into account an increase of 10% in component prices due to inflation and global price increases.

TABLE 9: SUMMARY OF PRICES FOR ELECTRICAL COMPONENTS

Identifier	Description	Cost
Normal cost	Electrical system components	$376
High end sensitivity	10% increase in components	$414

3.3.5 Manufacturing and Installation Costs

BlueEnergy, an experienced member of Wind Empowerment, estimated the labour costs for LMSWTs by considering the number of person-days required for manufacture and installation of a 1kW Piggott turbine (BlueEnergy, 2009). Daily costs for labour were assumed to be $13 (250 ETB), using the monthly salary of 6000 Birr for an aeroplane technician (Salary Explorer, 2014). The total labour costs for manufacturing and installation are summarised in Table 10, with a breakdown shown below in Figure 29. A more detailed breakdown can be found in *Appendix 8 Human Resource Costs* . Additional travel time and transport costs for installation technicians were modelled at 3 levels, representing different levels of accessibility. Identical daily wage costs from the analysis above were used and transportation costs were modelled at $62 (1200ETB) for up to a 4 hour round trip to include driver and fuel (Asrat, 2014). It is assumed 2 paid technicians would travel to site and support for the installation is given by the community free of charge.

FIGURE 29: HUMAN RESOURCE COSTS FOR MANUFACTURING AND INSTALLATION OF A 1KW LMSWT (BLUEENERGY, 2009; (KOEPKE 2013).

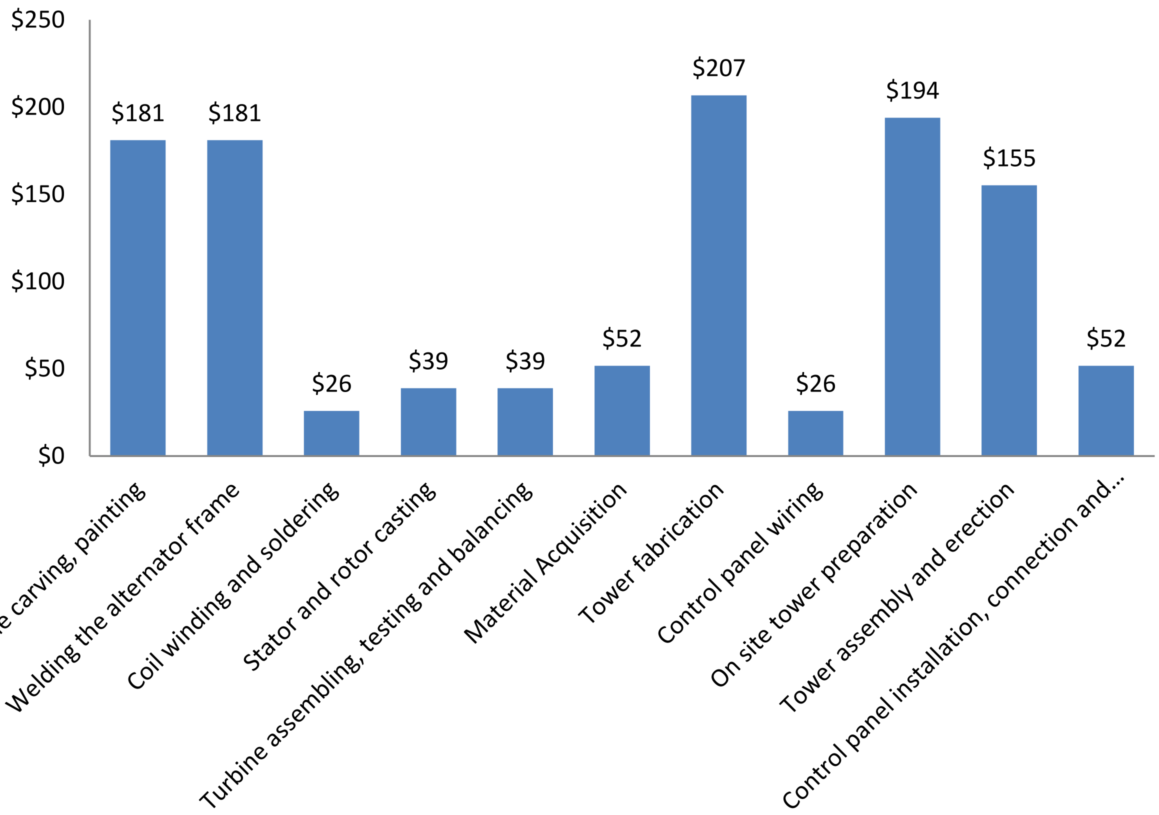


TABLE 10: TRANSPORT COSTS ASSOCIATED WITH LMSWT INSTALLATION (ASRAT, 2014).

Distance to installation site	Round Trip Travel Time	Labour Costs for travel	Transport Costs	Manufacture and Installation Costs	Total Labour and Transport Costs per Turbine
Low	0.5 days	$13	$62	$1150	$1225
Medium	1 days	$26	$124	$1150	$1300
High	2 days	$52	$248	$1150	$1450

Business costs were calculated to include rent on property, tool purchase and upkeep, interest on business loans and reduction in cost through efficiency gains from in specialism and batch production. Estimates for each parameter were based upon interviews with Ethiopian business and entrepreneurial experts (Lakew, 2014; Asrat, 2014), supplemented by the author's 10 years of experience running a similar organisation in the UK, V3 Power. An outline of the process is shown in *Appendix 9 Business Plan*, a list of tools required for starting a LMSWT business are shown in *Appendix 11 Start-up costs for tools* , and assumptions used for the calculations are shown below:

TABLE 11: BUSINESS COSTS FOR A LMSWT ORGANISATION IN ETHIOPIA.

Cost/parameter	Description	Value
Rent	Small workshop premises outside of Addis Ababa	$517/month
Staff	1 x Manager 1 x Junior Administrator 1 x General Labourer	$362/month $129/month $77/month
Business Loans	Repayment on workshops tools (Full list of tools in Appendix 4.11) 10 year loan period, 9% interest	$1533/year
Number of turbines built per year	Assumed to be 10 – one built and installed per month with 2 months holiday/research and development	10/year
Profit Margin	20% Assumed high due to risk of business in Ethiopia	$291/turbine
VAT	15% in Ethiopia (REF)	$218/turbine

BlueEnergy (2009) calculated the difference in the cost of components for a turbine if purchased individually ($4191) and if purchased in bulk ($2586), giving a saving from batch production of 40% (see Table 12). A similar saving was estimated for the labour costs and the resulting high and low sensitivity values are presented in Table 13.

TABLE 12: ESTIMATED SAVINGS FROM BATCH PRODUCTION.

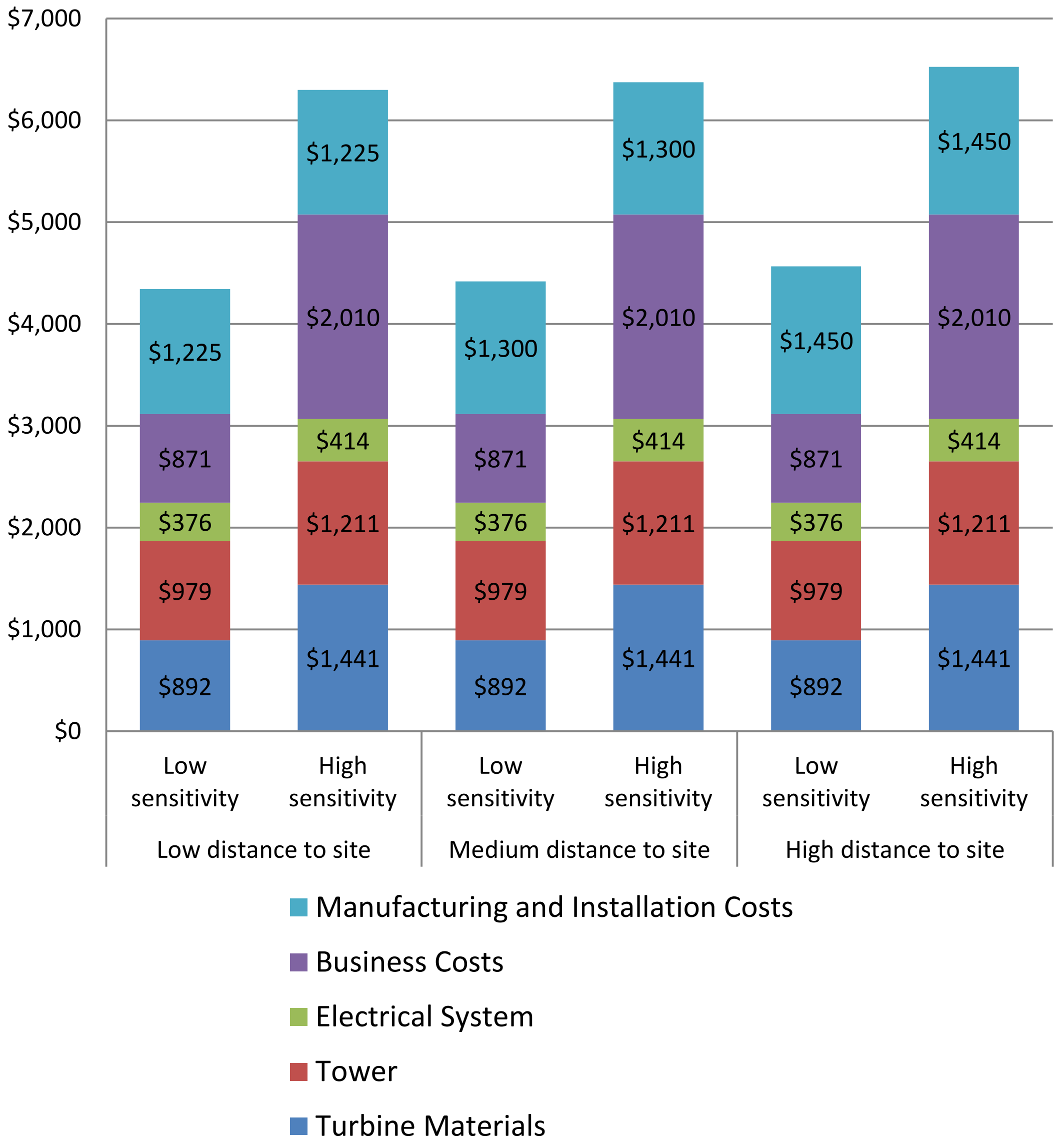
Type of Saving	Description	Percentage of original costs saved
Material Costs	Savings through bulk purchasing	40%
Labour Costs	Savings in time through specialisation, jig design and implementation, beginning mass production	20%

TABLE 13: SUMMARY OF BUSINESS COSTS.

Sensitivity Level	Assumption	Business Costs
High	Assume no savings are made through batch production, early stage of business development	$2010
Low	Assume maximum savings are made through batch production, business is established	$871

A summary of LMSWT costs s presented below, and fixed costs are outlined in Appendix 10.Before further implementation of LMSWT in Ethiopia, a full business plan must be drawn up to include detailed analysis of associated business costs for an organisation manufacturing SWTs locally.

FIGURE 30: SUMMARY OF LMSWT COSTS.



3.3.6 LMSWT Operation and Maintenance (O&M)

LMSWT require significantly more maintenance than solar PV due to the fact that they contain moving parts that are exposed to the elements. Sumanik-Leary et al. (2013) classify O&M costs for LMSWTs into preventative (regular check-ups) and corrective (fixing something when it breaks). A schedule outlining the key tasks that need to be carried out during a preventive maintenance check-up can be found in Appendix 12. In this study, it is assumed that 2 technicians would visit each installation site twice per year to perform both preventative and corrective maintenance.

Table 14 estimates the annual maintenance costs for LMSWT components, combining Ethiopian component costs with component lifetime estimates BlueEnergy (2009), who compiled a detailed plan of maintenance taking into consideration lifetime of specific components that would need replacing before the end of the project lifetime (20 years). Not included in the list are battery and inverter lifetimes as these are treated separately in HOMER.

TABLE 14: ANNUALISED COMPONENT REPLACEMENT COSTS.

Description	Lifetime (years)	Frequency per year	Unit Cost	Annual Cost
Diversion controller (Tristar 45)	4	0.25	$100	$25
Bearing	10	0.1	$47	$5
Generator	20	0.05	$648	$32
Break switch	2	0.5	$10	$5
Tower guy cables	10	0.1	$200	$20
Fuses	5	0.2	$40	$8
Consumables (resin, grease, paint, wires, nuts, electric tape, brushes, sand paper)	1	1	$30	$30
TOTAL				$125

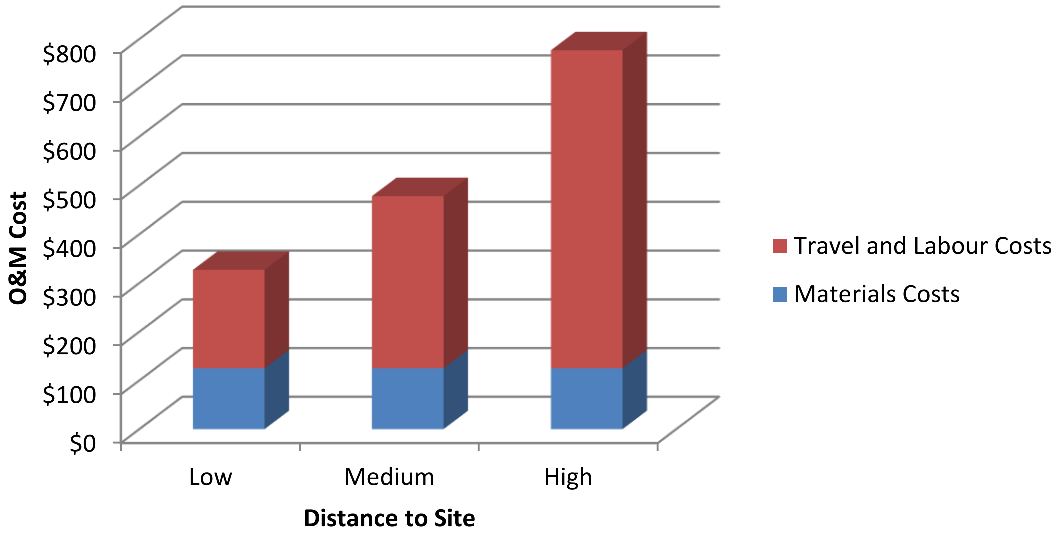
The second element to O&M costs is the travel and labour required to perform the O&M. This is dependent on the distance a community is from the site of turbine manufacture and has been modelled at 3 levels, outlined in below. It is assumed 2 skilled technicians are deployed with a wage of $13/day (250ETB) and transport costs as $62 (1200ETB) for up to a 4 hour round trip to include driver and fuel (Asrat, 2014). O&M costs are summarised in

Figure 31, and tabulated in *Appendix 13 O&M Costs for different levels of site access*.

TABLE 15: TRAVEL AND LABOUR COSTS FOR O&M.

	Round Trip Travel Time	Time on site	Labour Costs	Transport Costs	Frequency per year	Total Annual Costs
Low	0.5 days	1 day	$39	$62	2	$202
Medium	1 days	1 day	$52	$124	2	$352
High	2 days	1 day	$78	$248	2	$652

FIGURE 31: O&M COSTS FOR DIFFERENT DISTANCES TO SITE.



O&M costs are an important factor in the economic appraisal of a wind power system, and are dependent on the model of operation of the company that is building and maintaining the turbine. Although not the method presented in this study, one option is to train local communities in the O&M duties of the turbine, which reduces travel costs but increases the likelihood of something going wrong due to the reduced skill and knowledge base of the community. Another option is to employ local engineers to look after the turbine, and the costs for this model of O&M will mostly be determined by the distances the team of technicians needs to travel.

3.3.7 Solar PV

An overview of the major PV suppliers in Ethiopia can be found in Appendix 15 PV Suppliers. During the primary field work in Ethiopia, potential PV suppliers were assessed, and Lydetco were identified as a trusted local supplier, offering quality equipment at reasonable prices (Koepke 2013). Modules were selected based on quality, price and availability and the ET 120Wp was found to be suitable. A basic specification is shown in Table 16 and a full datasheet is provided in Appendix 14 PV Module specifications. It should be noted that global PV price trends have been decreasing significantly in recent years and are predicted to continue declining. IRENA (2012) predicted that PV prices in 2018 would have fallen by a third, meaning that a cost multiplier on 0.66 was used for the PV capital cost.

TABLE 16: SUMMARY OF PV MODULE INFORMATION (PHOTOVOLTAIC4ALL, 2014)

Name of Panels	ET-P636120
Peak Power	120W
Cell Type	Polycrystalline
Lifetime	20 years
Supplier	Lydetco PLC, Addis Ababa
Cost per Unit	$356

3.3.8 *Battery bank*

Based price and availability, RA12-260D deep cycle batteries were selected, available for purchase locally in Addis Ababa, Ethiopia. A string size of 4 batteries was selected and sensitivity set as 1, 2 or 3 strings in HOMER. Full battery specifications can be found in *Appendix 16 Battery Specifications*. Table 17 shows the upfront and O&M costs for this model that were obtained from a quote from local supplier of renewable energy equipment, Lydecto (2014).

TABLE 17: BATTERY COSTS (LYDETCO, 2014).

Total Cost (4 Batteries)	$2091
Annual O&M	$100

3.3.9 *Inverter*

A standard off grid inverter has been chosen to provide AC electricity from the 48V DC bus. Details of the inverter used are shown below.

TABLE 18: INVERTER PARAMETERS (GIRMA, 2013)

Size	2.5 kW
Capital	$700/kW
Replacement	$700/kW
O&M	70$/year
Lifetime	Lifetime 10 year
Efficiency	Efficiency 90%

3.3.10 *Diesel generator*

Figure 32 shows that unlike renewable energy systems, the majority of the costs related to diesel generators can be attributed to fuel. Table 19 lists the costs per kW for a diesel generator obtained from a HOMER study completed by Giday (2013).

FIGURE 32: TYPICAL LCOE COSTS FOR A DIESEL GENERATOR (BREYER ET AL. 2009).

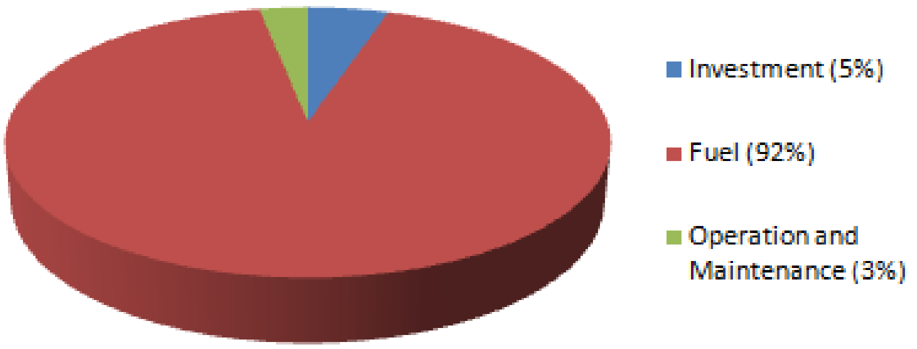


TABLE 19: DIESEL GENERATOR PARAMETERS USED IN HOMER (GIDAY 2013).

