KTH Industrial Engineering and Management

Techno-economic Assessment of Wind Energy to Supply the Demand of Electricity for a Residential Community in Ethiopia

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(820818-A936)

Master of Science Thesis

KTH School of Industrial Engineering and Management
Energy Technology EGI-2011-097MSC
Division of Heat and Power Technology
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Abstract

The electricity sector is a major source of carbon dioxide emission that contributes to the global climate change. Over the past decade wind energy has steadily emerged as a potential source for low carbon energy source which are grown through time. As wind power generation increases around the world, there is increasing interest in adding intermittent power to the electricity grid and to design an off-grid wind energy system.

The goal of the current thesis is to investigate techno-economically viable wind energy system that supplies electricity and Heat for a given residential community in Ethiopia. To ease the optimization process, HOMER software is used to identify the potential wind area and optimize cost effective wind energy system.

Based on the available wind speed data from NMSA (National Metrological Service Agency), 34 sites annual average wind speed is calculated and three wind potential areas (>4m/s) are identified for further investigation. The geographical locations of all 34 sites are plotted with its corresponding annual wind speed using surf 8 software. The three selected regions are Moyale, Mehalemeda and Negele.

To compensate the missed night time data while investigating an ideal potential area, scaling factor assumption made by B.Getachew and B.Palm is used. Based on the potential investigation, Moyale site is selected as an ideal place to implement wind energy system.

Once the ideal potential area is selected, wind energy system optimization process is done by calculating the electric appliance load of a hypothetical model of rural village of 100 households. In addition to household, loads required for community services like water pumping, clinic, school, milling house, business centers and administrative offices are determined. A total of 369.45KW load which is equivalent to 1417.5 KWh/year is demanded for a Moyale village of 100 household populations.

Various scenarios of wind energy models are considered while evaluating the cost-effective energy system. After a thorough analysis of different scenarios based on the design constraints of low net present cost (NPC), less cost of energy COE, high renewable fraction, low capacity shortage, considerable excess electricity and high capacity factor of components, **scenario A** (2-wind turbine of Fuhrlander100, 53 KW diesel generator, 200-surrette 6CS25P battery and 100KW converter) is selected as a cost effective energy system.

The selected energy system costs a total net present cost of $1,760,782 at interest rate of 8%. At the hub height of 70 m and current diesel price of $1/L. The designed wind energy system costs the customer about $0.344 per KWh.

Key Words: Wind Energy System, Wind Potential Investigation, HOMER, Least Cost of Energy and Household load

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Notations

AC	Alternating Current
Ah	Ampere-hours
AWEA	American Wind Energy Association
CFD	Cumulative Density Function
COE	Cost of Energy
CO_2	Carbon dioxide
DC	Direct Current
DC	Duration Curve
DOE	Department of Energy
EEPCo	Ethiopian Electric Power Corporation
EMSA	Ethiopian Meteorological Service Agency
EU	European Union
EWEA	European Wind Energy Association
GoE	Government of Ethiopia
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit
GWh	Gegawatt hour
HOMER	Hybrid Optimization Model of Electric Renewable
MW	Megawatt
NASA	National Aeronautics and Space Administration
NMSA	National Metrological Services Agency
NPC	Net Present Cost
O & M	Operation and Maintenance
PASDEP	Plan for Accelerated and Sustained Development to End Poverty
PDF	Probability Density Function
PV	Photo voltaic
TWh	Terawatt hour

Acknowledgment

First, I am grateful to my advisor Dr. Nabil Kassem from KTH for his valuable comments and suggestion that I have to correct each and every step of my thesis work. I have also deepest gratitude to my local advisor Dr. Solomon T/mariam for his constant courage and follow up while I work on this fruit full thesis.

Lastly, I am indebted to my class mate Degene Hagos for his help me to have a tiresome work of recording manual wind speed data to soft copy version.

Chapter One

1.1. Introduction and Background

Ethiopia is a Federal Democratic Republic (FDRE) since 1991 with nine Regional State and with two Municipality Administrations. It has a two tier government structure Federal and Regional. The federal government is mandated with defense, foreign affairs, immigration, currency and criminal matters. The Regional Council on the other hand is mandated with political, economic and social affairs regarding the particular Regional states.

With an estimated population of 79.2 million and 1.1million square kilometers of landmass, Ethiopia is one of the Horn of Africa countries located between the 330 and 480 East longitudes and between 30 and 180 North latitudes. It is bordered by Djibouti and Somalia to the east, Kenya to the South, Sudan to the west, and Eritrea to the North [Wikipedia, 2010]. It has a diverse climate condition due to the contrasting altitude, which ranges from the highest point of 4650meters above Sea Level at Ras Dashen Mountain to 420 meters below Sea level at Dallol depression. In this country the population density reaches 72 persons per Km2 and the Gross Domestic Product (GDP) per capita was USD 800 in 2005, with 50 % of the population below the poverty line.

Even though Ethiopia is the second most populous nation in Africa and has diversified resource for development, the country has been suffering from cyclical drought and is listed as one of the poorest nations in the world. Since the country's economy is highly dependent on back-warded and traditional agriculture for last decades. Recently Ethiopia is committed to shaping its economic future to change the image of country. The government has adopted the long-term goal of the five year development strategy, PASDEP (Plan for Accelerated and Sustained Development to End Poverty), is for Ethiopia to become a middle income country in 20-30 years. Since Ethiopia is not an oil producing country, it should achieve this target by strong industrial development in addition to mechanized agriculture.

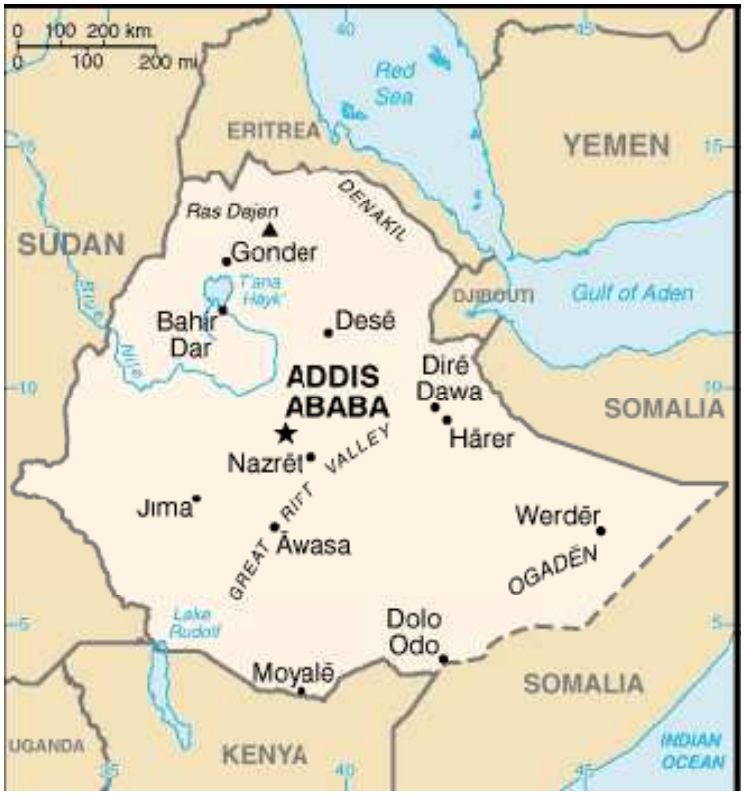


Figure 1.1: Ethiopia's Relative location in East Africa

A stable supply of enough energy is a must for industrialization. However, the access to energy in Ethiopia is relatively low, as little as 16 % (2005), while the average access rate of Sub-Sahara Africa is 26%. The access to energy is gradually improving to reach 20% in 2007 by the efforts of the EEPCo (Ethiopian Electric Power Corporation) and the GoE (Government of Ethiopia) constructing new power plants and expanding the national grid, although it is still lower than the Sub-Sahara African average. In addition, some say that this figure is not reflecting the number of the population who are actually using electricity. The official number, 16%, is calculated by the population living in the electrified area (which means the area the national grid reaches) but many of the poor do not have money to pay the cost for distribution lines from the national grid to their houses and they are left without electricity. The real access rate of the population that is actually using electricity is said to be much lower, about 6 %.