Capital cost	600$/kW
Replacement cost	500$/kW
O&M cost	0.075$/hour
Lifetime	15000hr

3.4 Load Profiles

Lakew (2013) carried out household surveys in remote communities supplied by diesel mini-grids in the Werder district in the Somali region (eastern Ethiopia). Lakew used this data to calculate a generic PUE load profile for a commercial centre, which is shown in Table 20. Whilst livelihoods vary greatly across Ethiopia, this load profile is typical for the region of highest wind potential – the Somali region. A similar study was conducted by Giday (2013) in the south of Ethiopia and Table 21 shows that the results of this analysis were very similar to Lakew's. HOMER requires hourly load profiles, and daily loads were converted to hourly loads using the assumptions detailed in Table 22. Figure 33 shows the resulting weekday load profile, which is summarised in Table 23. Figure 34 and Figure 35 show the random variation included in the HOMER model in order to mimic the unpredictability inherent in real systems.

TABLE 20: ELECTRICAL DEMAND FOR A GIVEN COMMERCIAL CENTRE (PER VILLAGE) (LAKEW 2013).

Load Type	Equipment Rating (W)	Number of Equipment	Running Time (Hrs/day)	Daily energy (kWh)
Lighting (CFL)	22	2	4	0.18
Lighting Ext. (CFL)	22	1	12	0.26
Fan (for air conditioning)	32	1	4	0.13
Refrigerator	600	1	8	4.80
Razor machine/barber	20	2	8	0.32
Beauty shop appliance	340	2	8	5.44
TOTAL				11.13

TABLE 21: ELECTRICAL DEMAND FOR A GIVEN COMMERCIAL CENTRE (PER VILLAGE) (GIRMA 2013)

Appliance type	Rating (W)	No. appliances	Run time	Daily Energy (kWh)
CFL lamp	15	15	8	1.8
Tape recorder	75	5	8	3
Television	250	4	6	6
Razor	20	8	12	1.92
Others	250	1	6	1.5
TOTAL				**14.2**
Grinding mill[3]	12000	1	14	168

[3] The grinding mill was not included in this total, as the peak power requirement is far above the capacity of the systems under analysis in this study.

TABLE 22: ASSUMPTIONS FOR DAILY LOAD PROFILE GENERATION.

Load	Assumption
Exterior Lights	On from 18.00 – 06.00
Interior Lights	On from 18.00 – 22.00
Fan	11.00 – 15.00
Fridge	Comes on for an hour every 3rd hour
Beauty Shop and Barbers	09.00 – 17.00

FIGURE 33: WEEKDAY DAILY LOAD PROFILE.

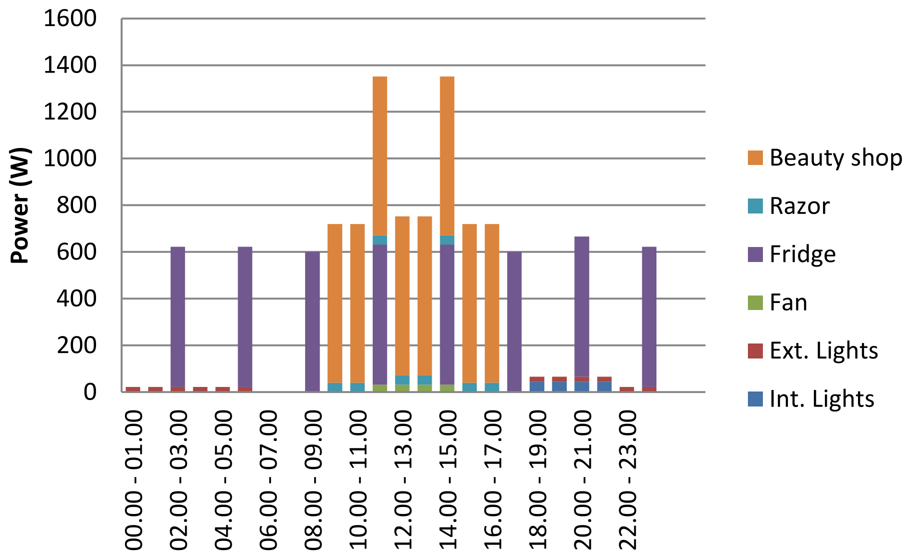


FIGURE 34: LOAD PROFILE FOR A WEEK IN JANUARY WITH ADDED RANDOM VARIABILITY.

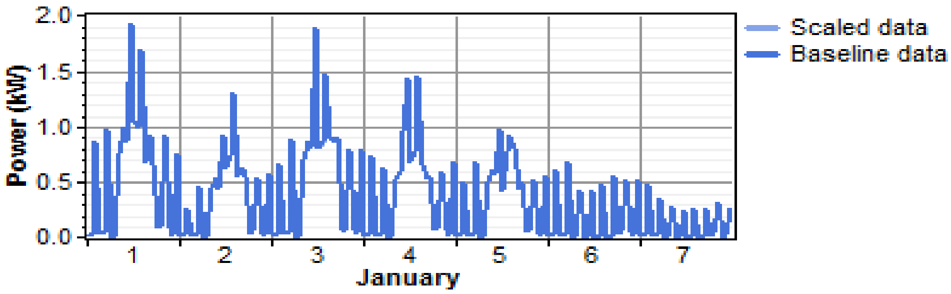


FIGURE 35: SEASONAL PROFILE OF MODELLED LOADS.

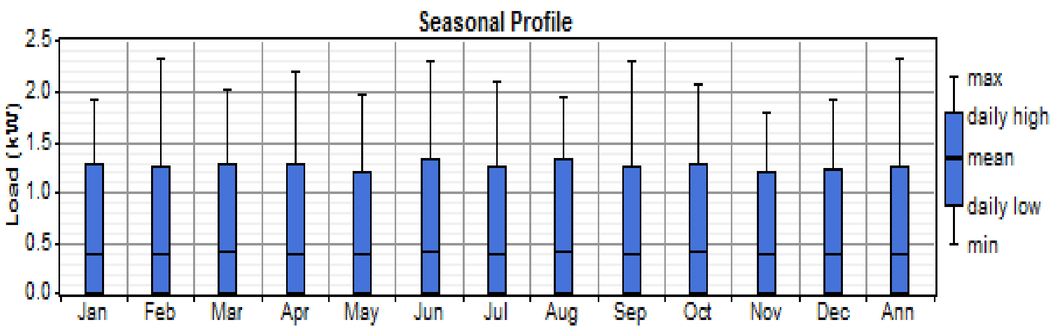


TABLE 23: LOAD PROFILE SUMMARY.

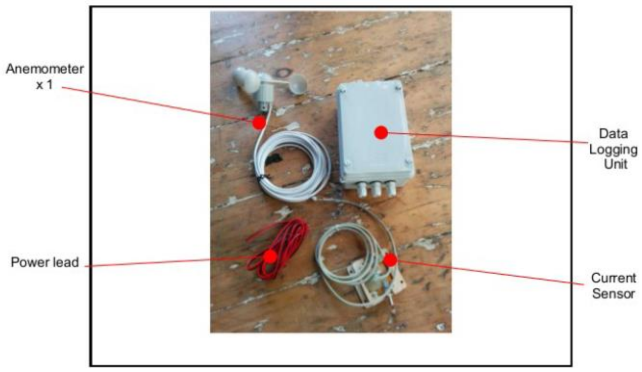
	Baseline
Average (kWh/d)	9.34
Average (kW)	0.389
Peak (kW)	2.32
Load factor	0.168

3.5 Field Data

3.5.1 Data Logging of Wind speed and Load Profiles

3.5.1.2 Data logging units and sensors

The data loggers used in the measurement campaign were provided Re-innovation UK and are based on open source hardware data logger designs. These data loggers were chosen due to their low cost and their open design, in order to encourage the local manufacturing of these units in future projects. Two types of logger units were used, one for wind resource measurements and one for both wind resource and electrical power measurements. The wind resource units logged data from a wind speed sensor (anemometer) placed on a tower at the hub height of a small wind turbine, typically 10m from the ground. The wind resource and electrical power units, along with receiving data from an anemometer, measured the battery voltage and the inverter current using appropriate voltage and current sensors. From these readings the average wind speed of the location and the wind distribution were calculated, along with the average power and energy provided by the system to the users. All data was recorded as a one minute average on a SD card which could be removed from the unit and sent to the team of engineers for further analysis.



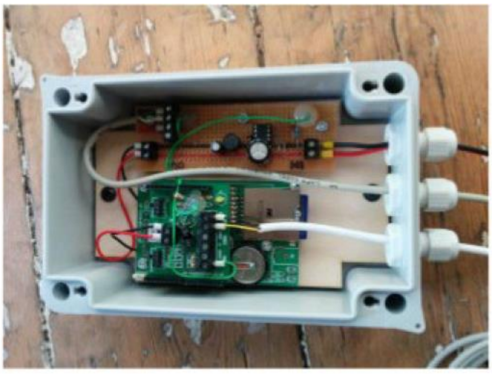


FIGURE 36: OPEN SOURCE DATA LOGGER UNIT AND SENSORS

The anemometers used with the data logger units were wind speed sensors from Maplin UK for use in wireless weather stations. The specific anemometers were chosen due to their low cost which makes them suitable for short terms measurements in the range of six months to one year. In order increase the accuracy of the wind resource measurement campaign, a Maplin anemometer was calibrated in the wind tunnel of the National Technical University of Athens by the Rural Electrification Research Group, one of Wind Empowerment’s member organisations. With the calibration graph shown in Figure 37 the anemometer readings could be accurately translated to wind speed values using the relationship Wind speed = 0.63 x Counts + 0.19.

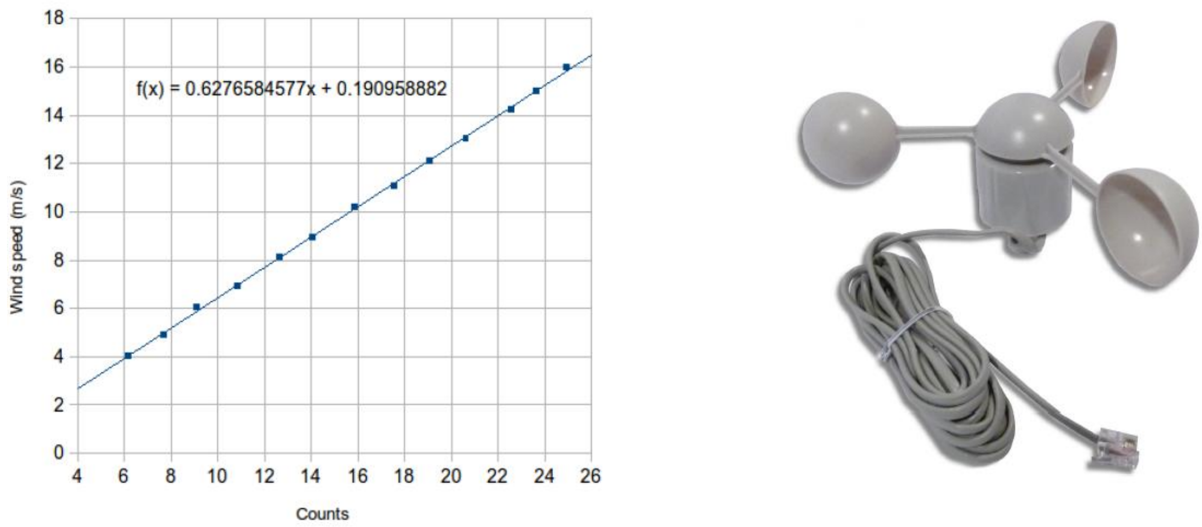


FIGURE 37: CALIBRATION GRAPH OF A MAPLIN ANEMOMETER

3.5.1.2 Wind resource assessment and energy monitoring in Hadew

The anemometer was installed at a height of 10m on a boom attached to the wind turbine tower. The battery voltage of the 24VDC battery bank was monitored along with the current from the battery bank to the inverter, which was then converted to AC current and fed to the loads of the shop. Wind speed, current and voltage data were logged for eight months starting in February 2015 until September 2015. The wind speed frequency distribution can be seen in Figure 38 (a), which corresponds to an average wind speed of 3.12m/s. The average wind speeds per month are presented in Figure 38 (b) where a seasonal variation in wind speeds can be seen between winter and summer months.

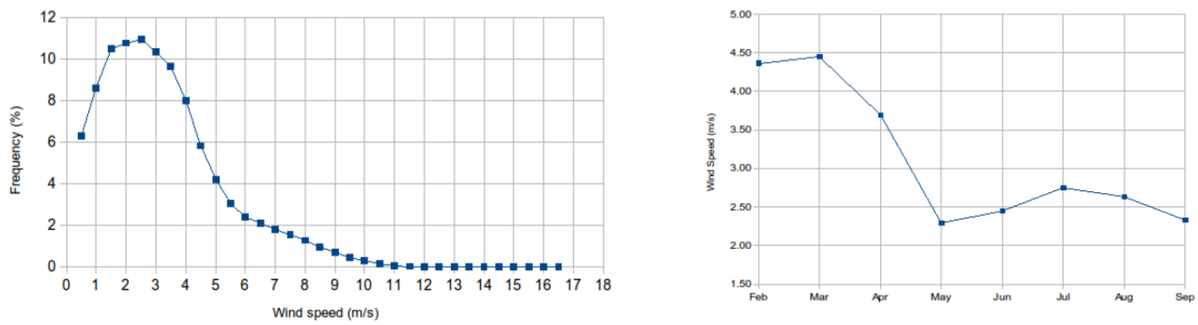


FIGURE 38: WIND SPEED FREQUENCY DISTRIBUTION AND (B) MEAN WIND SPEED PER MONTH IN HADEW

Data regarding the energy and power consumption of the shop can be found in Table 1. The system has been designed to supply a minimum consumption of 1.4kWh per day during all seasons of the year. In Figure 39 (a), the daily energy production from the installed 300W of solar panels can be seen. A seasonal variation in the solar resource is observed which coincides with the seasonal variation in mean wind speed as discussed earlier. The energy consumption of the shop increases gradually from 0.62kWh/day in February to 1kWh/day in May and then to 1.2kWh in August. This can be justified by the increased sales of the shop after the first few months of operation of the system. In addition the shopkeeper bought a fridge which started operating in June, in order to provide refrigeration services such as selling ice, cold refreshments etc. The increase in the daily energy consumption from June onwards can be seen in Table 24 and justifies the use of a fridge.

Month	Energy per day (kWh)	Avg Power per day (W)	Energy per month (kWh)	Avg Battery voltage (V)
Feb	0.619	27	19	26.26
Mar	0.753	31	23	26.15
Apr	0.706	50	22	26.01
May	0.670	28	21	25.32
Jun	1.001	43	31	24.71
Jul	1.303	55	40	24.35
Aug	1.207	50	37	24.51
Sep	1.160	50	36	24.04

TABLE 24: ENERGY AND POWER CONSUMPTION OF THE SHOP IN HADEW PER DAY AND PER MONTH

Both the increase in energy consumption and the decrease of the wind and solar resource for the months between May and September has reduced the average battery voltage during the daily charging and discharging cycles of the day, Figure 39 (b). This type of deep discharge will reduce the life time of the battery bank, but it is within the recommended operation of the battery bank and has already been taken into account in the design of the system. During the month of September for example, the battery bank cycled from 25V at noon, which corresponds to a 80% state of charge, to 24V during night time which corresponds to a 50% state of charge. In conclusion, the shopkeeper has been using the full potential of the hybrid renewable energy system in order to increase sales and expand the business.

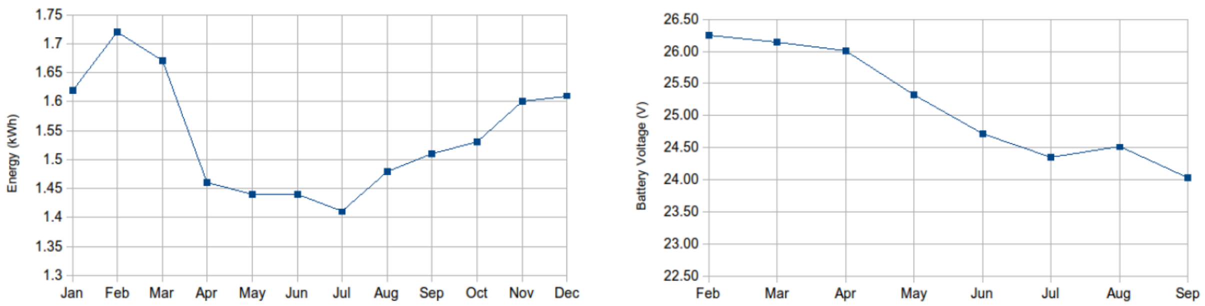


FIGURE 39: DAILY ENERGY PRODUCTION FROM A 300W SOLAR GENERATOR AND (B) AVERAGE BATTERY VOLTAGE

The loads of a typical day in September can be seen in Figure 40. The shop opens at 8am and starts offering its services until 2pm. Power consumption averages at 250W during this time. After 6pm, when it gets dark, there is a an average consumption of 50W until 11pm, which includes lighting in the shop and the house of the shopkeeper. Throughout the day and night there are power surges of 100W which correspond to the refrigerator motor switching on and power surges of 40W which correspond to the self consumption of the inverter.

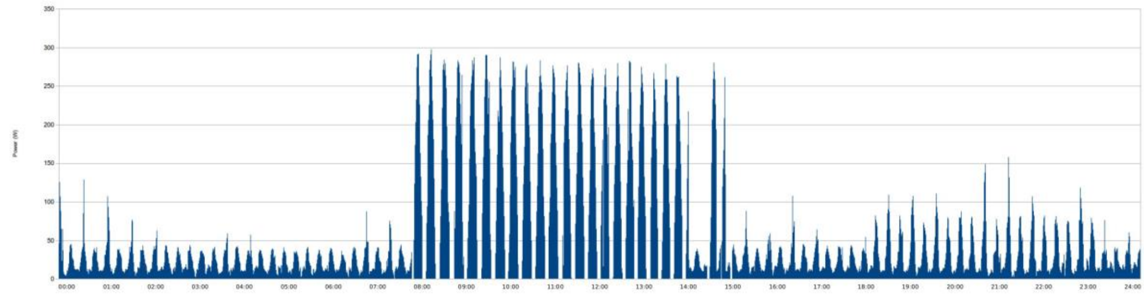


FIGURE 40:THE DAILY LOAD PROFILE OF THE SHOP DURING THE MONTH OF SEPTEMBER 2015

3.5.1.3 Wind resource assessment in Semara and Amibara

A wind resource measuring campaign was conducted in January 2015 in the University of Semera in the Afar region in order to evaluate the wind potential of the area in preparation for the second phase of the project. After a one day training course on wind resource measurements, an anemometer was installed on a eucalyptus pole at 10m from the ground and connected to a data logger, Fig.6. Course participants from the Amibara technical college were also trained and started a measuring camping in their area after few months. The results of all three wind resource assessments conducted during the project can be seen in Table 25.