On the other hand, Ethiopia is facing new difficulties, such as a food shortage caused by the lack of rain during the short rainy season; in 2008, the oil price surge hitting all over the world, and

hyper inflation which has reached 40%. Ethiopia has been recording two digit economic growths for the last five years but it is anticipated that it would slow down due to these new challenges. Further enhancement of the energy sector is a must in order to maintain the economic growth and become a middle-income country in 20-30 years through industrialization and mechanized agriculture, considering the difficult macro-economic situation.

Although Ethiopia is not well blessed with natural resources (oil) according to current knowledge, it has rich water resources such as the Nile River and good potential of renewable energy resource (solar, wind and Biomass, etc). Therefore, Ethiopia is aggressively developing hydropower plants, as it is relatively cost effective, not only to fulfill the domestic needs but also to export surplus electricity to the surrounding countries. For indication in the year of 2009/10 a total amount of 1.18GW power is added in the grid system successfully and planed to reach today's 1.8GW to 10GW in the next five years.

As can be seen from the expansion of hydro power plant, the Ethiopian electric energy system is highly dependent on hydropower, according to EEPCo its share is 97 % of the total energy generation. The total net has an installed capacity of 1895 MW in the Interconnected System and 31 MW in the Self Contained System. Due to the precipitation and siltation of the reservoirs some of the hydro power plants are losing storage volume resulting in reduced energy output throughout the year. Another restriction of the hydro system is caused by the variability of rainfall. In years of low rainfall and drought the amount of water available during the rainy season from July until September does not allow for the reservoirs be filled up to the maximum. These extreme changes in water availability indicate the problems of the Ethiopian electricity supply.

The energy sector in Ethiopia is expanding rapidly, and even with the new hydro power plants, the problem of the fluctuating water availability will not be solved entirely. Thus, in order to guarantee security of supply, the power generation system has to be diversified. The necessary increase of the electrification rate and the corresponding grid expansion, need additional capacity in the short-run to support the hydro system throughout the year and especially at the end of the dry season, when water levels are low and demand remains constant. Therefore, a fast-track implementation capacity increase is necessary. As a short-run solution to cover the increasing and suppressed demand, EEPCo evaluates two alternatives: wind and diesel power.

More than three diesel power plants were already commissioned to easy energy shortage caused by drought and to reduce load shedding. Ethiopia is fully reliant on fuel imports. Fuel prices have been steady increasing in the last years, which worsens the economic feasibility of the installed and new diesel power plants.

Ethiopian Electric Power Corporation (EEPCo) is planning the implementation of wind Parks in several areas of Ethiopia, which are estimated to comprise of up to 200 MW to the year 2012.The main reasons why EEPCo focus on wind energy among other energy sources are, oil crises, the wind has high potential in dry season and the country is gifted with wind energy which is estimated to provide 5,723.3 TWh [18].

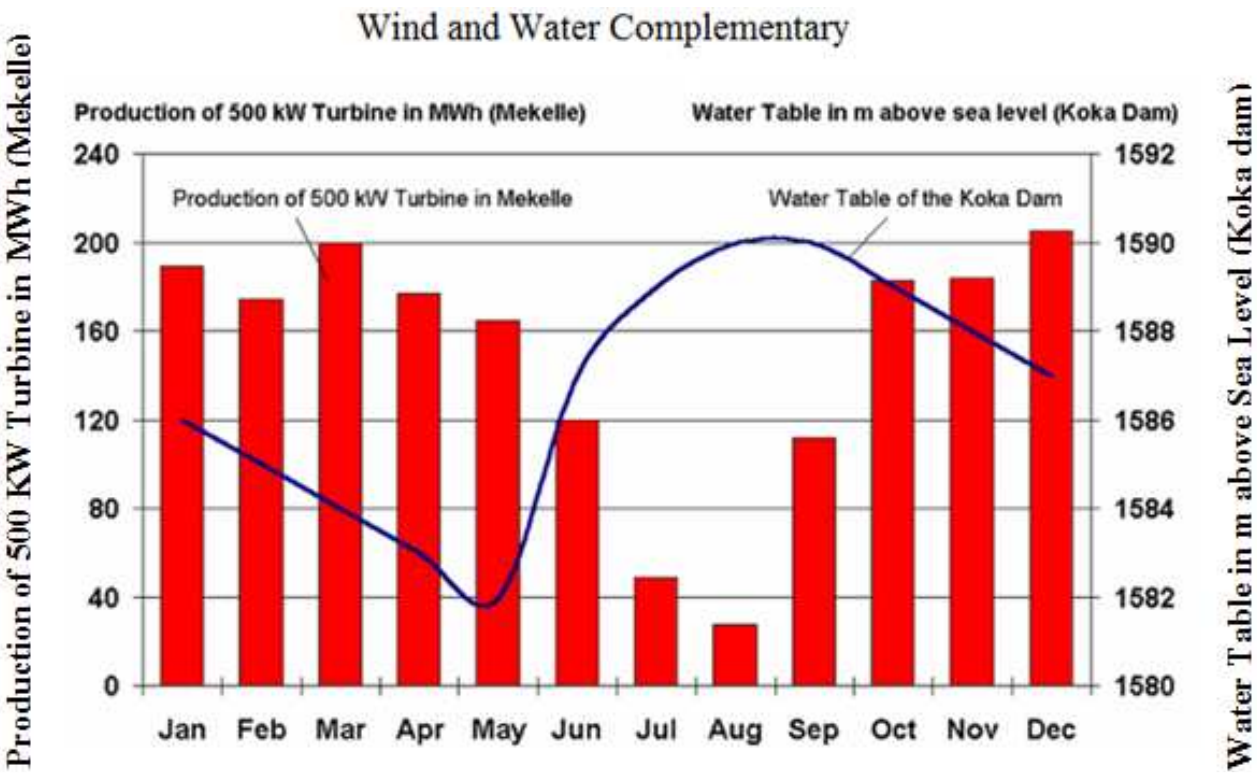


Figure 1.2: Wind and Water Complementary [Source: Benjamin Jargstorf "Wind Energy for Electricity Production – Experiences World-wide and Prospects for Ethiopia" in: Proceedings of Energy Conference 2002, Addis Ababa 2002, p. 205

In addition to the abundance of wind energy in Ethiopia, it is a clean source of energy, which is expected to be competitive with other form of energy in the near future. Considering the

transition towards a low-carbon economy, wind energy is a promising ingredient of the total energy mix to replace part of conventional fuels.