SEMARA								
Feb	Mar	Apr	May	Jun				AVERAGE
3.53	3.71	3.12	3.19	3.30				3.37
HADEW								
Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	AVERAGE
4.37	4.46	3.69	2.29	2.45	2.75	2.63	2.34	3.12
AMIBARA								
					Jul			AVERAGE
					3.35			3.35

TABLE 25: WIND RESOURCE MEASURING CAMPAIGNS IN SEMARA, HADEW AND AMIBARA

The monthly mean wind speeds and the overall mean wind speeds recorder for these regions show a low wind resource with seasonal variations in some cases. A full wind resource assessment needs to be conducted for a least 12 moths in order to reach a definitive decision with regard to the wind potential of these areas. According to the data collected so far, the area of Jijiga has a wind resource above 4m/s for some months of the year, a mean wind speed which could benefit small wind projects in the area.

FIGURE 41: CONDUCTING A WIND RESOURCE ASSESSMENT WITH THE STUDENTS OF SEMERA UNIVERSITY

3.5.2 Ability and Willingness to pay for Energy Services data

The success of a wind turbine project, and indeed any off grid renewable energy project relies on a rural population that is willing to pay for the energy services that the power system provides. During the pilot project installation of small wind turbines in Ethiopia run by Wind Empowerment in 2015, surveys were conducted with the rural community members to determine how much they are currently spending on energy services and what they would be willing to pay for additional energy services. Details of the studies are presented below.

Location and Date of Surveys	Hadow, Jigjiga: January 2015 SudanCamp, Semera: October 2015
Number of People Interviewed	Hadow: 14 Jigjiga: 18
Sample selection	Random
Format of data collection	Informal interviews

3.5.2.1 Summary of key findings in Semera:

- Sources of energy in the home included dry cell batteries for lighting by torches and also for phone charging. Most of the houses used firewood for cooking.
- 25% of the houses had pico-solar products for lighting and mobile charging.
- 2 people in the community had a generator neither of which was functioning at the time.
- Nobody used kerosene for lighting.
- The most common electrical appliances were cell phones and radios.
- If electricity was present the appliances that would be used were indicated to be: refrigerators, radios, cell phones, fans and TV's. It was indicated that computers would not be used.
- Charging phones is completed either through solar chargers, diesel generators, or travelling to the nearest town (Dubti or Detbahir) which is 25k walk from the village.

Indicative current energy spend determined by the surveys is as follows:

Item	**Cost**
Batteries for lighting:	12 – 14 ETB per week
Batteries for radio	42 ETB per week
Charging phones (in the town)	140 ETB per month
TOTAL:	*356 – 364 ETB per month*

3.5.2.2 Summary of key findings in Jijiga:

- The average number of people per household is 7 (max 14, min 2).
- Typical uses of energy are lighting, mobile charging, radio. Most of the houses used firewood for cooking.

- Sources of energy for the houses interviewed were batteries, kerosene, wood and pico-solar products
- The average price of pico-solar products used was 1300 ETB
- When asked what they would use electricity for, respondents said: lighting, heating, mobile charging, TV, music and refrigeration.
- When asked what they would be willing to pay for these additional services, the maximum answer was 1000 ETB/month, the minimum was 150 ETB/month and the average was 700 ETB/month.
- The cost of kerosene per period of time is shown below, the average of the 7 users is 10 ETB per day, or 300 ETB per month.
- Community members who did not have access to pico-solar products for mobile phone charging would walk 1 hour to the nearest charge point on the national electricity grid.
- Concerning awareness of renewable energy technologies, the majority did know what a solar panel is, however the majority did not know what a wind turbine is.

Average cost of kerosene:

Cost (ETB)	Days	Cost (ETB)/day
500	14	36
6	2	3
500	60	8
55	30	2
6	1	6
6	1	6
300	30	10
	Average:	10

3.5.1.3 Analysis

Based on the information above based on current energy spend and willingness to pay, it could be estimated that a figure of between 300 -700 ETB could be used to provide a reliable source of lighting and mobile charging in the villages surveyed. If power was available for additional services such as refrigeration, TV, then this figure could rise to 700 ETB per month. Many residents are already using Pico solar products indicating an ability to pay at larger amount up front for energy services such as phone charging and lighting.

The accuracy of the surveys cannot be guaranteed as the sample sizes are relatively small, and the enumerators were students without any formal training in social research methods or how to conduct questionnaires. It could also be envisioned that an expressed willingness to pay during a survey does not always equate to the same amount being available when the energy service arrives.

However, the results indicatively show that there is a willingness and ability to pay for renewable energy services including SWTs in the villages that were questioned. More research into these important socio-economic factors will be essential in the development of future business plans for SWT in Ethiopia.

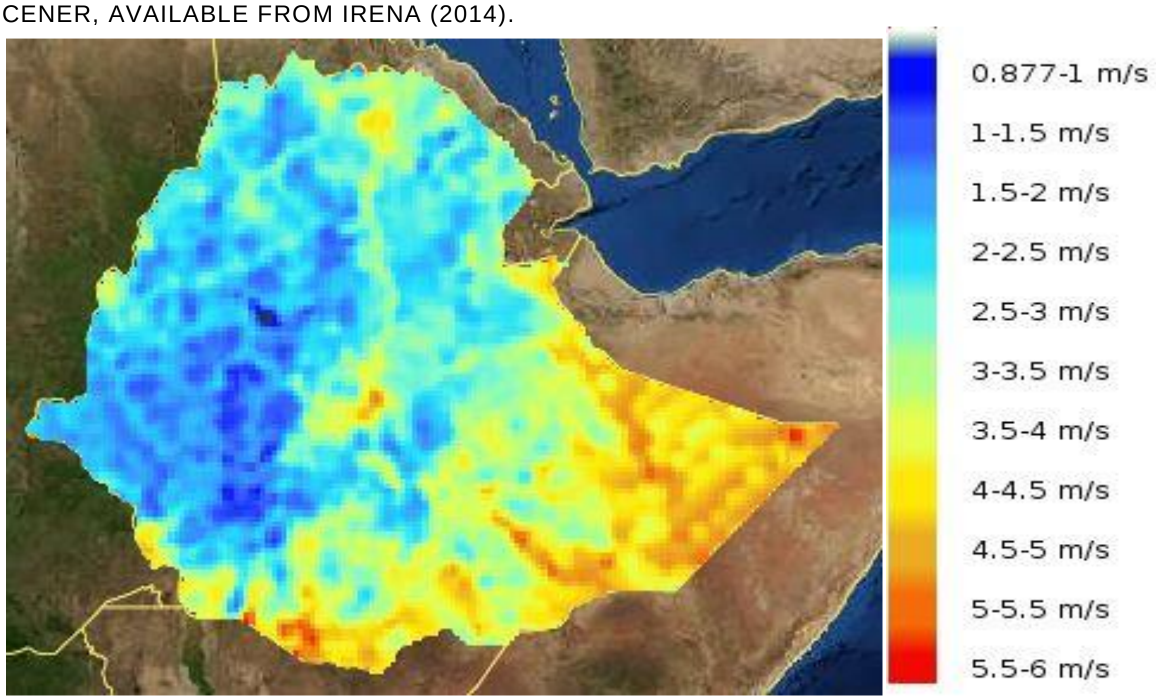
4 Results and discussion

4.1 Wind resources

Figure 42 shows the CENER wind map selected for further analysis in this study overlaid on a satellite image of the horn of Africa. It shows that Ethiopia's wind energy potential is highly variable, with annual mean wind speeds at 10m ranging from below 1 to 6 m/s, i.e. almost nothing to high potential for wind power generation. Regarding the areas of relevance to MercyCorps Ethiopia, the following observations can be made:

- Somali Region: Generally high and evenly distributed wind speeds.
- Oromia: Mixed wind speeds, higher in parts of the southern and eastern regions.
- Afar: Low wind Speeds, few areas where LMSWT could be viable.

FIGURE 42: FIGURE NATIONAL WIND MAP USED FOR GIS MAPPING. ORIGINAL DATA FROM CENER, AVAILABLE FROM IRENA (2014).



Whilst the wind maps provide a general indication of wind speeds in Ethiopia, they are not a definitive guide, as wind speeds at the heights typical of SWTs (10m – 20m) are extremely dependent on the surrounding site conditions, i.e. the presence of obstacles and the placement of the turbines in relation to hills, valleys and other geographical features. Nonetheless, it can be concluded that the likelihood of success for a wind project will be greatly increased in the eastern Somali and far southern tip of the Oromia region. Figure 45 shows that the land cover in these regions is almost exclusively 'grassland' or 'sparsely vegetated cover', which means that there will be few obstacles to create shelter or turbulence, meaning that lower towers can be used and the probability of each commercial centre having a suitably open site nearby is high. Within the Afar region, the western Somali and all of the Oromia region other than directly bordering Kenya, the wind resource is much lower and therefore, no wind power projects should be implemented in these areas without on the ground measurements from wind monitoring systems that confirm the presence of sufficient wind resources throughout the year.

Figure 4443 shows that the power available in the wind reduces significantly (by one third at 4000m above sea level) with altitude due to the reduced density of air. Figure 44 shows that this is particularly important in Ethiopia, where the topography is extremely varied and altitude ranges from below sea level in the Danakil Depression up to 3500m within the homeland of the Amhara tribes (Beall, 2006). The region of highest wind potential (the Somali region) is relatively low, with the majority under 2,000m, however the effect of altitude should still be taken into account, as it could reduce energy yields by up to 20% in this region.

FIGURE 43: VARIATION IN THE POWER IN THE WIND WITH ALTITUDE DUE TO CHANGES IN AIR DENSITY (SUMANIK-LEARY, WHILE, ET AL. 2013).

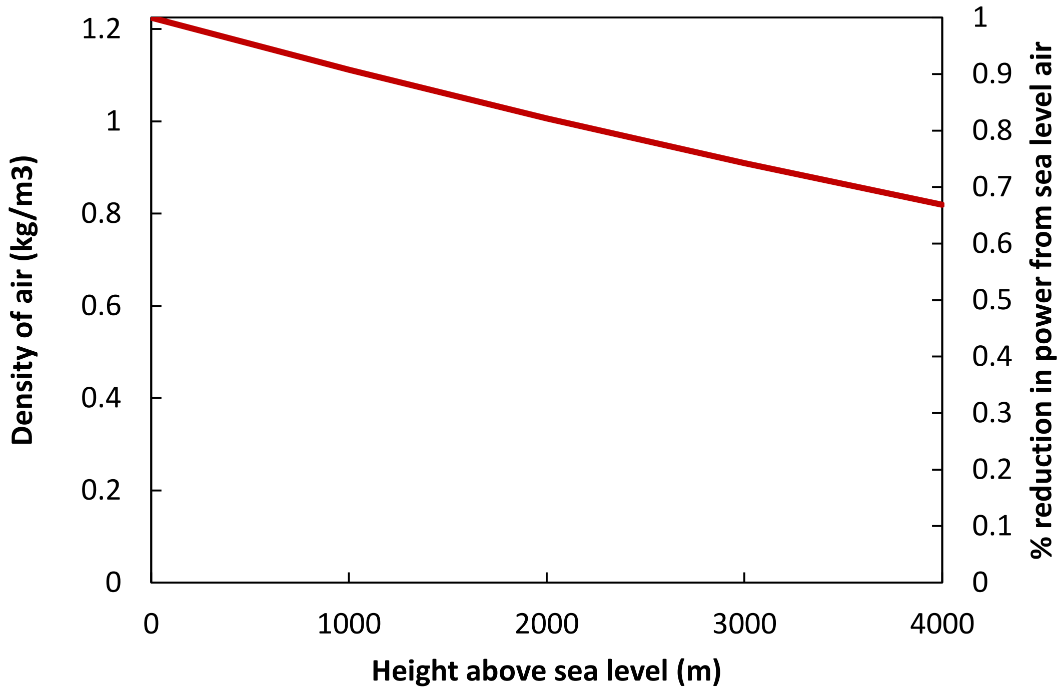


FIGURE 44: TOPOGRAPHY OF ETHIOPIA (WIKIPEDIA 2014)

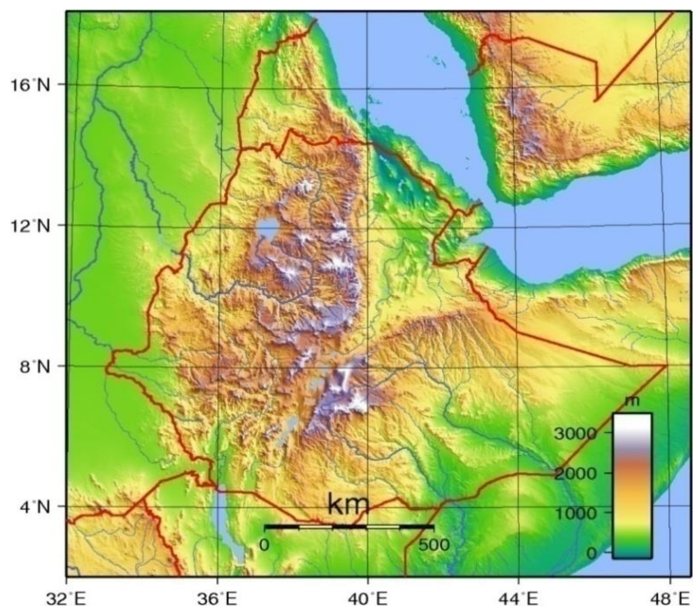
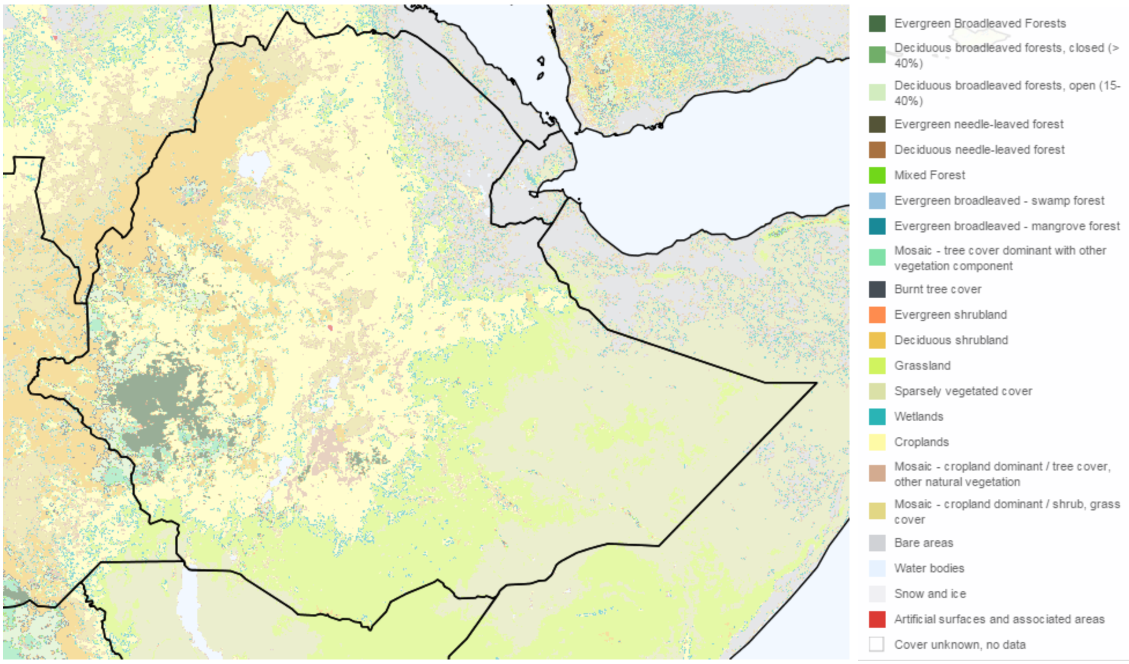


FIGURE 45: LAND COVER ACROSS ETHIOPIA. ORIGINAL DATA FROM GEOMODEL (INTERNATIONAL RENEWABLE ENERGY AGENCY 2014).



4.2 Solar resources

Figure 2121 shows the solar resource across Ethiopia. Whilst there is a wide variation across the country, the solar resource in the region of highest potential for SWTs, the Somali region, is relatively constant at around 6kWh m^{-2} day^{-1}. As a result, all sensitivity analyses conducted in the HOMER modelling that required a constant solar resource (PV capital cost, O&M costs, diesel fuel cost etc.) use this value.

4.3 Solar/wind complementarity

With the exception of locations 8 and 9, all of the 14 regions identified in Figure 22 exhibit seasonal complementarity of the solar and wind resources. In each of these 12 regions, the solar resource dips during the rainy season (May – July), which corresponds to a rise in wind resource. Figure 46 shows the wind and solar resource profiles for the western Somali district (region 10), indicating that there is a certain degree of complementarity between the two resources on seasonal basis. However, it should be noted that the variation in the wind resource is greater and that PV power generation is linearly proportional to the solar irradiance, whilst SWT power generation is cubically proportional to the wind speed. Figure 4747 compares the monthly energy yields of a 1kW PV and 1kW SWT on a good solar and wind resource site in this region. It can be seen that the seasonal variation in the solar resource has relatively little effect on energy yields, whilst the variation in the wind resource has a dramatic effect on the energy available at different times of the year. Unfortunately it was not possible to obtain data on the compatibility of these two resources over shorter timescales.

FIGURE 46: SOLAR AND WIND YEARLY PROFILE FOR WESTERN SOMALI REGION (LOCATION 10 ON FIGURE 22).