Although EEPCo currently managing the power generation and distribution all over the country in grid system which is controlled within a central system, the energy policy encourages for private company to engage itself to the generation of power both in a urban as well as in rural areas to satisfy the demand which is increasing with the rate of 16% per annual (EEPCo, 2006). So as to satisfy the demand wind is an ideal alternative since it is a free, inexhaustible resource and has excellent long term price stability due to easily projected operation and maintenance expenses [3]. If external/social costs are included, it is estimated that wind power in many countries is already competitive with fossil and nuclear power [4]. Wind energy has become one of today's lower cost renewable energy technologies. Wind energy is currently viewed as one of the most promising of the renewable energy sources. However, despite wind energy's long history and non-polluting qualities, concerns and questions about the technology and its use still exist.

Studies show that deployment of small wind turbines, particularly, in urban areas is getting more attractive, since it can provide between 10-30% of electricity needs of residential and office buildings. Therefore, this thesis conducts a techno-economic assessment of standalone wind energy to supply the demand of electricity and heat for 100 households at a selected site in Ethiopia with good wind potential. The viability of techno-economic assessment is done using HOMER software. The community of the selected site is expected to benefit from the obtained results and the total electricity production of the country would substantially increase.

1.2. Introduction to HOMER Software

The Hybrid Optimization Model of Electric Renewable (HOMER) Micropower Optimization Model is a computer model developed by the U.S. National Renewable Energy Laboratory (NREL) to assist in the design of micropower systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER remodels a power system’s physical behavior and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows the modeler to compare many different

design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs [5].

HOMER can model grid-connected and off-grid micropower systems serving electric and thermal loads, and comprising any combination of photovoltaic (PV) modules, wind turbines, small hydro, biomass power, reciprocating engine generators, microturbines, fuel cells, batteries, and hydrogen storage.

The analysis and design of micropower systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. Renewable power sources add further complexity because their power output may be intermittent, seasonal, and non dispatchable, and the availability of renewable resources may be uncertain. HOMER was designed to overcome these challenges.

HOMER performs three principal tasks: simulation, optimization, and sensitivity analysis. In the simulation process, HOMER models the performance of a particular micropower system configuration each hour of the year to determine its technical feasibility and life-cycle cost. In the optimization process, HOMER simulates many different system configurations in search of the one that satisfies the technical constraints at the lowest life-cycle cost. In the sensitivity analysis process, HOMER performs multiple optimizations under a range of input assumptions to gauge the effects of uncertainty or changes in the model inputs. Optimization determines the optimal value of the variables over which the system designer has control such as the mix of components that make up the system and the size or quantity of each. Sensitivity analysis helps assess the effects of uncertainty or changes in the variables over which the designer has no control, such as the average wind speed or the future fuel price.

To use HOMER, one should provide the model with inputs, which describe technology options, component costs, and resource availability. HOMER uses these inputs to simulate different system configurations, or combinations of components, and generates results that can be viewed as a list of feasible configurations sorted by net present cost. HOMER also displays simulation results in a wide variety of tables and graphs that help one compare configurations and evaluate them on their economic and technical merits. In addition it is possible to export the tables and graphs for use in reports and presentations [HOMER, 2005].

1.3. Objectives

1.3.1. General objective

The General objective of this study is to investigate the practicality of wind energy system in Ethiopia by assessing the techno-economic viability of wind energy that supplies the demand of electricity and Heat for a given residential community in Ethiopia.

1.3.2. Specific Objectives

The specific objectives of this study are to:

- Evaluate the wind energy potential in the selected sites based on the available wind speed data from weather metrological station of Ethiopia.
- Estimate the electricity and heat load demand based on a household model for the selected site which has relatively high wind potential.
- Configure the wind energy system to meet estimated load demand using different scenarios.
- Optimize the wind energy system or the proposed scenarios based on economic grounds.
- Conduct total cost analysis to assess the economic feasibility of the wind energy system.

1.4. Method of Attack

To achieve the above specific objectives the following method of attacks are conducted.

- A literature review on wind Energy systems for remote residential communities and major components of wind energy systems are studied.
- According to the availability of the data from NMSA, 34 location yearly average wind speed is calculated and three potential areas are selected for further study to select one ideal site in regard to wind potential. The pre-selected sites are namely, Mehalemeda, Moyale and Negele.
- Using HOMER Software, the potential of wind energy is investigated based on the [G.Bekele and Palm] assumption to select the most promising wind potential site among three sites stated above.
- A single household demand load is calculated and then the load required for the 100 households living nearby the selected site is also estimated accordingly.

- In addition to house use load, loads required for community services like water pumping, clinic, business centers and administrative offices are determined. Also two types of loads are identified while modeling the energy systems, namely: primary and deferrable load.
- Different set up of techno-economic models of the wind energy systems (scenarios) are developed.
- The computational algorithms using HOMER software are done for the proposed models to assess the system feasibility.
- Computer simulations are done for the proposed algorithms to generate results based on the input parameters.
- Finally, economic feasibility studies of the various scenarios are conducted to select the best combination of wind-generator-battery energy system to satisfy the electric demand of the selected site.

Chapter Two

Literature Review on Wind Energy System

2.1. Source of Wind Energy

Wind is the natural movement of air across the land or sea which is caused by uneven heating and cooling of the earth's surface and by the earth's rotation. The sun heats the earth and water areas at different rates depending on whether an area is below clouds, in direct sunlight, or covered with water. The air above the warmer areas heats up, becomes less dense, and rises. The rising air creates a low pressure area. Cooler air from adjacent higher pressure areas moves to the low pressure areas. This air movement is called wind. The rotation of the earth changes the direction of the flow of air which produces prevailing winds. Surface features such as mountains and valleys can change the direction and speed of prevailing winds [3].

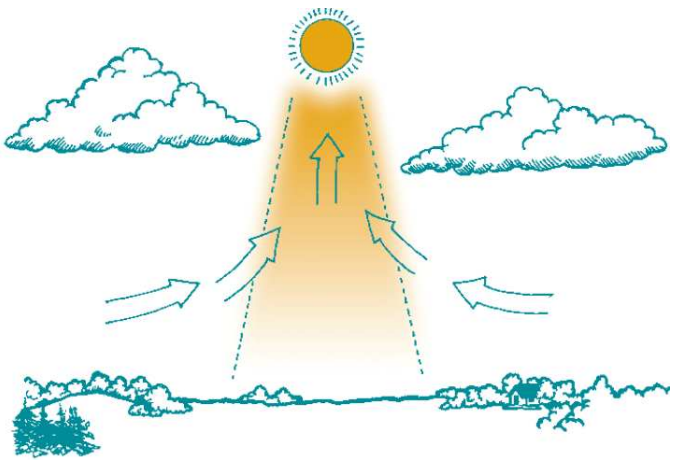


Figure 2.1: Wind is caused by the movement of air

2.2. History of Wind Energy

People have been capturing the energy contained in the wind's movement for hundreds of years. It has played a long and important role in the history of human civilization. The first known use of wind dates back 5,000 years to Egypt, where boats used sails to travel from shore to shore. And this technology is come later to western; Dutch-style windmills were first used in the 12th Century, and by the 1700s, had become a major source of power in Europe. In North America, farmers adopted windmill technology to pump water about a hundred years ago [7]. Today, the

turning rotors of a wind energy system can still be used to run pumps, and to run a generator to generate electricity.