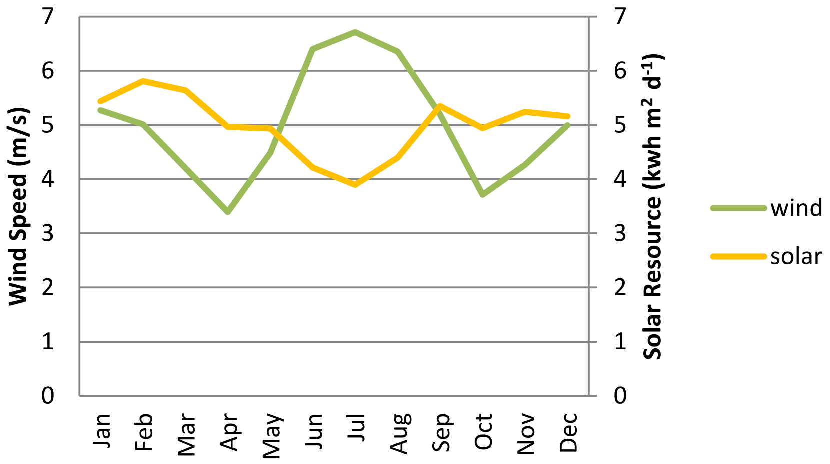
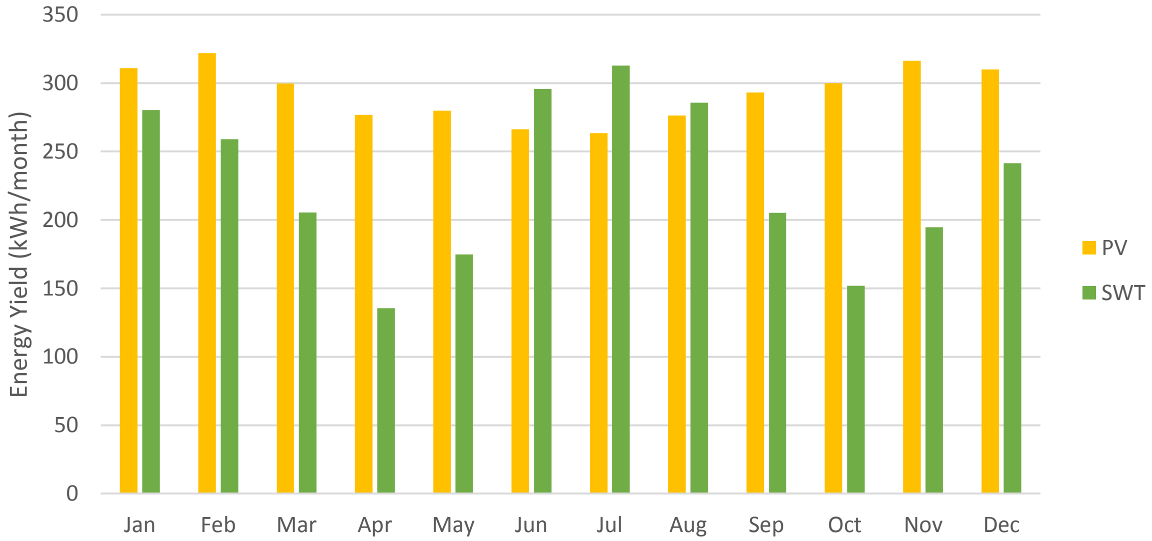


FIGURE 47: PREDICTED MONTHLY ENERGY PRODUCTION FROM A PV-SWT-GENERATOR SYSTEM (0.48KW, 1KW AND 2.5KW RESPECTIVELY) USING THE SEASONAL PROFILE FROM FIGURE 46 WITH A 6KWH M-2 DAY-1 ANNUAL MEAN SOLAR IRRADIANCE AND 5M/S ANNUAL MEAN WIND SPEED. MODELLED IN HOMER.



4.4 LCoE/GIS modelling results

The micro-grid simulation tool, HOMER, was used to model all systems proposed given the input parameters outlined above including any sensitivity values. The system configurations were ranked in order of lowest Levelised Cost of Energy (LCoE) and lowest Net Present Costs (NPC). The following section presents the results of the HOMER modelling and links it into the GIS mapping in QGIS in order to assess the viability of different system architectures across Ethiopia.

Figure 4848 shows a surface plot displaying optimal system architectures for the range of wind and solar resources typically seen across Ethiopia. It shows that when the solar and wind resource are both low, a generator/battery system is optimal, as indicated by the black area in the bottom left of the figure. When wind speeds are low but the solar resource is high, a PV/generator/battery system is most cost effective, represented by the red section on the left of the figure. Conversely, when wind speeds are high, but the solar resource is low, a SWT/generator/battery system is most cost effective, as shown by the blue area towards the right of the figure. Finally, in the areas where solar and wind are both reasonable, a SWT/PV/generator/battery system is recommended, as indicated by the central green strip. The yellow line indicates the threshold annual mean wind speed, 5.5m/s, above which, it becomes more cost effective to include a LMSWT in all systems, regardless of the solar resource. In the Somali region, where the solar resource is around 6kWh m^{-2} day^{-1}, SWTs are cost effective in locations with greater than 4.9m/s. However, when using the maximum cost multiplier (1.43, i.e. a worst case scenario for LMSWTs representing the early stages of business development, significant increases in component costs, etc.), this value increases to 5.8m/s (at 6kWh m^{-2} day^{-1} solar radiation).

FIGURE 48: SURFACE PLOT OF OPTIMAL CHOICES FOR COST MULTIPLIERS OF 1 (I.E. NO SENSITIVITY). YELLOW LINE INDICATES THE THRESHOLD WIND SPEED FOR LMSWTS.

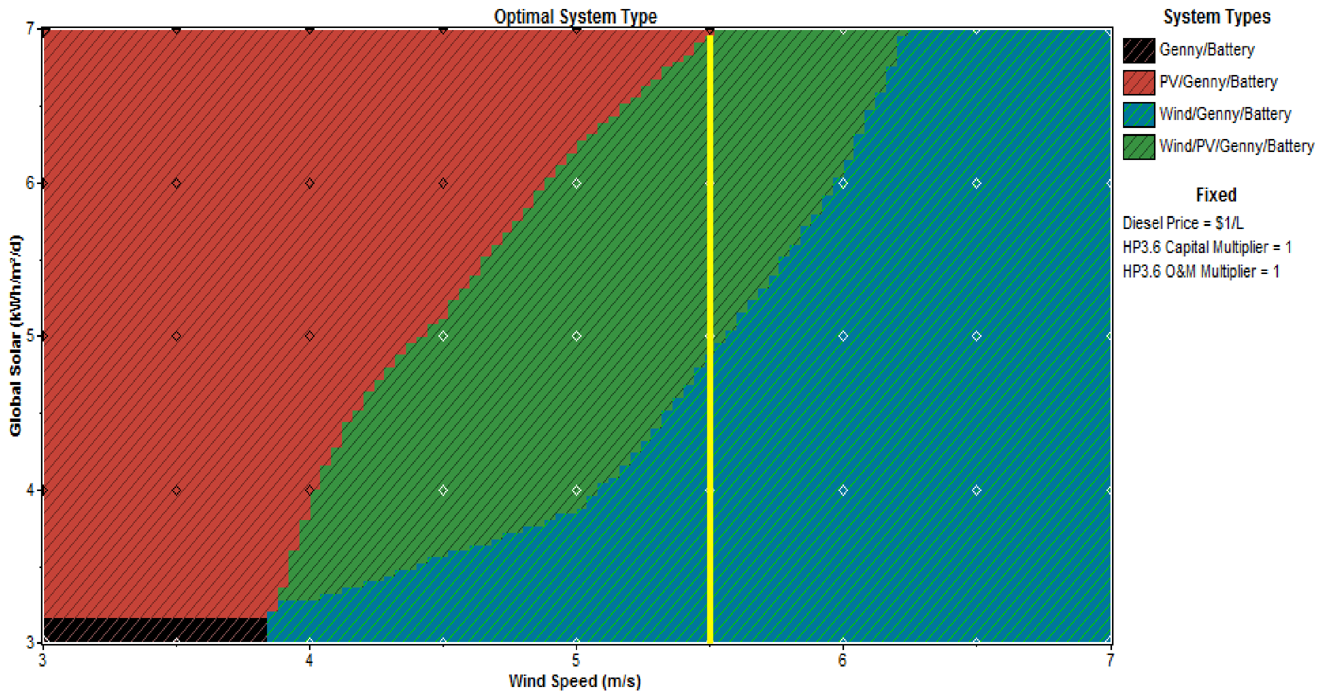


Figure 4949 shows the effect of the O&M cost multiplier on the optimal system architecture, indicating that when the cost multiplier is above 2.32, the red area representing a PV/generator/battery system spreads across the chart, meaning that PV/generator systems are always more cost effective, regardless of the wind resource. This implies that if the distance from the workshop where LMSWTs are manufactured to the site of installation is more than one day (2 days round trip), it will not be cost effective to include a LMSWT in the system unless the O&M costs can be significantly reduced. This could be achieved by establishing a service centre in an area with a significant number of potential users and/or by increasing the training offered to end-users themselves and ensuring that the most common spare parts and tools are kept on site, so that end-users are able to perform the majority of maintenance operations themselves. Of course, this is challenging in itself and has its own associated costs, which will need to be assessed.

FIGURE 49: WIND SPEED VS LMSWT O&M COST MULTIPLIER OPTIMISATION CHOICES.

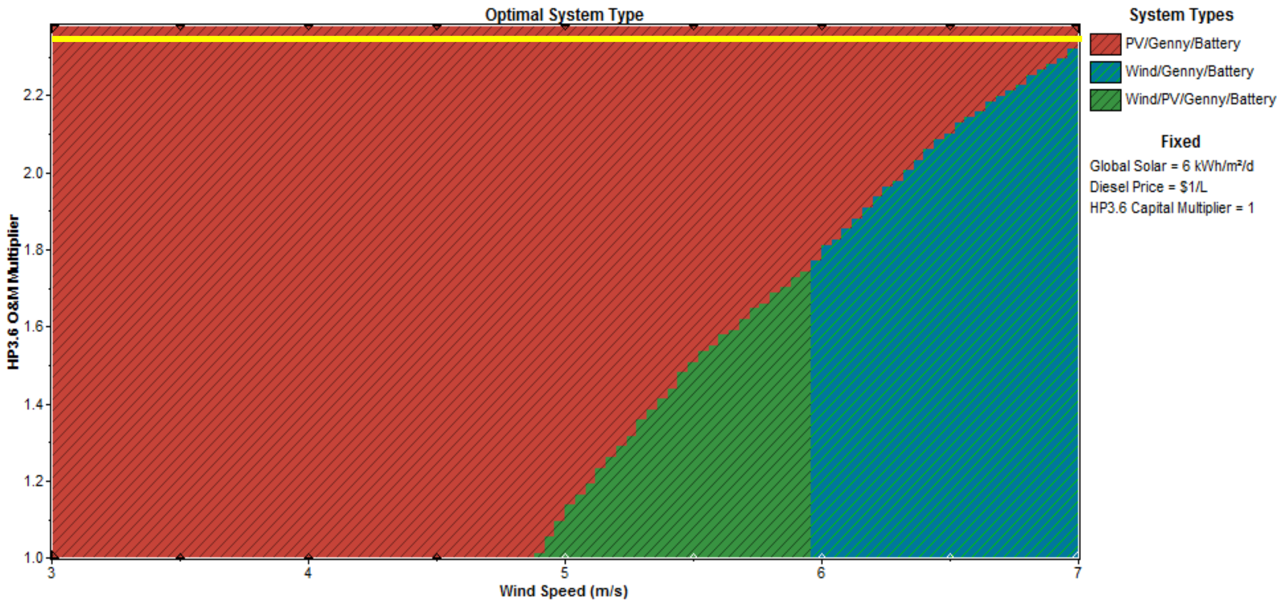


Figure 50 shows the effect of diesel prices increasing from the current $1.00 per litre to the predicted value for 2018: $1.35 per litre. It was found that increasing diesel costs reduce the threshold wind speed for LMSWT feasibility to 4.2 m/s, as the diversity in power generation sources offers significant advantages for hybrid systems and diesel is not able to offer this diversity cost effectively when fuel prices increase significantly. Similarly, Figure 51 shows that the effect of the PV cost multiplier, predicting that with 2018 price projections (cost reductions of 1/3), and the threshold for LMSWT implementation increases to 5.4 m /s.

FIGURE 50: WIND SPEED VS DIESEL COST MULTIPLIER OPTIMISATION RESULTS.

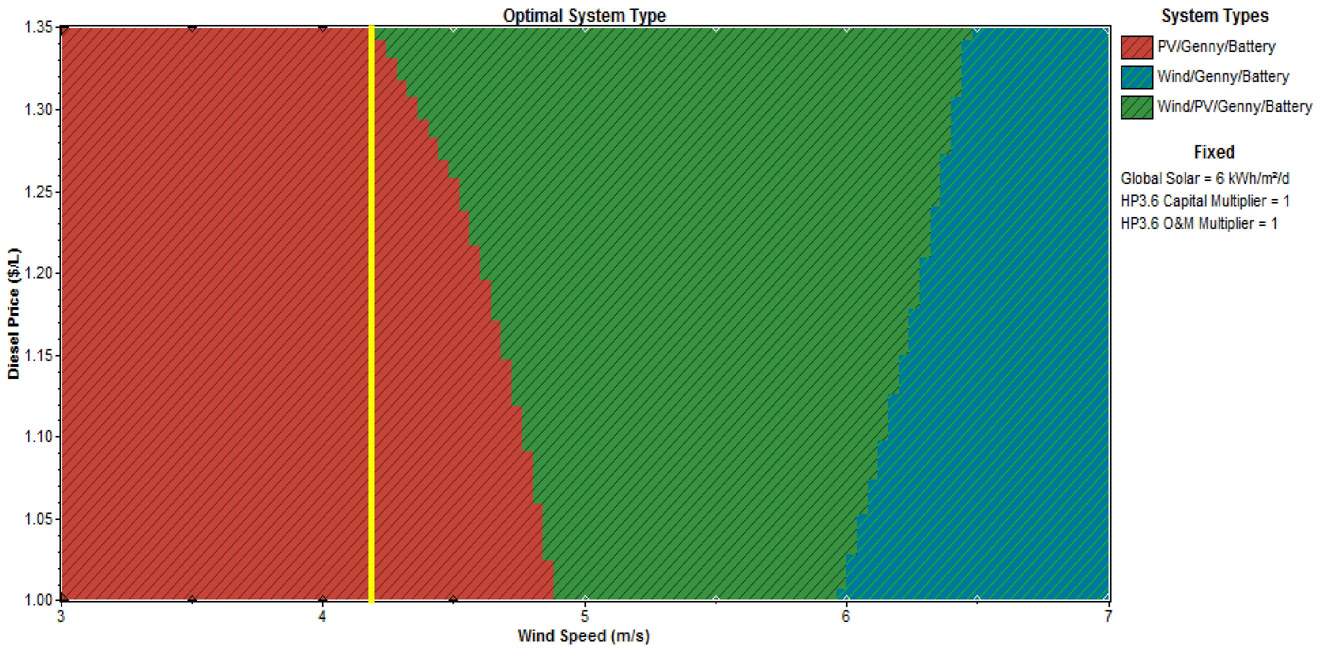


FIGURE 51: WIND SPEED VS PV COST MULTIPLIER OPTIMISATION CHOICES.

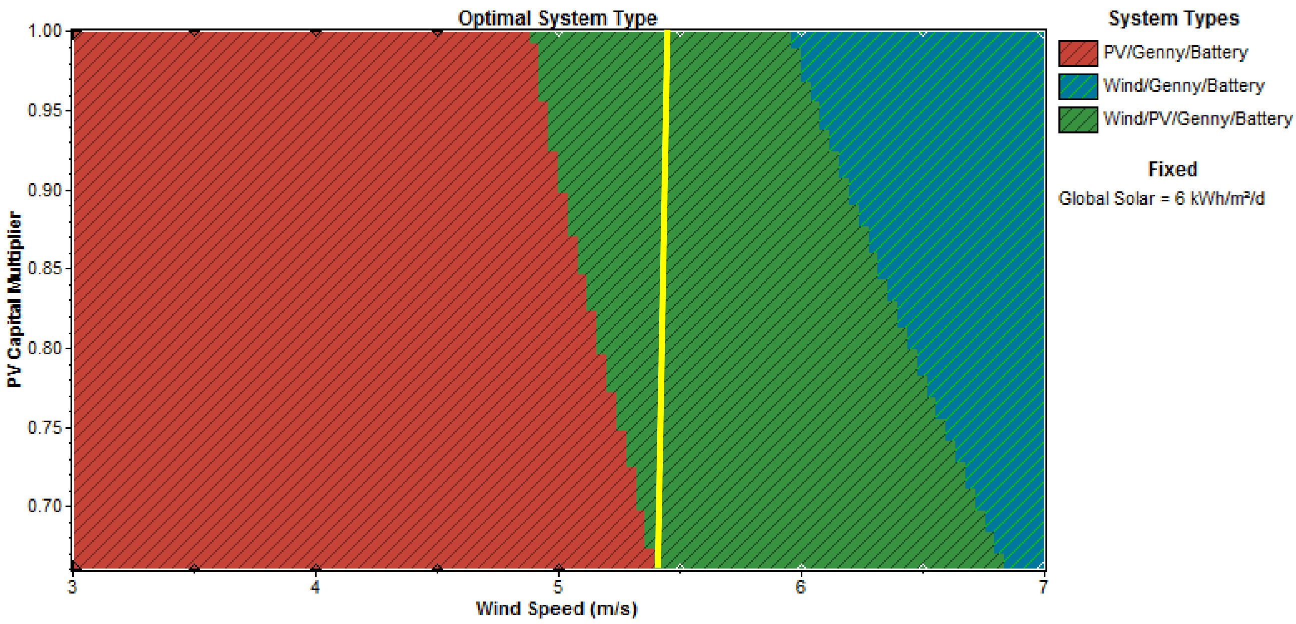


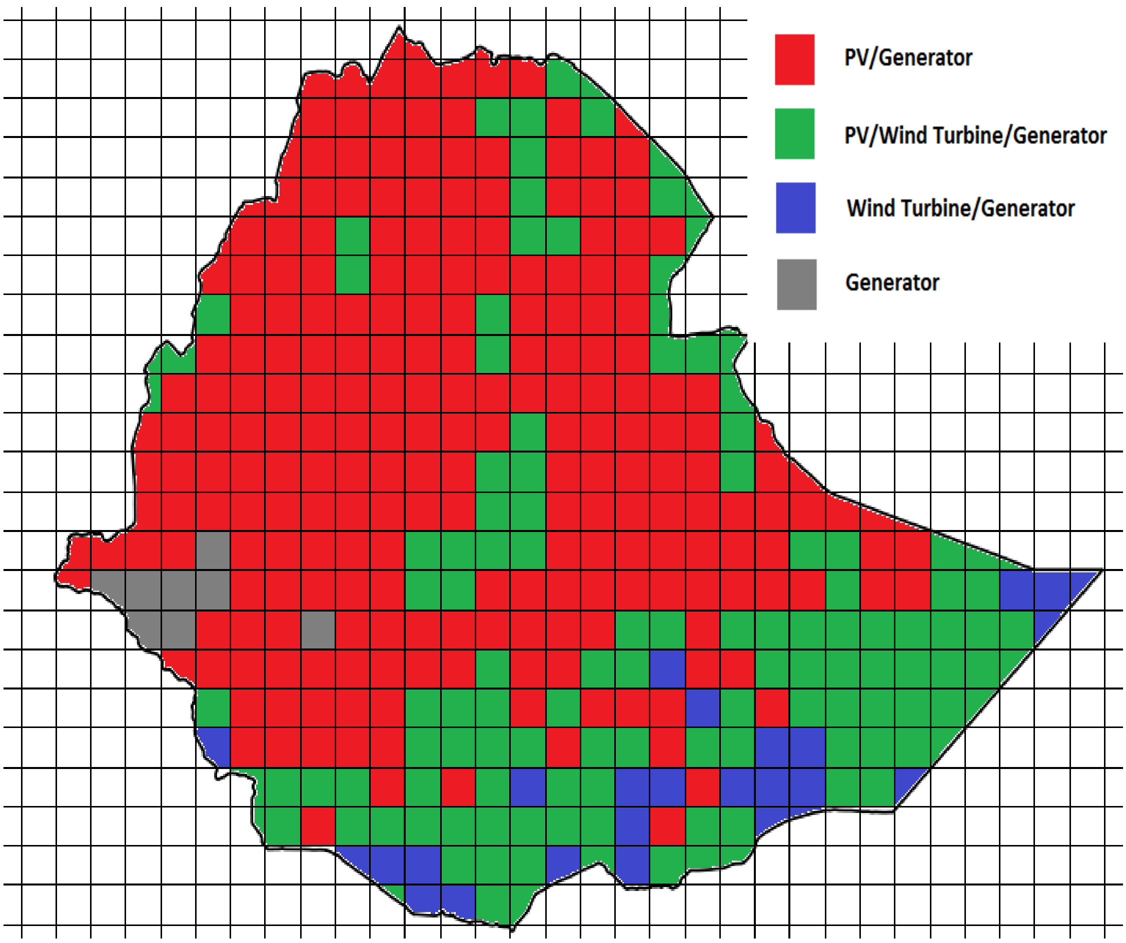
Table 26 lists the LCoE, total Net Present Cost (NPC) and Renewable Fraction (RF) for the three most viable system architectures in the Somali region. The lowest LCoE and NPC correspond to the highest wind resource, with a SWT/generator configuration and conversely, the most expensive system is with a low wind resource, where a PV/generator configuration is optimal. It should be noted that this also results in a much lower RF.

TABLE 26: DETAILS OF THREE SYSTEMS MODELLED FOR VARYING WIND AND SOLAR RESOURCES.

Wind Speed (m/s)	Solar Resource (kWh m^{-2} day^{-1})	System elements	LCoE ($/kWh)	Renewable Fraction	Total Net Present Cost
4	6	PV/generator	0.712	0.64	$20,665
5	6	PV/SWT/generator	0.701	0.84	$20,350
6	6	SWT/generator	0.636	0.84	$18,460

Figure 522 shows the combination of the results of the HOMER modelling for the range of wind/solar resources typically found in Ethiopia shown in Figure 48 with the spatial variation of these resources from the wind and solar resource maps shown in Figure 17 and Figure 18, in order to recommend the optimal system architecture for each unit. The map shows that for the load profiles and systems analysed in this study, a PV/generator system is optimal in the majority of Ethiopia (especially in the North and West), due to the high solar and low wind resource. However, in the South and East, there are several areas where including a LMSWT could reduce systems costs, and in some areas, the wind speed is high enough to recommend an SWT/generator system without any PV. In the West, there is a small area where the wind and solar resource are both low and a generator only system is the most economical.

FIGURE 52: MAP OF OPTIMAL OFF-GRID ENERGY SYSTEMS.



4.5 Additional factors

4.5.1 Existing infrastructure

It is assumed that communities with access to the national grid will have a cheaper supply of electricity and an off grid system incorporating a LMSWT would not be economically feasible. The costs per kWh for electricity are low in Ethiopia, as generation is predominantly from hydropower (one of the cheapest forms of electricity long term) and grid infrastructure itself is heavily subsidised (Ethiopia Electric Power Corporation, 2014). The map below is taken from IRENA and shows the existing grid network with associated voltages.

FIGURE 53: ETHIOPIA GRID INFRASTRUCTURE (INTERNATIONAL RENEWABLE ENERGY AGENCY 2014).

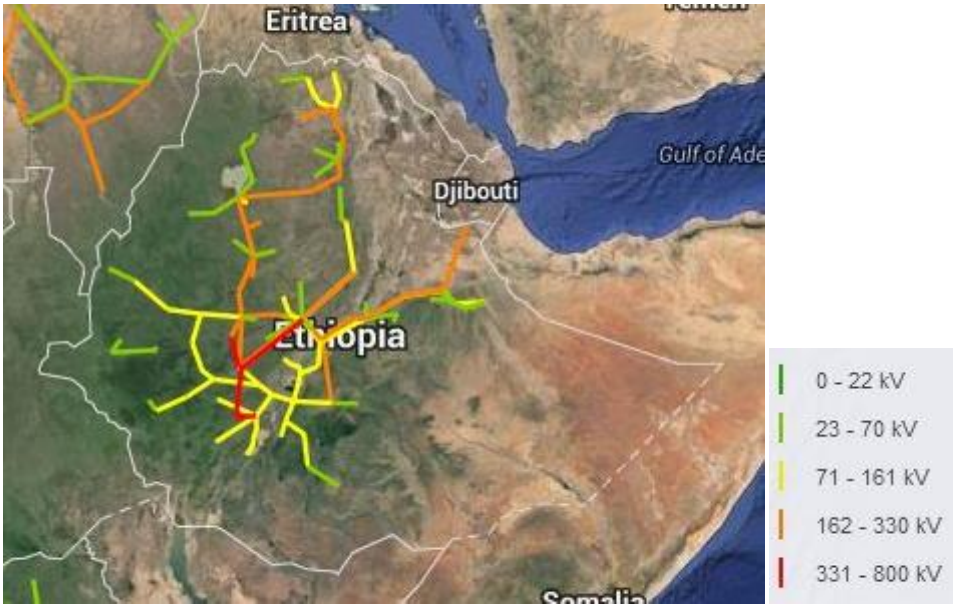


Figure 54 shows in red the areas where grid use or extension is more feasible than other options in Ethiopia, taking into account population density and cost of extension (Masdar Institute of Science and Technology 2012a). It can be seen that areas identified for LMSWT implementation generally correspond to areas not currently serviced by the electricity grid. It is also interesting to note that the areas identified as suitable for micro-hydro, although not part of this assessment, correspond to some areas where wind and solar resources are both low. Figure 55 shows Ethiopia's population distribution, with the current electricity grid superimposed. Logically, the grid serves areas of high population, however it is important to note that where the wind speed is high, population density is generally low, meaning that these populations are very unlikely to be offered a grid connection in the short-, medium- or even long-term.

FIGURE 54: OPTIONS FOR ELECTRICITY SUPPLY IN ETHIOPIA (MASDAR INSTITUTE OF SCIENCE AND TECHNOLOGY 2012A).

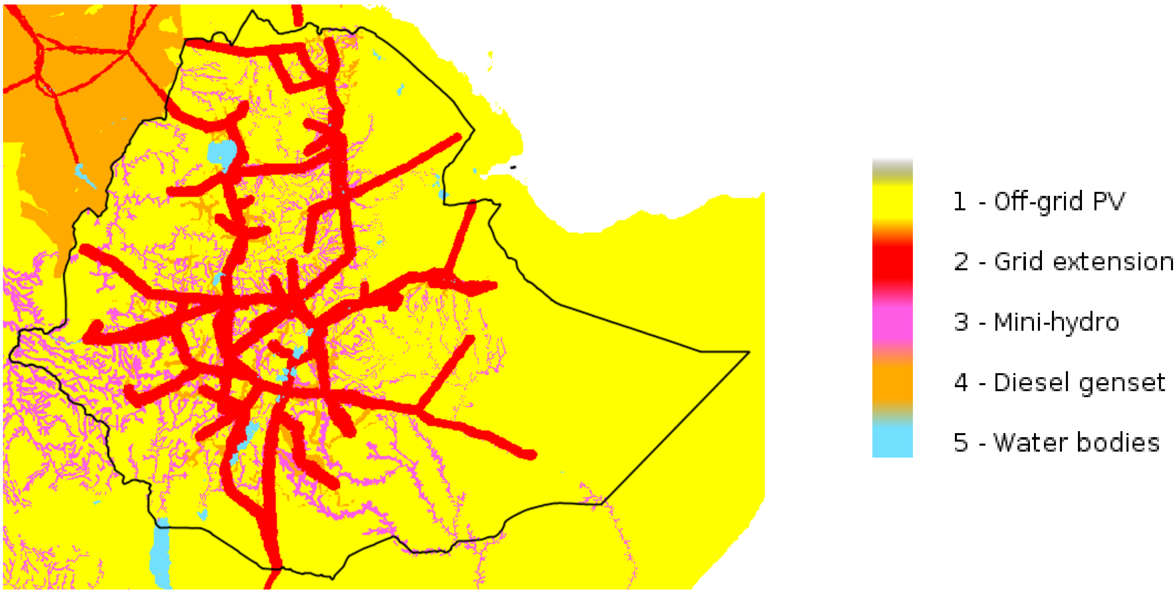
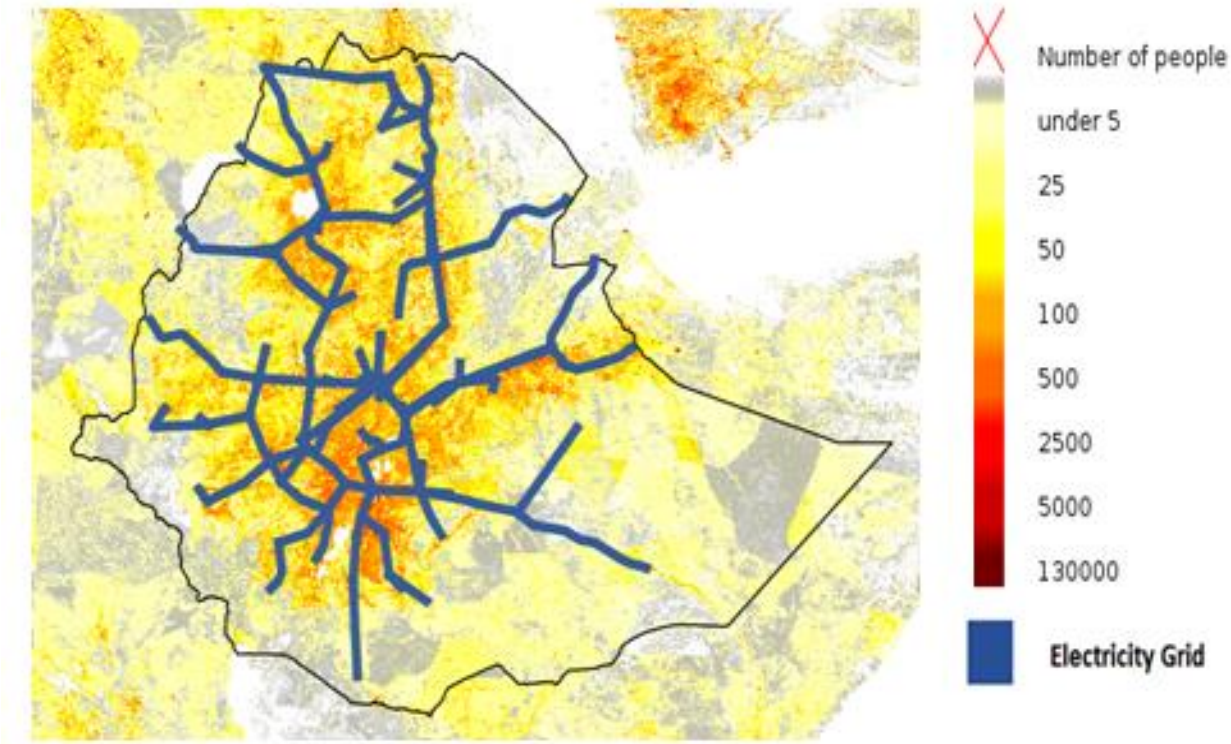


FIGURE 55: POPULATION AND ELECTRICITY GRID FOR ETHIOPIA (INTERNATIONAL RENEWABLE ENERGY AGENCY 2014).



The two maps below show a close-up view of the South East of the country, where wind resources are most favourable. It is clear that population density is sparse, but that the wind speed map shows significant variability, indicating the importance of on the ground wind resource assessments prior to the implementation of any projects in new areas.

FIGURE 56: CLOSE-UP VIEW OF POPULATION AND ELECTRICITY GRID IN SOUTH- EASTERN ETHIOPIA (INTERNATIONAL RENEWABLE ENERGY AGENCY 2014). LEGEND IDENTICAL TO FIGURE 53.

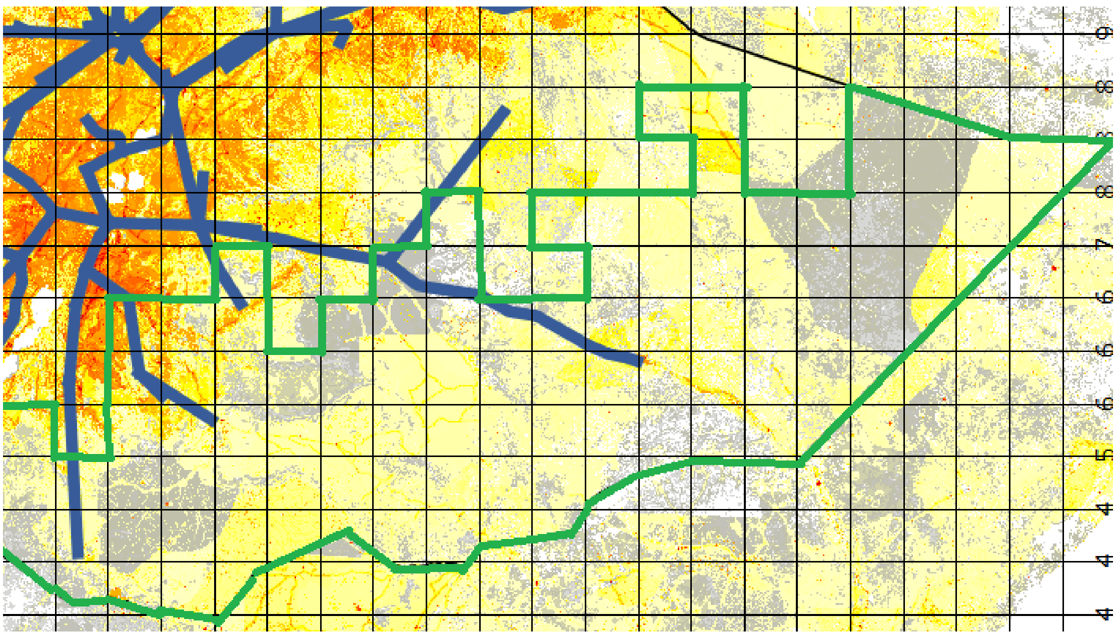


FIGURE 57: CLOSE-UP VIEW OF WIND SPEED IN SOUTH-EASTERN ETHIOPIA (GEOCATALOG 2014).

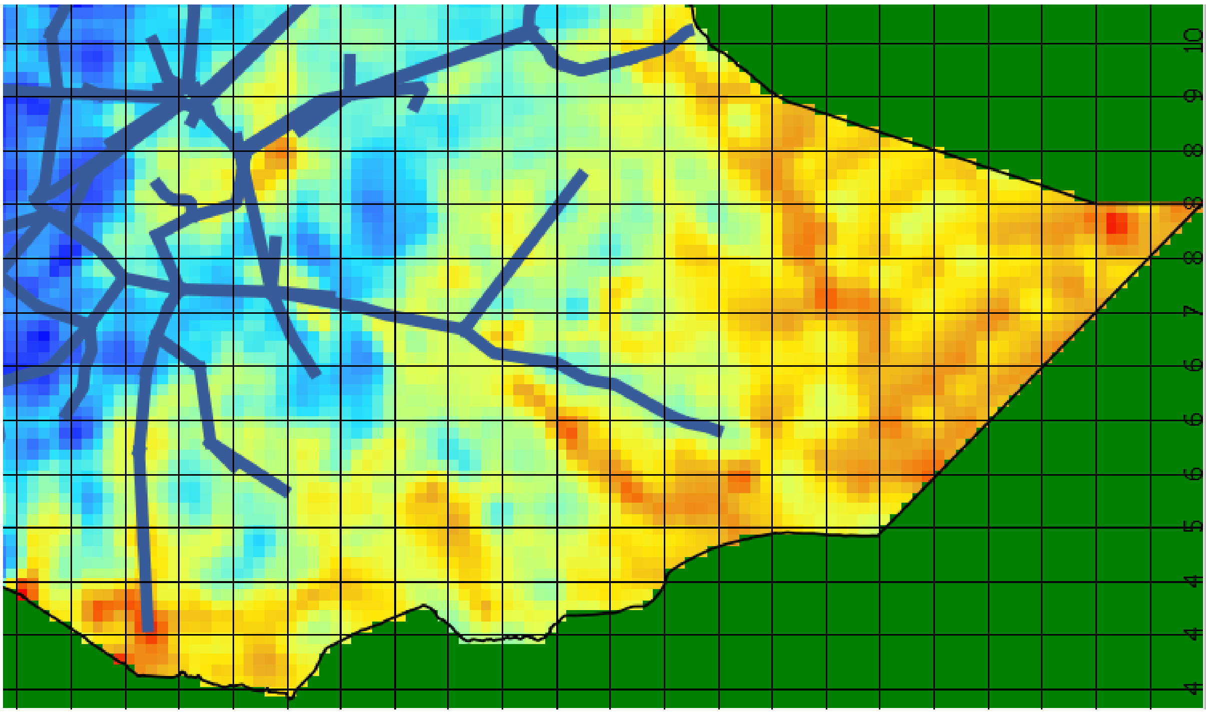
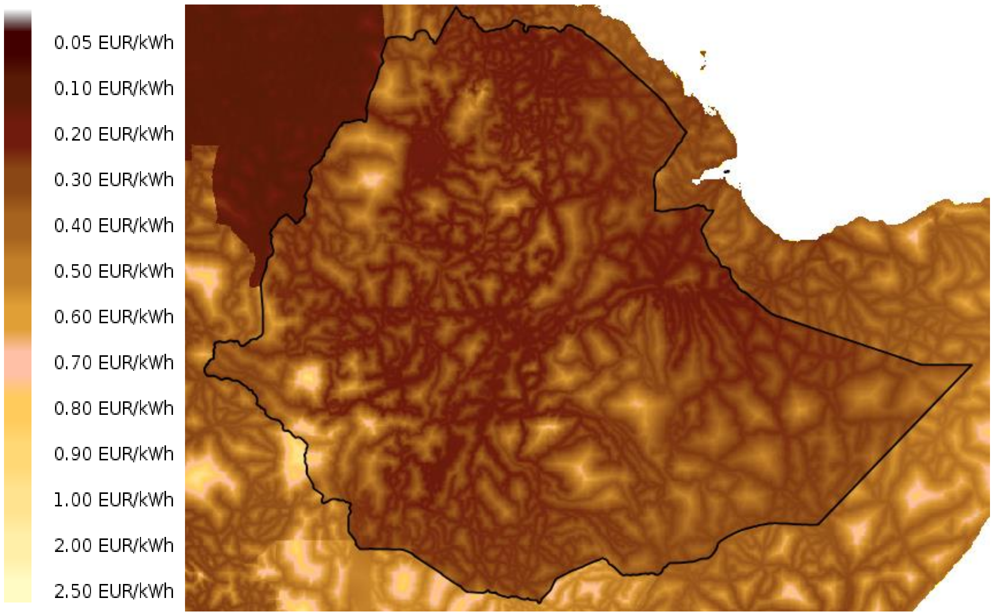


Figure 58 shows how diesel generation costs vary across Ethiopia and is a useful indication of accessibility of travel, as areas with higher diesel costs correspond to increased travel time due to the resulting increases in fuel distribution costs. This has important implications for LMSWTs, as the areas on this map represented by high diesel costs also imply higher O&M maintenance costs for SWTs, due to longer distances that technicians must travel. This map can be used as an indicator: lighter areas should be avoided in the initial stages of LMSWT implementation as the O&M costs will make them unfeasible in the short term.