For indication, cumulative global wind energy generating capacity topped 39,000 MW and reached 39,294 MW at the end of 2003. New equipment to totaling 8,133 MW in capacity was installed worldwide during the year, an increase of 26%, according to estimates by the American Wind Energy Association (AWEA) and the European Wind Energy Association (EWEA) [8]. This growth is increased every year with double digit and reached an installed wind energy capacity of 159’213MW at the end of 2009[11]. From this figure, America and Europe took the Lion’s share.

In general, the growth of renewable energies has been influenced by international obligations. At the global level, there are obligations set forth by the Kyoto Protocol. The EU has to reduce its green- house gas emissions by 8% of 1990 levels by 2008 –2012. Beyond the different framework conditions in the singular EU Member States which influence the success of renewable energies also the deployed instruments for their promotion play a crucial role. The main instruments for promoting renewable are feed-in tariffs, quota obligations, tenders and (energy) tax exemptions [10].

2.3. World View of Wind Energy

According to world wind energy report of 2009, the global wind energy generating capacity reached 159’213MW at the end of 2009. As shown in the fig 2.2 this 159’213MW wind energy was only 24’322MW in the year of 2001which is accelerated with growth rate of 31.7%, the highest rate since 2001. Referring to figure 2.2, it can be concluded that the installed wind capacity is more than doubling every third year. Totally, the generating capacity of all wind turbines installed by the end of 2009 worldwide are reached 340TWh per annum, equivalent to the total electricity demand of Italy, the seventh largest economy of the world, and equaling 2 % of global electricity consumption [11].

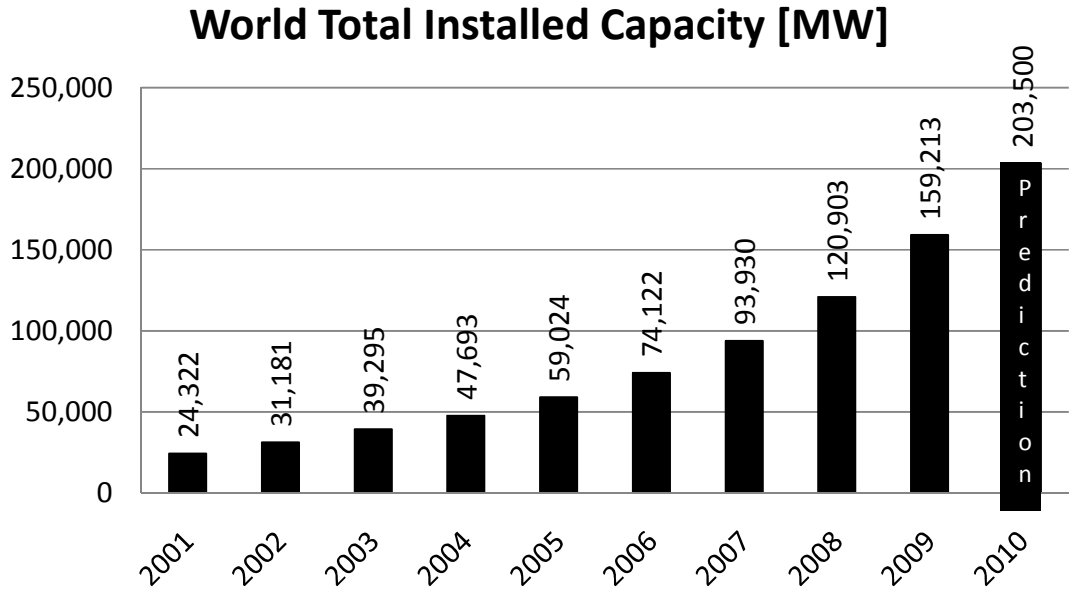


Figure 2.2 :World total installed capacity of wind, *source:* 9th World Wind Energy Conference & Exhibition, Large-scale Integration of Wind Power, held in Istanbul, Turkey in June 2010 [11]

In comparison, according to the International Atomic Energy Agency (IEA) the share of nuclear power in the global energy supply went again down in the year 2009 and the number of nuclear power stations worldwide decreased by one.

The main reason for the reduction of nuclear power and an increase of wind power is Kyoto Protocol; a series of greenhouse gas reduction targets has cascaded down to a regional and national level. These in turn have been translated into targets for increasing the proportion of renewable energy, in energy mix supply. Kyoto Protocol called for global cut of 8% from 1990 levels through the period 2008-2012, a series of greenhouse gas reduction targets has cascaded down to regional and national levels. Wind power and other renewable energy technologies generate electricity without producing the pollutants associated with fossil fuels and nuclear power generation, and emit no carbon dioxide, the most significant greenhouse gas.

For this reason, the global financial and economic crisis, all in all, had no negative impact on the general development of the wind sector worldwide. Many governments sent clear signals that they want to accelerate wind deployment in their countries and indicated that investment in wind and other renewable technologies is seen as the answer to the financial as well as to the still ongoing energy crisis.

As an indication, China continued its role as the locomotive of the international wind industry and added 13’800 MW within one year as the biggest market for new turbines, more than doubling the installations for the fourth year in a row. The USA maintained its number one position in terms of total installed capacity and China became number two in total capacity, only slightly ahead of Germany, both of them with around 26’000 Megawatt of wind capacity installed. Asia accounted for the largest share of new installations (40.4 %), followed by North America (28.4 %) and Europe fell back to the third place (27.3 %). Latin America showed encouraging growth and more than doubled its installations, mainly due to Brazil and Mexico.

Table 2.1: Global Wind Energy Generating Capacity in top 10 Countries [11]

Rank 2009	Country	Total Capacity End 2009 [MW]	Added Capacity End 2009 [MW]	Growth rate 2009 [%]	Rank 2008	Total Capacity End 2008 [MW]	Total Capacity End 2007 [MW]	Total Capacity End 2006 [MW]
1	USA	35’159.0	9’922.0	39.3	1	25’237.0	16’823.0	11’575.0
2	China	26’010.0	13’800.0	113.0	4	12’210.0	5’912.0	2’599.0
3	Germany	25’777.0	1’880.0	7.9	2	23’897.0	22’247.4	20’622.0
4	Spain	19’149.0	2’460.0	14.7	3	16’689.0	15’145.1	11’630.0
5	India	10’925.0	1’338.0	14.0	5	9’587.0	7’850.0	6’270.0
6	Italy	4’850.0	1’114.0	29.8	6	3’736.0	2’726.1	2’123.4
7	France	4’521.0	1’117.0	32.8	7	3’404.0	2’455.0	1’567.0
8	UK	4’092.0	897.0	28.1	8	3’195.0	2’389.0	1’962.9
9	Portugal	3’535.0	673.0	23.5	10	2’862.0	2’130.0	1’716.0
10	Denmark	3’497.0	334.0	10.6	9	3’163.0	3’125.0	3’136.0

Table 2.2: Global Wind Energy Generating Capacity by Regions [11]

Rank 2009	Region	Total Capacity End 2009 [MW]	Added Capacity End 2009 [MW]	Growth rate 2009 [%]	Rank 2008	Total Capacity End 2008 [MW]	Total Capacity End 2007 [MW]	Total Capacity End 2006 [MW]
1	Europe	76’218.0	10’474.0	15.9	1	65’744.0	57’313.0	48’625.0
2	Asia	39’961.0	15’496.0	63.3	3	24’465.0	15’872.0	10’625.0
3	North America	38’478.0	10’872.0	39.4	2	27’606.0	18’669.0	13’063.0
4	Australia	2’338.0	505.0	27.6	4	1’833.0	1’064.0	988.0
5	Latin America	1’406.0	747.0	113.4	5	659.0	516.0	516.0
6	Africa	770.0	169.0	28.1	6	601.0	501.0	337.0

Global wind power capacity increased alarmingly over the past nine years, growing from 24’322 MW at the end of 2001 to more than 159,213 MW at the end of 2009, an increase of over 134’891 MW. According to World Wind Energy Report 2009, from total share of wind energy production in the world Europe accounts for 47.9%, Asia accounts 25.1% and : North America accounts 24.2%. But other regions which accounts almost 2.8% share of wind are beginning to emerge as substantial markets for the wind industry. Almost 82 countries around the world are now contributed to the global total, and the number of people employed by the industry worldwide is estimated to be around 550’000.