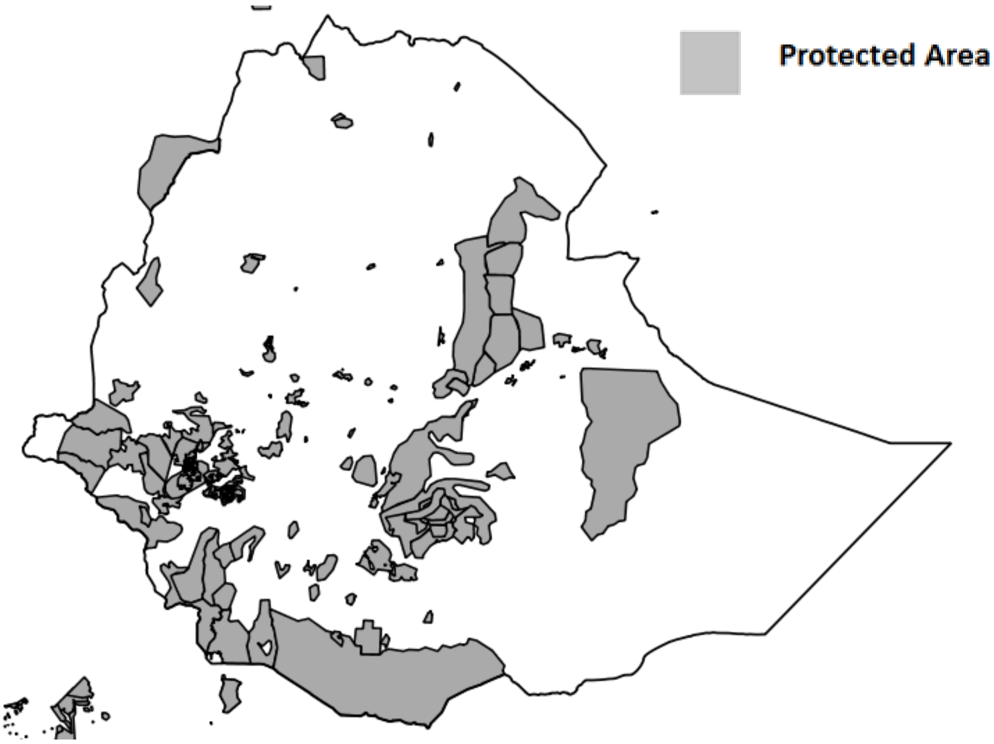
FIGURE 58: COST OF DIESEL GENERATION IN ETHIOPIA REPRESENTED GEOGRAPHICALLY (MASDAR INSTITUTE OF SCIENCE AND TECHNOLOGY 2012B).



4.5.2 Protected Areas

The figure below shows protected areas such as national parks as taken from the IRENA world database of protected areas. Some protected areas coincide with areas identified for LMSWT. Protected areas are more of a concern for major infrastructure and government policy may allow small, less visually intrusive wind turbines into protected areas, although more research is required into government policy to confirm this.

FIGURE 59: PROTECTED AREAS IN ETHIOPIA (INTERNATIONAL RENEWABLE ENERGY AGENCY 2014).



4.5.3 *Civil Unrest*

Taken from the British Foreign and Commonwealth Office (2014), the figure below is a map of travel advice for areas in Ethiopia. The areas in red are currently marked as "advise against all travel", as there is a perceived threat of kidnapping, terrorism or general civil unrest in these areas. It should be noted that these areas correspond to regions of high wind resource, and those without a grid connection, i.e. the most viable regions for LMSWTs.

FIGURE 60: FOREIGN AND COMMONWEALTH OFFICE TRAVEL ADVICE FOR ETHIOPIA (BRITISH FOREIGN AND COMMONWEALTH OFFICE 2014).

4.5.4 Additional developmental impact of local SWT manufacturing

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.

4.5.5 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. It is also far more engaging for any participant than simply sitting through another dry PowerPoint presentation. 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. The end-users of the SWTs installed during the pilot projects run in parallel with this market assessment participated in the construction process and in line with Sumanik-Leary, Marandin, et al.'s (2013) findings in Nicaragua, it was 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.

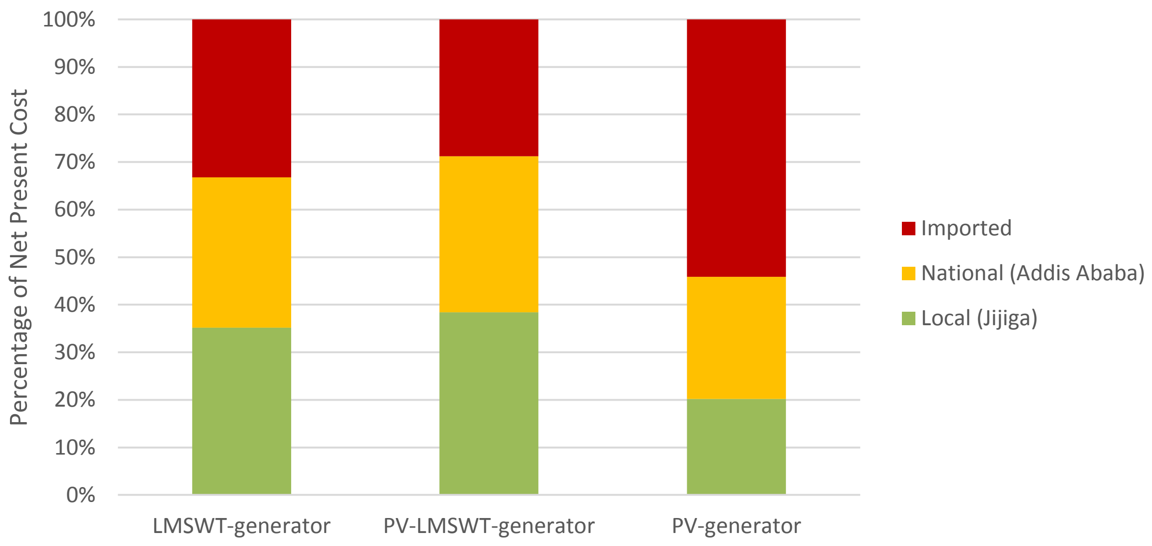
4.5.6 Local economic development

The requirement for foreign exchange places a huge burden on developing economies, who 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 61 presents a value chain analysis of the three most viable system configurations modelled during this study (presented in Figure 26). It categorises the costs associated with the manufacture/purchase, installation and maintenance of each of the three technologies, according to where these expenditures occurred (see Appendices for detailed breakdowns of these costs). Money spent locally in Jijiga is shown in green, whilst that spent in 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 (see Appendix 9 Business Plan). 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 61: VALUE CHAIN ANALYSIS OF OFF-GRID LMSWT, PV AND GENERATOR SYSTEMS. SEE FIGURE 16 FOR DETAILS.



5 Conclusion and recommendations for next steps

The local manufacture of SWTs may be a viable option for the electrification of commercial centres in the south-eastern part of the Somali region of Ethiopia. However, MercyCorps should weigh up the comparative advantages and disadvantages of SWTs, PV and diesel generators shown in Table 1 in order to decide whether to support the implementation of the technology in this region. SWTs require significantly more support over a much longer timescale than either PV or diesel generators and a judgement will have to be made on whether the benefits (most of which are longer term) outweigh the additional work that will be required. In fact, generators and PV should be seen as complementary rather than competing technologies, as the wind is a highly variable resource and therefore installing SWTs without one (or both) of these technologies is not recommended. Due to the falling global price of PV and increasing price of fuel, it is recommended that any SWTs that are installed should also include at least a small amount of PV in order to diversify the power generation mix and reduce dependency on generator backup.

Due to the significant challenges involved in the implementation of SWTs in the context of rural electrification, the majority of Wind Empowerment's member organisations are based around an expert (or experts) who have a deep knowledge and passion for the technology. For this reason, if further development of small wind in Ethiopia is to be supported, there should be a focus on building this local capacity. This could be achieved by designing follow-on projects in such a way that technical support from external experts (such as Wind Empowerment) and financial support from NGO's (such as MercyCorps) is gradually reduced as local technical and income generation capacity is increased, with the ultimate aim of building a local team with the knowledge and financial means with which to function self-sufficiently.

Based upon the findings of this report and the experience gained by the Wind Empowerment team during the practical wind turbine construction courses and pilot installations, the following recommendations for specific actions to support the development of a successful future small wind turbine initiative in Ethiopia that is based on local manufacture are outlined below:

Build local capacity in the region where SWTs are most viable and most scalable.

- Mix those with practical SWT experience with those with rural electrification experience
    - To take the project forward, a team of experts should be recruited, who already have experience in renewable energy implementation in Ethiopia, experience of solar PV installations and off-grid systems, or experience of infrastructure projects in Ethiopia. Students from previous courses run by Wind Empowerment in Semera and Jigjiga should join the team to contribute their knowledge and experience gained on the wind turbine construction courses.
- Focus further SWT pilot projects in the southeast of Ethiopia, principally the southeast Somali region.
    - Ideally the organisation building the turbines should be based in Jigjiga, or another big town in the southeast.
    - The development of service networks should be supported in parts of the south-eastern Somali region with a critical mass of potential users (e.g. the Werder district)

to bridge the geographical gap between the place of manufacture and the end-user. These could be new or could build upon existing service networks for related technologies such as for PV, diesel generators, bicycles, motorbikes or cars.

Deepen understanding of locally available renewable resources

- Conduct site specific wind resource assessments.
    - Until the resource has been verified in a particular area, dataloggers should be employed to verify the resource, even in places that wind maps indicate to have a high wind resource. Ideally, at least 6 months of data should be gathered and only sites with an annual mean wind speed of 5m/s or above should be considered.
- Update this study as wind maps improve
    - Both the quantity and quality of publically available wind resource maps is improving rapidly. Revisiting this study when a significant amount of new data becomes available would be beneficial.
- Investigate solar/wind compatibility on shorter timescales.
    - Collecting data on the compatibility of the solar and wind resources over shorter timescales would be valuable, i.e. are windy days normally cloudy days (and vice versa) and is there a daily pattern to the availability of the wind resource?
- Install hybrid systems
    - Generators and PV are complementary rather than competing technologies. Due to the high variability in the wind resource and global price trends (PV falling rapidly whilst diesel is steadily increasing), it is recommended that any SWTs that are installed should also include at least a small amount of PV and a backup generator in order to diversify the power generation mix, but reduce fuel consumption.

Find a locally appropriate delivery model

- Quantify scalability of delivery model & investigate alternative applications
    - Determine the number of rural commercial centres in the regions identified as viable for SWT. Investigate the possibility of other applications within this region, e.g. schools or water pumping.
- Develop a full business plan
    - Research needs to be conducted into the best institutional mechanisms for LMSWT implementation, such as finding the best business organisational structure, size and level of infrastructure required.
    - This business model research should be Ethiopian led, and a business expert with experience of off grid rural electrification projects in Ethiopia should be recruited. To achieve the above it is recommended business and entrepreneurial hubs are consulted to participate in any future training sessions.
- Learn from previous experiences
    - The participation of Arthur Karomba from I Love Windpower Tanzania in the most recent SWT construction course was extremely beneficial due to his in depth understanding of SWTs in an African context. Wind Empowerment has 10 member organisations in Africa (5 of which are in East Africa) and learning from their experiences of what has worked and what hasn't in their particular context would be extremely valuable. This could be achieved either by further direct participation of staff members in future training courses or through Skype interviews.
    - Financial mechanisms are required to enable potential users to overcome the barrier of high upfront costs of LMSWTs. Research into specific delivery models such as community ownership, micro-finance, cooperatives, or pay-as-you-go that have been successfully implemented in Ethiopia for similar technologies such as PV should be

conducted. This research should identify which models would be most compatible with LMSWTs with the aim of developing partnerships with the implementing organisation.
    - Revisit the pilot projects carried out in parallel with this market assessment in order to evaluate the financial and technical sustainability of the system.

Create a positive enabling environment

- Map the market
    - This market assessment can be extended by conducting a participatory market mapping exercise. This would involve inviting key stakeholders from throughout the potential market chain (policy, project development, manufacturing, distribution, retail and energy consumption) in order to map the market system they would be part of and identify key barriers. Solutions can then be proposed collaboratively, which should ultimately result in the development of a joint action plan.
    - A supplier's database should be developed, with addresses, prices and availability of components to make purchasing of materials streamlines and reduce costs. Materials lists can be updated with new prices regularly.
- Inform policy actors
    - The Ethiopian Ministry of Water and Energy and local rural electrification planning departments should be informed of the results of this project. They may be able to provide institutional support, such as a waiver of import tax on magnets or electrical items that need to be imported, or subsidies for new wind turbine organisations.
- Tap into existing or create new knowledge sharing networks
    - An Ethiopian Wind Energy Association should be formed, possibly as an extension of the existing Ethiopian Solar Energy Association, which will exist to share best practice, conduct research and support the growing industry.
    - Wind Empowerment can continue to provide technical support in areas such as data logging, development of the design suited to local conditions, or further training courses.
- Develop higher education opportunities
    - Universities should be encouraged to offer technical wind energy training programs in their engineering departments and link to business and social science programmes in order to further understanding of locally appropriate delivery models for SWTs in Ethiopia.

References

Beall, 2006. Andean, Tibetan, and Ethiopian patterns of adaptation to high-altitude hypoxia. *Human Biology*, (46(1)), pp.18–24.

Bekele, G. & Palm, B., 2009. Wind energy potential assessment at four typical locations in Ethiopia. *Applied Energy*, 86(3), pp.388–396. Available at: http://dx.doi.org/10.1016/j.apenergy.2008.05.012.

Breyer, C. et al., 2009. Electrifing the Poor: Highly economic off-grid PV Systems in Ethiopia–A Basis for sustainable rural Development. *Proceedings 24th European Photovoltaic Solar Energy Conference, Hamburg*, pp.21–25.

British Foreign and Commonwealth Office, 2014. Ethiopia travel advice.

Capital, 2013. Government approves major wind farm project. Available at: http://capitalethiopia.com/index.php?option=com_content&view=article&id=3385:government-approves-major-wind-farm-project&catid=54:news&Itemid=27 [Accessed November 10, 2015].

Centre for Alternative Technology, 2014. Wind Power Double Module - Wind Resource.

Chevalier, P., 2011. *I Love Windpower 2.4m Piggott CAD Drawings*, Available at: http://www.i-love-windpower.com/rad_ojf.html.

DEEP EA, Small Wind Fact Sheet. *Developing Energy Enterprises Project East Africa*. Available at: http://www.gvepinternational.org/sites/default/files/factsheet_small_wind_web_final.pdf.

DfID-IED, 2013. *Low Carbon Mini-Grids. Support Study for DFID. Final Report*, London: Department for International Development and Innovation Energie Développement.

Eales, A., 2014. *Locally Manufactured Small Wind Turbines in Ethiopia: Is the Levelised Cost of Energy Competitive with Alternatives for Rural Electrification, and if so, where?* Center for Alternative Technologies. Available at: https://www.academia.edu/7865944/Locally_Manufactured_Small_Wind_Turbines_in_Ethiopia_Is_the_Levelised_Cost_of_Energy_Competitive_with_the_Alternatives_for_Rural_Electrification_and_if_so_where.

ENF Company Directory, 2014. Solar Panels Manufacturers from Africa | PV Companies List |.

ET Solar, ET Solar Module specification sheet.

Ethiopian Electric Power Corporation, 2014. Ethiopian Electric Power Corporation | Home.

Geocatalog, 2014. Geocatalog@Webservice-Energy.

Giday, Z.G., 2013. Technical and Economic Assessment of solar PV/diesel Hybrid Power System for Rural School Electrification in Ethiopia. *International Journal of Renewable Energy Research (IJRER)*, 3(3), pp.735–744.

Girma, Z., 2013. Hybrid renewable energy design for rural electrification in Ethiopia. *Journal of Energy Technologies and Policy*, 3(13), pp.38–52.

GIZ, Energy Coordination Office. Available at: http://www.giz.de/en/worldwide/18899.html [Accessed March 17, 2014].

GIZ, 2011. *Productive Use of Energy – PRODUSE A Manual for Electrifi cation Practitioners*, Available at: http://www.giz.de/fachexpertise/downloads/giz-eueipdf-en-productive-use-manual.pdf.

Hellpap, C., 2013. GIZ's EnDev Programme,. In *Global Conference Rural Energy Access: A Nexus*

Approach to Sustainable Development and Poverty Eradication. United Nations Economic Commission for Africa Addis Ababa, Ethiopia. 4-6 December 2013.

International Energy Agency, 2012. IEA - The Energy Development Index.

International Renewable Energy Agency, I., 2014. Global Atlas for Renewable Energy.

IRENA, 2013. Global Atlas for Renewable Energy. Available at: http://irena.masdar.ac.ae/ [Accessed May 15, 2015].

IRENA, 2014. *Overview of Solar and Wind Maps*, Abu Dhabi, United Arab Emirates. Available at: http://www.irena.org/DocumentDownloads/Publications/GA_Booklet_Web.pdf\nhttp://irena.masdar.ac.ae/.

IRENA, 2012. *Solar Power*, Abu Dhabi: International Renewable Energy Agency.

Jacobson, A., 2007. Connective Power: Solar Electrification and Social Change in Kenya. *World Development*, 35(1), pp.144–162.

Kamp, L.M. & Vanheule, L.F.I., 2015. Review of the small wind turbine sector in Kenya: Status and bottlenecks for growth. *Renewable and Sustainable Energy Reviews*, 49, pp.470–480. Available at: http://linkinghub.elsevier.com/retrieve/pii/S1364032115003524.

Koepke, T., 2013. *Personal conversation regarding staff costs for renewable energy practitioners in ethiopia*,

Kojima, M., 2013. *Petroleum product pricing and complementary policies: experience of 65 developing countries since 2009*, Washington, DC: World Bank.

Lakew, S., 2013. *WIND AND SOLAR RESOURCE ASSESSMENT AND OFF-GRID HYBRID SYSTEM OPTIMIZATION FOR REMOTE DISTRICTS OF WERDER ZONE – ETHIOPIA*. University of Arba Minch, Ethiopia.

Lemaire, X., 2011. Off-grid electrification with solar home systems: The experience of a fee-for-service concession in South Africa. *Energy for Sustainable Development*, 15(3), pp.277–283.