But the installed capacity and growth rate of wind energy in Africa is not significant compared to the rest of the world. All wind turbines installed in Africa in 2009 had a capacity of 770 Megawatt (0.5 % of the total worldwide capacity), out of which 169 Megawatt were added, in two countries, Egypt and Morocco. Although Africa was already on a comparatively low level, the growth rate of 28 % was again below the global average of 31.7 %.

However, an increasing number of African governments were getting aware of the potentials of wind energy in their countries and showed interest in setting up the necessary frameworks. New

wind projects are on the way not only in the leading countries Egypt and Morocco, but also in South Africa, Ethiopia, Kenya, Namibia, and Tunisia as well as in Cap Verde.

In light of the fact that the majority of the African population still has no access to electricity, it is expected that small decentralized and stand-alone wind energy systems, in combination with other renewable energies, will play a key role in energy mix supply in Africa. This process of deploying technologies for rural electrification is still in its early stage. The main limiting factors are still the lack of access to know-how as well as to financial resources. Therefore, this in depth analysis of "techno-economic assessment of wind energy to satisfy the demand of electricity and heat for a given residential community in Ethiopia" plays a vital role to boost a clean energy growth by significant figure for zone of Africa.

2.4. Global Wind Energy Potential and Electricity Demand

Wind energy is a significant and powerful resource. It is safe, clean, and abundant. Unlike conventional fuels, wind energy is a massive indigenous power source permanently available in virtually every nation in the world. It delivers the energy security benefits of avoided fuel costs, no long term fuel price risk, and wind power avoids the economic and supply risks that can with reliance on imported fuels and political dependence on other countries.

The total available wind resource that is technically recoverable is estimated to be 53,000 Terawatt hours/year. This is over twice as large as the projection for the world's entire electricity demand in 2020 [12]. Lack of resource is therefore unlikely ever to be a limiting factor in the utilization of wind power for electricity generation.

Future electricity demand is assessed regularly by the International Energy Agency. The IEA's 2002 World Energy Outlook assessment shows that by 2020, total world demand will reach 25,578 TWh. For wind power to meet 12% of global consumption it will therefore need to generate an output in the range of 3,000 TWh/year by 2020.

The produced world electricity share of wind energy at the end of 2009 reached 2% of the total energy demand of the world at the same year. Therefore, the projected wind energy share of 12% of total energy by the year 2020 can be attained if the growth rate of 31.7% wind energy development is continued for every year.

2.5. Environmental Benefit of Energy from Wind

The excepted growth of renewable energy is being driven by environmental, social, political and economic concerns. A reduction in the levels of carbon dioxide being emitted into the world's atmosphere is an important environmental benefit from wind power generation. Carbon dioxide is the gas largely responsible for aggravating the greenhouse effect, leading to the disastrous consequences of global climate change. On the assumption that the average value for carbon dioxide saved by switching to wind power is 600 tonnes per GWh. As it has been discussed early by 2020 the total wind energy installation capacity in the world will reach a 12% share of total energy demand of energy system in the world (25, 578TWh). Therefore, based on the stated assumption a 12% wind energy share of the total energy production by 2020 will save 5,115.6 million tonnes of carbon dioxide production annually [12].

Chapter Three

Wind Energy Basics and Components of Wind Turbine

3.1. Energy in the Wind

Wind turbines convert mechanical power from the wind into electrical power via a rotor connected to a generator. The theoretical energy which the wind transfers to the rotor of wind turbine is proportional to density of the air, the rotor area which the wind over flow and the cube of the wind speed.

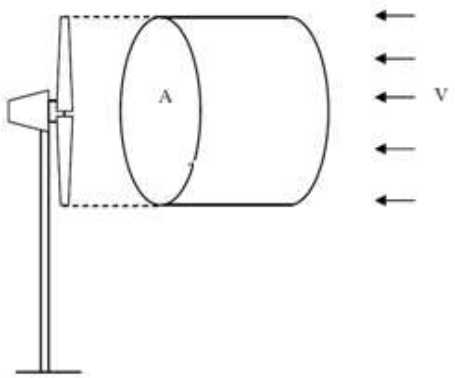


Figure 3.1: Air flow through Rotor area

$$P = {}^{1}/_{2}\,\rho A V^{3} \qquad Equ.3.1$$

Where P is theoretical power in the wind, ρ density of air, A is rotor area and V is the wind speed.

Theoretical power available in wind stream given by Equ.3.1 could not be achieved by rotor because energy extraction implies decrease of fluid velocity (decrease of kinetic energy of the stream), which cannot fall down to zero. Therefore, the actual power extracted by the rotor blades is the difference between the upstream and the downstream wind powers.

$$P_o = {}^{1}/_{2} * mass\ flow\ rate * \{V^2 - {V_o}^2\} \qquad Equ.3.2$$

Where P_o is rotor power, V is upstream wind velocity at entrance of the rotor blades and V_o is downstream wind velocity at exit of rotor blades. Assuming the air velocity is discontinuous from V to V_o at the plane of the rotor blades in the macroscopic sense, the mass flow rate of air through the rotating blades is,

$$mass\ flow\ rate = \rho * A * \left\{\frac{V + V_0}{2}\right\} \qquad Equ.3.3$$

Substituting Equ.3.3 in to Equ.3.2, the mechanical power extracted by the rotor, which is driving the electrical generator is,

$$P_0 = {}^{1}/_{2}\,\rho A V^3 \frac{\left(1 + \frac{V_0}{V}\right)\left[1 - \left(\frac{V_0}{V}\right)^2\right]}{2} \qquad Equ.3.4$$

Then the power extracted by blade is customarily expressed as function of power coefficient (C_p) which is the ratio of rotor power to power in the wind,

$$P_0 = {}^{1}/_{2}\,\rho A V^3 C_p \qquad Equ.3.5$$

$$\frac{\left(1 + \frac{V_0}{V}\right)\left[1 - \left(\frac{V_0}{V}\right)^2\right]}{2} = C_p \qquad Equ.3.6$$

The plot of power coefficient versus ($\frac{V_0}{V}$) shows that C_p is a single, maximum-value function (figure 3.2) at downstream wind speed equals one-third of the upstream speed.

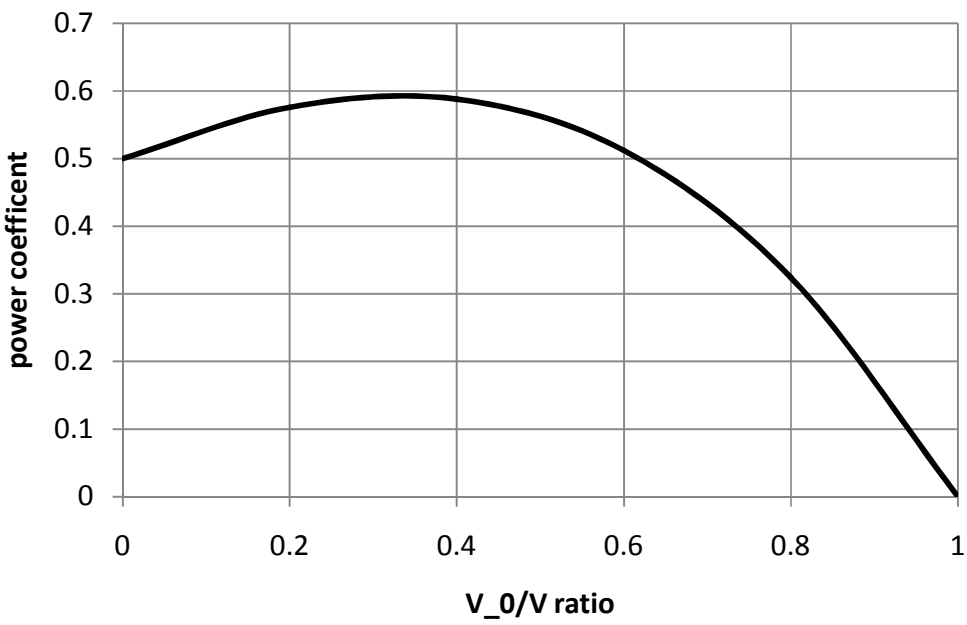


Figure 3.2: Rotor efficiency versus $\frac{V_0}{V}$ ratio

A maximum of 59 % of the available wind power can be converted to mechanical power at ideal conditions but actual power coefficient of the wind turbine would further be reduced by various aerodynamic losses ($0.2 < C_p < 0.5$), as well as mechanical and electrical losses (η_m, η_{el}) [15].

Since the density of air is dependent on temperature, atmospheric pressure, elevation and air constituents, it can be related by using ideal gas law,

$$\rho = \frac{p}{RT} \qquad Equ. 3.7$$

Where p is air pressure (Pa), and R is specific gas constant ($287\,\mathrm{J/kg^{\circ}K}$) and T is temperature in°K. According to S. Mathew [14], if the elevation Z and temperature T is known at a site, then the air density can be calculated by

$$\rho = \frac{353.049}{T} e^{\left(-0.034\frac{Z}{T}\right)} \qquad Equ. 3.8$$

Having the cubic relation with the power, the wind speed is the most critical data needed to appraise the power potential of a candidate site. It is influenced by the weather system, the local

land terrain, and the height above the ground surface. The variations in wind speed are best described by the Weibull probability distribution function [15].

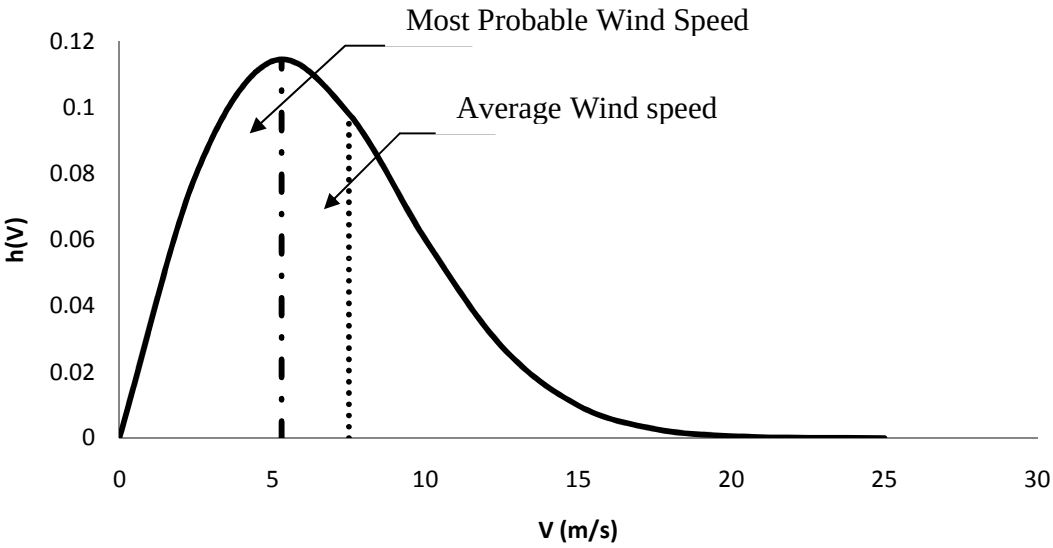


Figure 3.3: Weibull probability distribution of wind speed, k = 2.0 and c = 7.5

The probability of wind speed being *V* during any time interval for a typical distribution plot of wind speed data (figure 3.3) is given by,

$$h(V) = \left(\frac{k}{c}\right)\left(\frac{V}{c}\right)^{(k-1)} e^{-\left(\frac{V}{c}\right)^{k}} \quad for\ 0 < V < \infty \qquad Equ.\ 3.9$$

Where *h* is probability distribution function, *k* is the shape parameter, *c* is the scale parameter and *V* is wind speed. The area under the curve (figure 3.3) is always unity. The mean wind speed can be obtained by summing up the products of each wind speed interval and the probability of getting that wind speed. Therefore, the mean wind speed is,

$$\mathrm{V_{mean}} = \frac{\sum_{i=1}^{n} \mathrm{V_i h_i}}{\sum_{i=1}^{n} \mathrm{h_i} = 1} = \sum_{i=1}^{n} \mathrm{V_i h_i} \qquad \text{Equ. 3.10}$$

Where V_i is the velocity at i_{th} observation time, and h_i is the probability of wind speed being V_i at the same time interval. Also, the wind shear at ground surface causes the wind speed to increase with the height in accordance with the expression [15],

$$V_2 = V_1 . \left(\frac{h_2}{h_1}\right)^{\alpha} \qquad Equ. 3.11$$

Where V_1 is wind speed measured at the reference height h_1, and V_2 is wind speed estimated at heighth_2, and α is ground surface friction coefficient. The friction coefficient is low for smooth terrain (Lake, ocean and smooth hard ground) and high for rough ones (City area with tall buildings).