Lilienthal, P., 2014. How to Classify Microgrids: Setting the Stage for a Distributed Generation Energy Future. *Microgrid News by HOMER Energy*. Available at: http://microgridnews.com/how-to-classify-microgrids-setting-the-stage-for-a-distributed-generation-energy-future/ [Accessed November 10, 2015].

Lydetco, 2014. LYDETCO | Ethiopia Solar System & Components.

Marandin, L. et al., 2013. *Market Assessment for Small Scale Wind Turbines in Nicaragua 2012-13*, Managua: Green Empowerment.

Masdar Institute of Science and Technology, 2012a. *Modelled most economic rural electrification option (off-grid PV system, grid extension, mini-hydro, diesel generator)*,

Masdar Institute of Science and Technology, 2012b. stimated costs of electricity (Euro/kWh) delivered by a diesel generator using the diesel price for each country and taking into account the cost of diesel transportation.

Ministry of Federal Democratic Republic of Ethiopia, 2011. Ethiopia's Climate- Resilient Green Economy Strategy.

Ministry of Water and Energy, 2013. Ethiopia's Renewable Energy Power Potential and Development Opportunities.

Mulugetta, Y., 1999. Energy in Rural Ethiopia: Consumption Patterns, Associated Problems, and Prospects for a Sustainable Energy Strategy. *Energy Sources*, 21(6), pp.527–539.

NREL, 2014. Ethiopia Direct Normal Solar Radiation. Available at: http://en.openei.org/w/index.php?title=File:NREL-ethiopiadni.jpg [Accessed November 12, 2015].

Pasternak, A.D., 2000. *Global Energy Futures and Human Development: A Framework for Analysis*, University of California, Lawrence Livermore National Laboratory for the U. S. Department of Energy.

Piggott, H., 2013. *A Wind Turbine Recipe Book*, Scoraig, Scotland: Scoraig Wind Electric. Available at: www.scoraigwind.com.

Piggott, H., 2000. *Windpower Workshop*, Machynlleth, UK: Centre for Alternative Technology Publications.

RITAR, 2008. Ra12-260D Datasheet. Available at: http://www.rpc.com.au/pdf/ritar_12V_260Ah.pdf [Accessed November 11, 2015].

Smith, D., 2013. Ethiopia opens Africa's biggest windfarm. *The Guardian*. Available at: http://www.theguardian.com/global-development/2013/oct/28/ethiopia-opens-africa-biggest-windfarm [Accessed November 10, 2015].

Sumanik-Leary, J., Marandin, L., et al., 2013. Participatory Manufacture of Small Wind Turbines: A Case Study in Nicaragua. *Engineers Without Borders and Enginners Against Poverty present: Going Global*.

Sumanik-Leary, J., While, A. & Howell, R., 2013. *Small wind turbines for decentralised rural electrification: case studies in Peru, Nicaragua and Scotland*. PhD Thesis, University of Sheffield.

UNDP, 2013. Data | Human Development Reports.

UNPD, 2011. Sustainable energy access critical for development in Africa | Helen Clark | UNDP.

Wikipedia, 2014. Geography of Ethiopia - Wikipedia, the free encyclopedia.

Wind Empowerment, 2015. Wind Empowement Projects Database. Available at: http://windempowerment.org/category/projects/ [Accessed November 10, 2015].

Wind Empowerment, 2014. WindEmpowerment | Association for the development of locally built small wind turbines for sustainable rural electrification." Available on request - windempowerment@gmail.com

Wind Empowerment, 2014 "Proposal to implement locally manufactured small wind turbines in Ethiopia on request from windempowerment.group@gmail.com

Asrat, 2014. *Personal conversation regarding staff costs for renewable energy practioners in Ethiopia*,

Yadoo, A., 2012. *Delivery models for decentralised rural electrification: case studies in Nepal, Peru and Kenya*, London: International Institute for Environment and Development.

Appendicies

Appendix 1 Wind resource datasets

TABLE 27: DESCRIPTION OF WIND RESOURCE DATASETS AVAILABLE FOR ETHIOPIA

Source	Name	Description of data
3 Tier	3TIER's Global Wind Dataset 5km onshore wind speed at 80m height units in m/s	3TIER's Global Wind Dataset provides average annual wind speed at 80 meters above ground. Average values are based on over 10 years of hourly data created through advanced computer model simulations. 3TIER created this dataset using a combination of statistical methods and physics-based numerical weather prediction models, which create realistic wind fields throughout the world by simulating the interaction between the entire atmosphere and the Earth's surface.
MERRA	Global wind intensity at 10 meters in m/s from MERRA 1985 - 2012 and the global average.	MERRA is a NASA reanalysis for the satellite era using a major new version of the Goddard Earth Observing System Data Assimilation System Version 5 (GEOS-5). The Project focuses on historical analyses of the hydrological cycle on a broad range of weather and climate time scales and places the NASA EOS suite of observations in a climate context.
CENER	Wind map Ethiopia 10km CENER 2008-2010	Wind map is calculated, by simulating the atmosphere conditions with SKIRON mesoscale model. GFS 12 UTC cycle, from NCAR/NCEP is used as input. The period simulated is since January-2008 until December-2010. SKIRON long-term simulation is launched to cover the entire 3 years, generating hourly maps to the entire simulated period. With this output Africa wind map is computed averaging 10 meters wind speed from the nine years. Typically the grid horizontal resolution is 0.1 x 0.1 and has 38 vertical levels
Vortex	Wind speed East Africa 9km Vortex	10 years 80m mean wind speed at mesoscale resolution (9 km), useful for prospecting purposes only. Generated by Vortex from NCEP reanalysis using WRF model solely.

Appendix 2 Wind Turbine Component Prices

TABLE 28: COMPONENT PRICES FOR 1KW LMSWT

	Name	Description	Unit	Quantity	Unit Cost	Total Cost
Blades	Wood	Light, straight grained wood, free from knots 3 x 195mm x 60mm x 1800 mm	m3	0.064	$594.64	$38.06
	Sand Paper	sheets of sandpaper	sheet	2	$1.81	$3.62
	Wood Screws	Stainless Steel Woodscrews, 32mm	Screws	54	$0.01	$0.59
	varnish	for protecting blades	tin	0.3	$12.93	$3.88
Alternator	Resin	Polyester casting resin with accelerator	kg	3.5	$4.91	$17.19
	Catalyst	Catalyst	kg	0.05	$15.51	$0.78
	Talc	Talcum Powder	kg	2.2	$5.48	$12.06

	Fibre Cloth	Fiberglass Cloth (CSM) [1-300g/sq.meter]	m2	2	$4.65	$9.31
	Vaseline	Vaseline or mould release agent	kg	0.2	$20.68	$4.14
	Silicone	Silicone Sealant	tubes	0.2	$3.57	$0.71
	Magnets	NdFeb grade 42 46mm x 30mm x 10mm magnetised through 10mm axis	Magnets	32	$10.34	$330.93
	Solder	Lead solder	m	0.1	$17.84	$1.78
	Tape	insulation tape	rolls	0.5	$0.78	$0.39
	Conduit	Flexible conduit or hose, 20mm diameter	m	0.5	$1.24	$0.62
	Winding wire	Enamelled Copper wire, 1.5mm diameter	kg	5	$23.79	$118.93
	Steel Disks	10mm Thick Steel, OD 400, ID 100	plates	2	$22.16	$44.32
	6mm Ply	Plyboard, 6mm thick	sheet	0.25	$10.34	$2.59
	9mm Ply	Plyboard, 9mm thick	sheet	1	$41.37	$41.37
	12mm Ply	Plyboard, 12mm thick	sheet	0.5	$41.37	$20.68
	18mm Ply	Plyboard, 18mm thick	sheet	1	$41.37	$41.37
	superglue	small tube of superglue	tube	1	$0.62	$0.62
andMounting	Pipe 1.5	Steel Pipe 1.5" nominal, 4mm Wall Thickness 48.3mm OD	m	1.8	$15.93	$28.67
	Pipe 2.5	Steel Pipe 2.5" nominal 4mm Wall Thickness, 73mm OD	m	0.9	$10.34	$9.31
	Pipe 3	Steel Pipe 3" nominal 4mm Wall Thickness 88.9mm OD	m	0.7	$14.22	$9.95
	Angle	steel angle 50mm x 50mm x 6mm thick	m	1.5	$6.72	$10.08
	6mm Bar	Steel bar, 6mm thick 50mmm wide	m	1.7	$4.14	$7.03
	10mm Bar	Steel bar 10mm thick, 100mm wide	m	0.9	$14.48	$13.03
	Bearing	Trailer bearing with stub and hub, or car bearing from rear axel of car, 150mm pcd	bearings	1	$46.54	$46.54
	threaded bar	M14 Stainless steel threaded	m	2	$4.65	$9.31
	cutting disk	115mm steel cutting disk	disks	2	$1.76	$3.52
	grinding disk	115mm	disks	1	$1.40	$1.40
	welding rods	3.2mm x 350mm 5kg	box	0.3	$14.48	$4.34
	Paint	Metal paint for mounting	tin	0.5	$12.82	$6.41
Assembly Consumables	M14 nuts	14mm Stainless steel nuts	nuts	30	$0.52	$15.51
	M14 washers	14mm Stainless steel washers	washers	30	$0.26	$7.76
	10mm Bolts	M10 Bolt 50mm long	bolts	3	$1.55	$4.65
	M8 Nuts	M8 Nuts and washers	nuts	30	$0.41	$12.41
	threadlock	thread locking solution	tube	0.1	$2.38	$0.24
	paint brushes	for use with resin work	brushes	2	$1.19	$2.38
	grease	for greasing bearing and tail	tub	0.3	$6.98	$2.09
					TOTAL	$888.54

Appendix 3 Electricity Costs of Manufacturing 1 LMSWT

TABLE 29: ENERGY CONSUMPTION OF TOOLS AND MACHINERY TO BUILD A LMSWT.

Tool	Power consumption (kW)	Time (h)	Energy (kWh)
Hand Drill	0.72	4	2.88
Jig Saw	0.72	2	1.44
Angle Grinder	0.8	6	4.8
Welder	2	8	16
Orbital Sander	0.6	4	2.4
Planer	0.96	4	3.84
Pillar Drill	0.8	3	2.4
Lights	0.5	48	24
Computers and Internet	1	48	48
		TOTAL	**105.76**

TABLE 30: EEPCO PRICE TARIFF (EEPCO, 2014)

Range (kWh)		Price Rate (ETB)	Price Rate (USD)
From	To		
0	50	0.273	0.014
51	100	0.3564	0.018
101	200	0.4993	0.026
201	300	0.55	0.028
301	400	0.5666	0.029
401	500	0.588	0.030
501	1000000	0.6943	0.036

TABLE 31: COST OF ELECTRICITY FOR BUILDING A LMSWT.

Range (kWh)		Price Rate ($/kWh)	kWh in range	Total price ($)
From	To			
0	50	0.014	50.0	0.71
51	100	0.018	49.0	0.90
101	105.76	0.026	4.8	0.12
		Total unit cost		$1.61
		Service Charge: 30 days x 0.07 $/day		$2.17
		TOTAL		$3.78

Appendix 4 Tower Costs

TABLE 32: COMPONENTS FOR LMSWT 12M TOWER

Name	Description	unit	Quantity	Unit Cost	Total Cost
Tower Sections	Steel Water Pipe 6m x 88.9mm (3") 4mm WT	6m lengths	2	$85.32	$170.64
Top stub and gin pole	Steel Water Pipe 73mm (2.5") 4mm WT	6m length	2	$62.05	$124.10
6mm Steel Plate	Steel Bar 50mm wide bar, 6mm thick	m	1.6	$4.14	$6.62
8mm Steel Plate	Base Hinge 50mm wide bar, 8mm thick	m	0.1	$23.27	$2.33
rebar steel	steel rebar for anchors	m	60	$1.65	$99.28
cement	bags of cement for anchors	bag	13	$11.17	$145.19
sand	bags of sand for anchors	bag	0.6	$53.16	$31.89
Steel Angle	Base Hinge 50mm x 50mm angle 1 m	m	1	$6.72	$6.72
Steel Wire Rope	8mm thick	m	110	$0.83	$91.01
Threaded Bar	For base hinge 2m M14	m	0.125	$9.31	$1.16
Primary Shackle	12mm D Shackle	shackle	8	$1.81	$14.48
Primary Thimble	Wire rope protectors 4mm	thimble	8	$0.57	$4.55
Primary Steel Cable Clamps	for clamping steel cable 4mm	cable clamp	24	$0.78	$18.61
Primary Turnbuckles	for tightening guys12mm	turnbuckle	4	$2.95	$11.79
Secondary Shackle	As above 10mm	shackle	8	$1.81	$14.48
Secondary Thimble	As above 4mm	thimble	8	$0.57	$4.55
Secondary Steel Cable Clamps	As above 4mm	cable clamp	24	$0.78	$18.61
Secondary Turnbuckles	As above 10mm	turnbuckle	4	$2.33	$9.31
chain	Chain length for anchors	m	5	$1.03	$5.17
bolts	12mm stainless	bolt	4	$1.03	$4.14
washers	12mm stainless	washer	4	$0.52	$2.07
Cable	AWG6 tower base to control panel	m	50	$1.55	$77.56
PVC pipes	for protecting cable under ground	m	30	$0.52	$15.51
inside tower wire	Electrical connection inside tower	m	40	$1.55	$62.05
ground	grounding rod	rod	1	$29.99	$29.99

wire	ground to tower base	m	2	$1.55	$3.10
Welding rods	3.2mm x 350mm 5kg	box	0.25	$14.48	$3.62
cutting disk	115mm steel cutting disk	disks	2	$1.76	$3.52
grinding disk	115mm	disks	1	$1.40	$1.40
				TOTAL	$978.53

Appendix 5 18m Tower Sensitivity

TABLE 33: SUMMARY OF 12M TOWER COSTS AND SENSITIVTY INCREASE FOR 18M TOWER

Cost of 12m Tower		**$978.54**
Tower Height Increases to 18m		
Variables that Change	Change	Total Cost
Tower Sections	Increase to 3 lengths	$255.95
6mm Steel Plate	Use 0.4m more	$8.27
Steel Wire Rope	Use 170m	$140.64
Inside tower wire	Use 60m	$93.07
All other materials	Increase in 10%	$713.04
	New Cost	$1,210.99

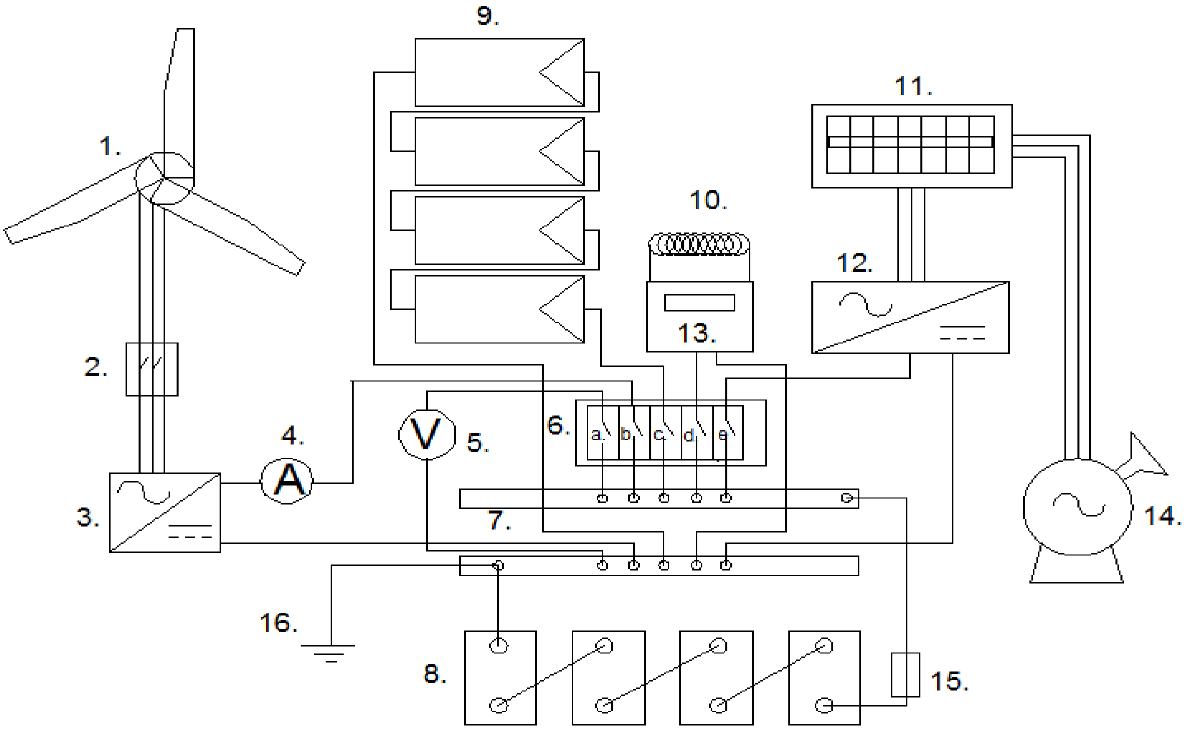
Appendix 6 Electrical Contractors

TABLE 34: LIST OF ELECTRICAL CONTRACTORS IN ADDIS ABABA

Name of Supplier	**Address**	**Telephone Number**	**Equipment supplied**
Elsewedy Cables Ethiopia Plc	Telemedanalem street, Addis Ababa, Ethiopia	251-11-6616161	Copper wire, PVC
Dagm Classic	Urael Church, Addis Ababa, Showa, Ethiopia	251-911-698737	Switches, cables, plugs
Hagbes PVT ltd	Africa Avenue, Sevita Building, 3rd Floor, Addis Ababa, Ethiopia	251-11-6638678	Alternators, generators, hand tools
Fa Light trading	Canningeham Street, Addis Ababa, Ethiopia	251-11-1553217	General electric supplies
Surafel Makasha	W.23, K.12, Addis Ababa, Shoa, Ethiopia	251-9-237854	General electric supplies

Appendix 7 Components for Electrical System

FIGURE 62: SCHEMATIC OF PROPOSED ELECTRICAL SYSTEM WITH COMPONENT SPECIFICATION.