3.2. Wind Turbine Technology

A design of wind turbine system considers various factors such as dynamic loading, steady mechanical stress due to centrifugal forces and fatigue under continuous vibrations, aerodynamic losses (or efficiency), material science, reliability, cost, number of blade and the entire assembly. Hence, manufacturers have developed a variety of turbine sets with this design requirement. In general, the wind turbine must be designed to:

- Withstand high wind loads; optimum robustness and solidity
- Compliant to accommodate shade loads
- Manage loads mechanically and/or electrically

Therefore, in this thesis work none of the component of wind turbine is designed based on the stated factors, instead various standard alternatives are assessed based on the advantage and disadvantage of their application for the demanded loading condition to come up with best choice in regard to technology and cost. The most important design variables which are thoroughly accessed in this thesis work are:

- Number of blades
- Power control system
- Generator types
- Tower height
- necessity of Gear Box

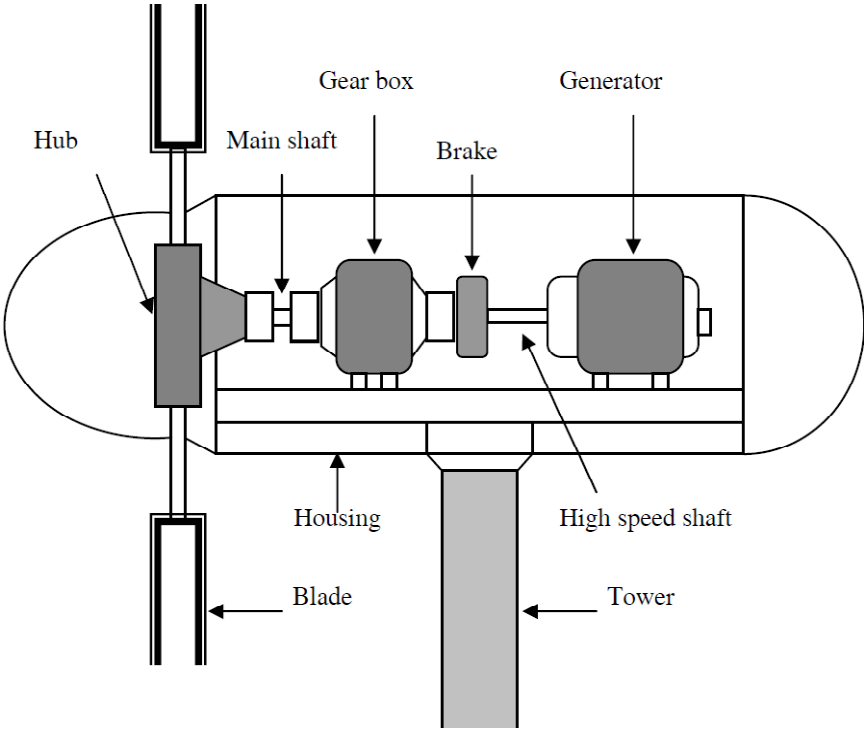


Figure 3.4: Basic wind Turbine Components

As wind is an intermittent source of energy, for standalone wind energy system, there are additional components which are required to secure power generation at off-wind conditions. These are in various form and standard which should be assessed to come up with best type and combination to achieve the required power quality, such as:

- Energy storage device (batteries),
- Inverters and
- Diesel generators

3.2.1. Turbine Blade

With advantage of low cut-in wind speed, easy furling, high power coefficient and stability, three bladed horizontal axis wind turbines are currently the most commonly used type although the design is complex and expensive because of power unit assembly placed over the tower, and yawing is required. Stability is the most important reason for this. Turbines with even number of blades give stability problems. The reason is that at the very moment when the uppermost blade bends backwards, because it gets the maximum power from the wind, the lowermost blade

passes into the wind shade in front of the tower [17]. Also, multi-bladed turbine (6, 8, 12 and even more) is not recommended because of higher aerodynamic losses but it is applicable for high torque machine (water pumping) [14].

3.2.2. Power Regulation

Power generated by the turbine needs to be regulated to its rated level between the rated and cut-out wind speeds. If not regulated, the power would have been increased with wind speed and causes damage to components. Even at wind velocities higher than the cut-off limit, the turbine is not allowed to produce any power due to safety reasons. Since the probability for such high wind velocities is very low in most of the wind regimes, it is not economical to design strong transmission lines and larger generators to accommodate higher level of power. Therefore, the power regulation mechanisms must be implemented in such a way that power output is limited close to the rated value, as wind turbines have their highest efficiency at the wind speed they are designed for, as shown in figure 3.5. The common methods to regulate the wind power are:

- Pitch control
- Stall control
- Active stall control, and
- Yaw control

In Pitch control mechanism, electronic controller, which depends on the output power, sends a signal to the blade pitch mechanism so as to turn the rotor blades out of the wind to the exact degree required and to keep the rotor blades at the optimum angle for maximized output at all wind speeds. In pitch control mechanism the rotor blades are rotated around their longitudinal axis. The pitch control mechanisms are driven by a combination of hydraulic and mechanical devices. It allows smooth and effective power regulation of the turbine at any wind speed with complicated mechanical arrangement in the rotor hub which increases costs and decrease reliability.

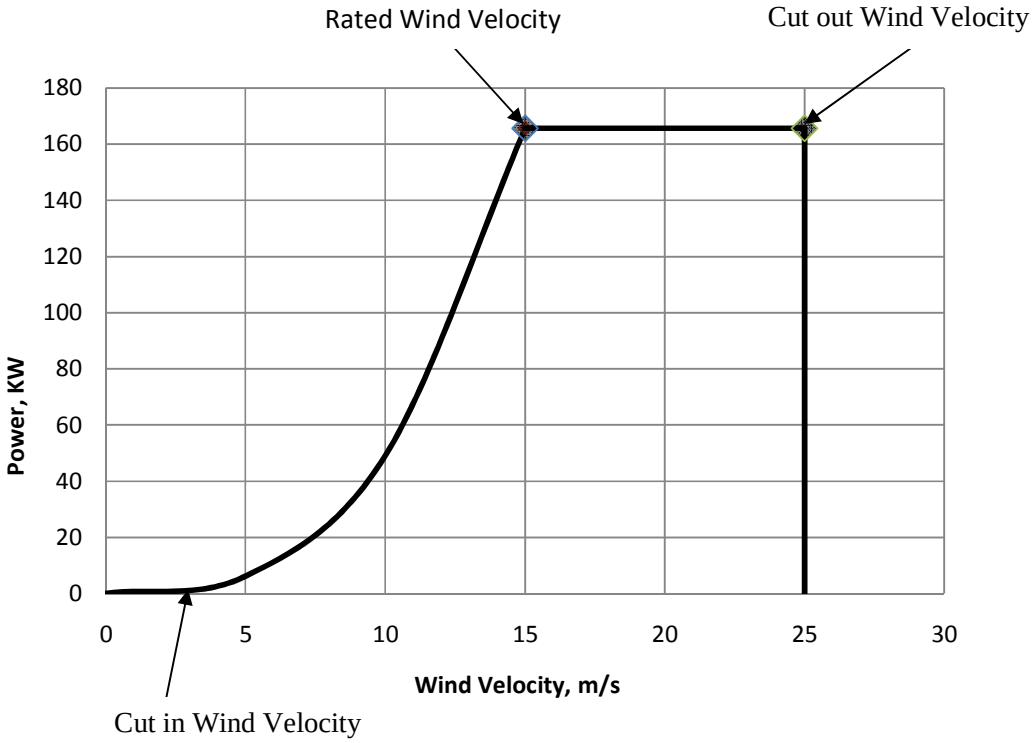


Figure 3.5: Power Curve of a typical Wind Turbine

In stall regulation, the aerodynamic design is to increase the angle of attack at which the relative wind strikes the blades, causes the flow separates and swirls on the suction side to reduce the lift forces at the moment the wind speed gets high. Stall controlled wind turbines have their rotor blades bolted onto the hub at a fixed angle for simplicity and low cost. Its drawback is impossibility of maintaining perfectly stable output power because the power from the rotor drops slightly at wind speeds above the nominal one.