	Component Name	Description	Unit	Quantity	Unit Cost	Total Cost
1.	Wind Turbine	1kW LMSWT star connected 3 phase alternator,	Included in separate budget			
2.	Brake Switch	double pole single throw switch	switch	1	$10	$10
3.	Bridge Rectifier	60A 300V single phase rectifier	rectifier	3	$7	21
4.	Ammeter	Displays Current from Batteries	meter	1	$10	$10
5.	Voltmeter	Displays Battery Voltage	meter	1	$10	$10
6.	Fuse/Disconnect Box	Consumer unit to house fuses with fuses inside.	Box and fuses	1	$40	$40
a.	Voltmeter Fuse/Disconnect	1A MCB DC	Included in Fuse/disconnect box			
b.	Wind Turbine Fuse/Disconnect	30A MCB DC	Included in Fuse/disconnect box			
c.	PV Disconnect	Min 7A 48V DC switch	Included in Fuse/disconnect box			
d.	Charge Controller Fuse/Disconnect	50A MCB	Included in Fuse/disconnect box			
e.	Inverter Fuse/Disconnect	50A MCB	Included in Fuse/disconnect box			
7.	Bus Bars	Copper bus bars for connections	Bus bars	2	$5	$10
8.	Battery Bank	4 x 12V 260Ah Deep Cycle Lead Acid Batteries	Included in separate budget			
9.	PV Modules	4 x ET 120Wp Polycrystalline	Included in separate budget			
10.	Dump Load	Resistive Element	dump load	1	$40	$40

11.	AC Distribution Board	Primary loads connected through distribution board	Board	1	$10	£10
12.	Inverter		Included in separate budget			
13.	Charge Controller	Tristar Charge Controller 45 (cost split with PV)	controller	1	$100	$100
14.	Generator		Included in separate budget			
15.	Battery Fuse	100A fus with holder	fuse	1	$40	$40
16.	Ground	grounding rod	rod	1	$30	$30
17.	Connections	Crimps and connection devices	crimps	14	$1.8	$25.2
18.	Triplex board	1m x 0.5m Heat resistant board	m2	0.5	$20	$10
19.	Rectifer Mounting	Aluminium Heat Sink	mounting	1	$20	$20
			TOTAL			$376.2

Appendix 8 Human Resource Costs

TABLE 35: HUMAN RESOURCE COSTS FOR MANUFACTURING AND INSTALLATION OF 1KW LMSWT

Item	Days	Cost
Blade carving, painting	14	$181
Welding the alternator frame	14	$181
Coil winding and soldering	2	$26
Stator and rotor casting	3	$39
Turbine assembling, testing and balancing	3	$39
Material Acquisition	4	$52
Tower fabrication	16	$207
Control panel wiring	2	$26
On site tower preparation	15	$194
Tower assembly and erection	12	$155
Control panel installation, connection and grounding	4	$52
TOTAL		$1150

Appendix 9 Business Plan

TABLE 36: FIXED COSTS.

Item	Description	Monthly cost	Annual Cost
Rent	10,000 ETB per month	$517	$6,024
Manager	7000 ETB	$362	$4,343
Administrator	2500 ETB	$129	$1,551
Labourer	1500 ETB	$78	$931
Loan Repayment	Total cost of tools $14,060 10 year loan period 9% interest	£128	$1,533
TOTAL Annual Cost			£14,563

TABLE 37: COSTS PER TURBINE.

Cost per turbine	Assume 10 turbines built per year	**$1,456**
Cost including Profit	20% Profit Margin	$1,747
Cost including VAT	VAT is 15% in Ethiopia	$2,010

TABLE 38: SAVINGS FROM BATCH PRODUCTION.

Area for Savings	Original Cost	% original cost saved	Savings
Materials	$2,243	40%	$897
Labour	$1,212	20%	$242
		Maximum total Savings	$1139

Appendix 11 Start-up costs for tools

TABLE 39: WORKSHOP TOOLS REQUIRED TO START A LOCAL SWT MANUFACTURING BUSINNESS

		No.	price	total	USD
metal processing	drilling machine with stand/press drill chuck 25mm	1	11500	11500	594.64
	miter saw/disk cutter 2000 W; ø 30-35cm	1	8500	8500	439.51
	bench grinder w. Stand 2850rpm; 2 disks ø200mm;	1	7400	7400	382.64
	thread cutter set M3-M12	2	6780	13560	701.16
	protractor 150mm	2	1122	2244	116.03
	caliper 160mm	3	1400	4200	217.17
	precision divider	3	575	1725	89.20
	center punch	4	221	884	45.71
	wrenches set 6-22	2	4436	8872	458.75
	hex/alles keys set .5-12	2	504	1008	52.12
	combination pliers	2	675	1350	69.81
	long nose pliers	2	675	1350	69.81
	side cutter	2	595	1190	61.53
	soldering gun 30 W	2	1620	3240	167.53
	300mm	2	705	1410	72.91
	200mm	2	539	1078	55.74
	engineering 300g	3	320	960	49.64
	claw 450g	3	810	2430	125.65
	drilling bits set 1-13mm	3	2458	7374	381.29
	files set 5 pieces	3	2182	6546	338.48
wood processing	combination table and miter saw with stand	1	18000	18000	930.74
	drilling machine with stand/press drill	1	11500	11500	594.64
	disk and belt sander	1	8000	8000	413.66
	band saw 750 W; height 162cm	2	15000	30000	1551.23
	protractor 150mm	2	1122	2244	116.03
	caliper 160mm	3	1400	4200	217.17
	precision divider	3	575	1725	89.20
	scriber	4	221	884	45.71
	broaches/wood chisel set 3/8“, 5/8“	2	1300	2600	134.44
	Saw 600mm	2	543	1086	56.15
	half round 250mm	2	89	178	9.20
	round 250mm	2	49	98	5.07
	flat 250mm	2	53	106	5.48

	flat 300mm	2	81	162	8.38
	screw drivers set flat + Phillips 10pcs	2	1700	3400	175.81
protection	first aid set	1	500	500	25.85
	safety glass	7	28	196	10.13
	ear	10	308	3080	159.26
	gloves	10	50	500	25.85
	clothes	7	350	2450	126.68
workshop	exhaustion blower 3600 W; 4“ outlet; 5m hose	2	7500	15000	775.61
	900mm, 600mm, 450mm, 300mm	10	750	7500	1106.21
	bench vise 6“ steel	5	2600	13000	672.20
	toolbox cupboard	3	15000	45000	2326.84
		TOTAL		271930	14060.85

Appendix 12 Preventative Maintenance Schedule

V3 POWER WIND TURBINE MAINTENANCE SCHEDULE

TABLE 40: OPERATIONAL MAINTENANCE

Gale force winds predicted	**Lower tower**
Lightning storm predicted	Apply brake

TABLE 41: PREVENTATIVE AND BASIC CORRECTIVE MAINTENANCE

Check every day for first month	**Watch it and monitor power** **Listen for strange sounds**
Check every week for first month	Check the cable and untwist as necessary Check all the anchors are secure
Check every month	Watch with binoculars Monitor power output Listen for strange sounds Untwist cable Check all the anchors are secure, cable clamps are tight, and that the turnbuckles haven’t loosened.
Take-down after six months & every year thereafter	Re-tighten all the bolts and nuts Repaint blades and metal mounting as necessary Repaint stator and rotor discs as necessary Refresh grease on yaw and tail pivot Check the bearing and re-grease if needed Vaseline electrical connections Grease turnbuckles if needed

Appendix 13 O&M Costs for different levels of site access

TABLE 42: PREVENTATIVE AND BASIC CORRECTIVE MAINTENANCE

O&M	Materials Costs	Travel and Labour Costs	Total	Cost Multiplier
Low	$125	$202	$327	1
Medium	$125	$353	$478	1.46
High	$125	$652	$777	2.38

Appendix 14 PV Module specifications

TABLE 43: THE CHOSEN PANEL (120W) IS HIGHLIGHTED IN RED (ET SOLAR N.D.).

ET Module

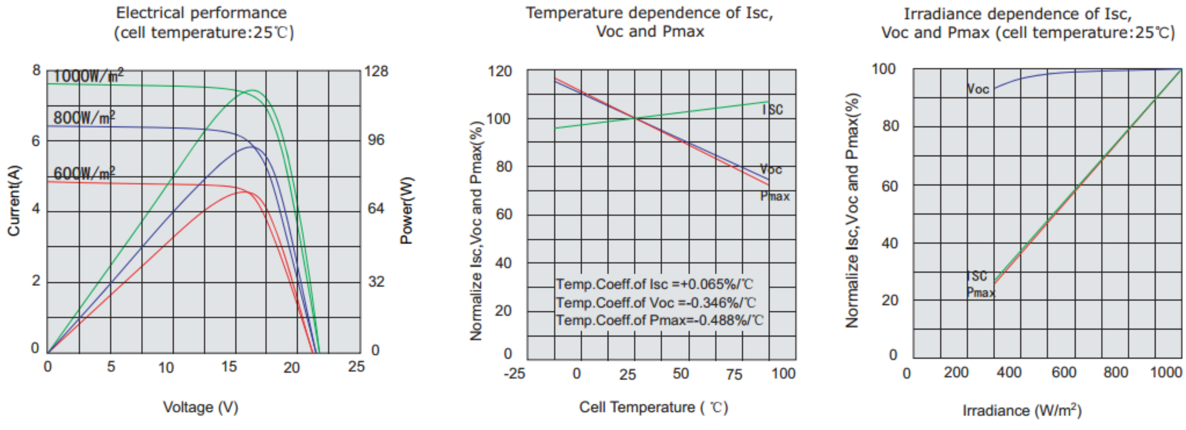
ET-P636145 ET-P636140 ET-P636135 ET-P636130 ET-P636125 ET-P636120 ET-P636115

SPECIFICATIONS

Model type	ET-P636145	ET-P636140	ET-P636135	ET-P636130	ET-P636125	ET-P636120	ET-P636115
Peak power (Pmax)	145W	140W	135W	130W	125W	120W	115W
Cell type	PolyCrystalline Silicon, 156mm x 156mm						
Number of cells	36 cells in series						
Weight	12.0 kg (26.5 lbs)						
Dimensions	1482×676×34 mm (58.3×26.6×1.3 inch)						
Maximum power voltage (Vmp)	17.80V	17.60V	17.60V	17.41V	17.40V	17.40V	17.20V
Maximum power current (Imp)	8.15A	7.95A	7.67A	7.47A	7.18A	6.89A	6.68A
Open circuit voltage (Voc)	21.96V	21.96V	21.96V	21.75V	21.75V	21.75V	21.75V
Short circuit current (Isc)	8.50A	8.41A	8.41A	8.10A	7.80A	7.63A	7.55A
Maximum system voltage	DC 1000V						
Temp. Coeff. of Isc (TK Isc)	0.065 %/℃						
Temp. Coeff. of Voc (TK Voc)	-0.346 %/℃						
Temp. Coeff. of Pmax (TK Pmax)	-0.488 %/℃						
Normal Operating Cell Temperature	45.3±2℃						

Note: the specifications are obtained under the Standard Test Conditions (STCs): 1000 W/m² solar irradiance, 1.5 Air Mass, and cell temperature of 25℃.

ELECTRICAL CHARACTERISTICS



Appendix 15 PV Suppliers

TABLE 44: SUPPLIERS OF PV EQUIPMENT IN ETHIOPIA (GIZ, 2012)

Importing company	Major PV product	PV business sector	Equipment sources	Contact details
Everbright	Modules and balance of systems including controllers, batteries and light bulbs	SHS and small commercial systems market	Imports products mostly from China	Tesfaye Legese Tel: (+251) (0) 911619474
Lydetco P.L.C	All modules and system components from major PV multinational PV company in Europe	Institutional, telecom	PV products mainly from Europe	Dereje Walelign Tel: (+251) (0) 911207283 or 114 663189 lydet@ethionet.et
BETA Electrical Engineering P.L.C.	Modules: Opportunistic, BOS: India, Europe.	Household, small commercial and institutional systems market	Mostly from India	Kassa W.Senbet Mob: (+251) (0) 911242766 route@ethionet.et
Ethio-Ducth Business P.L.C	Product list includes modules, BOS	Institutional system markets	China and Europe	Adane W. Michael Tel: (+ 251) (0) 113200021 adane@solar-man.net
Solar 23	PV Panels, Charge Controllers, Solar Home Systems	Institutional systems market, wholesale to distributers.	Europe	Nabil Ishak Nefas Silk Lafto Sub City Kebele 06 - House No. 182 P.O. Box 22572/1000 Addis Ababa / Ethiopia Tel: (+251) (0) 118 500 024 Mob: (+251) (0) 911 714 668 nabil.ishak@solar23.com

Appendix 16 Battery Specifications

FIGURE 63: RITAR RA12-260D DATASHEET (RITAR 2008).

RA12-260D (12V260Ah)

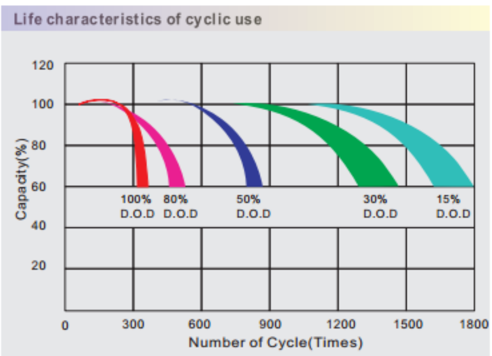
RA12-260D is AGM Deep cycle battery with 10 years floating design life, specially designed for frequent cyclic discharge usage. By using strong grid and specific paste plate, it makes battery have 30% more cyclic life time than standby series. It is applicable for solar energy system, golf cart, electric wheelchair, etc..

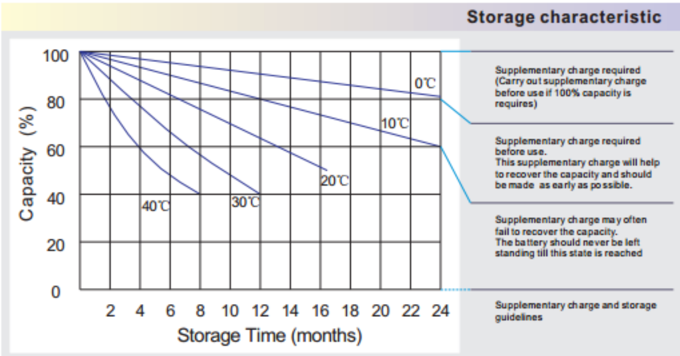
Specification

Cells Per Unit	6
Voltage Per Unit	12
Capacity	260Ah@10hr-rate to 1.75V per cell @25°C
Weight	Approx. 74.0 Kg
Max. Discharge Current	2600 A (5 sec)
Internal Resistance	Approx. 3.5 mΩ
Operating Temperature Range	Discharge: -20°C~60°C Charge: 0°C~50°C Storage: -20°C~60°C
Normal Operating Temperature Range	25°C±5°C
Float charging Voltage	13.6 to 13.8 VDC/unit Average at 25°C
Recommended Maximum Charging Current Limit	78 A
Equalization and Cycle Service	14.6 to 14.8 VDC/unit Average at 25°C
Self Discharge	RITAR batteries can be stored for more than 6 months at 25°C. Self-discharge ratio less than 3% per month at 25°C. Please charge batteries before using.
Terminal	Terminal F14
Container Material	A.B.S. (UL94-HB), Flammability resistance of UL94-V1 can be available upon request.

Constant Current Discharge Characteristics: A (25°C)

F.V/Time	5MIN	10MIN	15MIN	30MIN	1HR	2HR	3HR	4HR	5HR	8HR	10HR	20HR
9.60V	896.2	642.2	467.3	287.0	162.2	92.62	65.15	53.91	42.43	31.00	26.22	13.86
10.0V	872.2	611.0	457.7	282.3	161.5	91.92	64.90	53.66	42.18	30.75	25.96	13.61
10.2V	821.9	589.5	450.5	279.8	160.0	91.23	64.40	53.41	41.93	30.50	25.71	13.36
10.5V	738.0	543.9	428.9	272.8	158.5	90.53	64.15	52.92	41.43	30.25	25.46	13.11
10.8V	666.1	496.0	395.4	260.8	154.8	88.91	62.40	51.67	40.68	29.74	25.21	12.86
11.1V	579.9	443.3	354.6	244.4	147.0	84.96	59.65	49.17	38.94	28.48	24.45	12.10





Appendix 17 Description of the Hugh Piggott turbine

The rotor element of the turbine is comprised of three blades carved from wood well treated to withstand the elements attached with a disk made of plyboard or steel. The blades are attached to an axial flux permanent magnet alternator comprising of two rotor disk containing neodymium or ferrite magnets cast in polyester resin rotating either side of a stationary stator containing hand wound enamelled copper coils similarly cast in resin. The magnets induce a voltage in the electrical coils in the stator through an axial flux configuration. This alternating current (AC) is then converted to direct current (DC) by a set of diodes to charge batteries.

The alternator is held in place by a steel mounting made of steel pipe, angle and plate and spins on a bearing which is either a rear car hub or a trailor stub bearing. A tail vane made steel pipe and plyboard maintains the turbine in the direction of the wind. The turbine incorporates a furling over protection system whereby the tail will hinging at the frame in the direction of the blades at wind speeds over 10m/s, mechanically protecting the blades from failure.

The turbines AC output is converted to DC via a bridge rectifier to charge batteries. When the batteries are fully charged, a simple electronic load controller diverts the electrical power to dump loads thereby protecting the batteries from getting overcharged. In case of emergency, any operator can easily stop the turbine by applying an electro-mechanical break using a short-circuit switch.

The turbine is generally installed on a tower up to 20m in height depending on surrounding wind resource and surrounding terrain. A standard tilt-up tower consists of steel pipe held up by steel wire rope attached to ground anchors, with chain and turnbuckles to tighten the guys. A gin pole and winch is used for erecting and taking down the tower for turbine maintenance and inspection.

Appendix 18 Wind speed height corrections

The CENER wind map has a reference height of 10m above ground level, however a 12m hub height is recommended for LMSWTs in Ethiopia and an additional calculation was run to explore the option of an 18m tower. To determine the wind speeds at the increased height, the wind logarithmic law (Centre for Alternative Technology 2014) was used with a roughness factor of 0.01:

$$\frac{U(z)}{U(z_r)} = \frac{\ln\left(\frac{z}{z_0}\right)}{\ln\left(\frac{z_r}{z_0}\right)}$$

U = Wind speed at height, z
z = height at which to calculate wind speed (12m, 18m)
z_r = reference height with a known wind speed (10m)
z_o = roughness factor (0.01)

The resulting wind speeds for a 12m and 18m tower have been calculated and are shown below.

TABLE 45: ADJUSTED WIND SPEEDS FOR CHANGE IN HEIGHT.

Key	Wind Speed at 10m (m/s)	Wind Speed at 12m (m/s)	Wind Speed at 18m (m/s)
	0.877 - 1	0.09 – 1.03	0.95 - 1.09
	1 – 1.5	1.03 – 1.54	1.09 – 1.63
	1.5 – 2	1.54 – 2.05	1.63 – 2.17
	2 – 2.5	2.05 – 2.57	2.17 – 2.71
	2.5 – 3	2.57 – 3.08	2.71 – 3.26
	3 – 3.5	3.08 – 5.59	3.26 – 3.80
	3.5 – 4	3.59 – 4.11	3.80 – 4.34
	4 – 4.5	4.11 – 4.62	4.34 – 4.88
	4.5 – 5	4.62 – 5.13	4.88 – 5.43
	5 – 5.5	5.13 – 5.65	5.43 – 5.97
	5.5 – 6	5.65 – 6.16	5.97 – 6.51