The principle of active stall controlled power regulation exploit the advantages of both the pitch and stall controlled options for regulating wind turbine power. In this method, the blades are pitched to attain its best performance in lower winds. However, once the wind exceeds the rated velocity, the blades are turned in the opposite direction to increase the angle of attack and thus forcing the blades into a stall region. The active stall allows more effective power control and the turbine can be run nearly at its rated capacity at high winds [14].

In yaw control, the rotor spin axis is pushed partly away from the wind direction at higher wind speeds. When the velocity exceeds the cut-off limit the axis position would be nearly perpendicular to the wind vector, thus ceasing the power generation. When the rotor is partially yawed, it experiences cyclic stresses. Due to this reason, yaw control is employed only for small wind turbines.

In general, all control methods have their advantages and disadvantages but most modern wind turbines are pitch or active-stall controlled since simplicity of construction is not an issue for the big machines, where output optimization and power quality are the ultimate goals.

3.2.3. Wind Turbine Generator

The wind energy conversion system consists of the rotor shaft with bearings, brakes, an optional gearbox, as well as a generator and optional clutches. Among these, the generator is one of the most important components of a power transmission unit. In contrast with the generators used in other conventional energy options, the generator of a wind turbine has to work under fluctuating power levels, in tune with the variations in wind velocity. Different types of generators are being used with wind machines. Small wind turbines are equipped with DC generators of a few Watts to kilo Watts in capacity. Larger systems use single or multiple phase AC generators.

Both DC and Ac generators can be used as the motor for converting the electrical power into mechanical power, or as the generator converting the mechanical wind power into the electrical power since these generators work on the principles of the electromagnetic actions and reactions and the resulting electromechanical energy conversion is reversible. Commonly for large-scale wind generation plants which are generally integrated with the grid system, multiple-phase AC generators are the right options. These generators can either be induction (asynchronous) generators or synchronous generators.

Most of the wind turbines are operational with induction generators. They are simple and strong in construction and offer impressive efficiency under varying operating conditions. Induction machines are relatively inexpensive and require minimum maintenance and care. Characteristics of these generators like the over speed capability make them suitable for wind turbine application [14]. It has a slightly softer connection to the network frequency than the synchronous generator, as it allows a limited amount of slip, or variation, in generator RPM. Three- phase induction generators are mostly used in wind turbines [13].

Unlike the induction generator, synchronous generators are used in most of the electrical power consumed in the world. The generator works at a constant speed related to the fixed frequency. Therefore, it is not well suited for variable-speed operation in the wind plants but it is used for small wind velocity variations. The synchronous speed of the induction motor is given by

$$N_s = \frac{120f}{P} \qquad 3.12$$

Where f is frequency and p is number of poles.

In general the above discussed wind generators works for larger scale wind turbine but the small scale wind turbine may have different design; it often has direct drive generators (without a gearbox) and give out direct current for DC devices. But still for electricity generation it is possible to use inverters with Dc generator or AC generators instead of DC.

3.2.4. Tower

Among major components of a commercial wind turbine, tower is one of the critical components which need various considerations to design since it supports the rotor and nacelle of a wind turbine at the desired height and it determines the wind power with height variations. The major types of towers used in modern turbines are lattice tower, tubular steel tower and guyed tower, shown in figure 3.6.

Lattice towers are light and cheap since they consume only half of the material that is required for a similar tubular tower. As Legs of these towers are spread widely as shown in the figure 3.6 the load is distributed over a wider area, they require comparatively lighter foundation, which will again contribute to the cost reduction. But Lattice towers have draw backs such as poor aesthetics, increase rate of avian mortality (danger to bird life) and difficulty of maintenance.

Due to the stated limitations, most of the recent installations are provided with tubular steel towers. These towers are fabricated by joining tubular sections of 10 to 20m length. The complete tower can be assembled at the site within 2 or 3 days. The tubular tower, with its circular cross-section, can offer optimum bending resistance in all directions. These towers are aesthetically acceptable and pose less danger to the avian population [14].

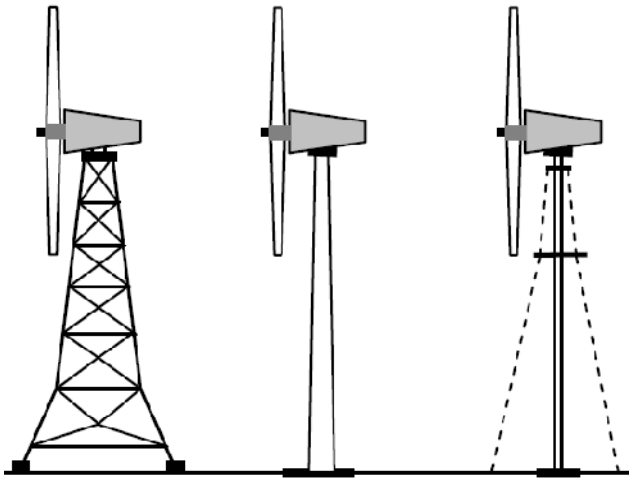


Figure 3.6: Different types of towers

For small systems, towers with guyed steel poles are being used. By partially supporting the turbine on guy wires, weight and thus the cost of the tower can be considerably reduced. Usually, four cables equally spaced and inclined at 45o, support the tower. As accesses to these towers are difficult, they are not popular with large scale installations. However, guyed towers are in use even with MW sized installations in Germany [14].

Load acting on the tower increases with size of the turbine. Hence, the recent trend for **MW** sized systems would in turn demand for higher tower dimensions in terms of diameter and wall thickness. But the need of larger tower is limited by transportation and manufacturing process. Usually, inland transportation of structures with size higher than 4.3 m and weight more than 50 to 60 tons is difficult. Further, fabricating these huge structures is not an easy task, as rolling and welding plates with wall thickness more than 50 mm is difficult [14].

Due to the stated limitations, hybrid towers are proposed for high capacity systems. One is concrete-tubular hybrid tower, the lower part is made of concrete where as the upper part is with conventional tubular steel structure. Another design is combination of truss, tubular and guyed towers.

Wind velocity increases with height due to wind shear. Hence, the taller the tower, the higher will be the power available to the rotor. Therefore it is recommended to choose a type and

dimension of tower considering velocity as a governing factor. Rate at which the available power increases with height depends on the surface roughness of the ground stated in equation 3.11.

The discussion made above is mainly considering large scale wind turbine while for small wind turbine it is recommended to choose tubular tower because of its advantages stated above. The height of small wind turbine tower in the past has been in the 20 to 50-meter range [15].

3.2.5. Gear Box

One of the most important main components in the wind turbine is the gearbox which is placed between the main shaft and the generator, its task is to increase the slow rotational speed of the rotor blades to the generator rotation speed. The primary advantage for using a gearbox for changing speed is to enable the full power to be transmitted at the different speeds. Electric motors and other prime movers are rated for a maximum torque at the optimum speed.

One might think that the gearbox of a wind turbine could be used to change speed, just like a normal car gearbox. However this is not the case with a gearbox in a wind turbine. In this case the gearbox has always a constant and a speed increasing ratio, so that if a wind turbine has different operational speeds, it is because it has two different sized generators, each with its own different speed of rotation (or one generator with two different stator windings).

Many turbines, particularly those above 10 kW, use a gearbox to match the rotor speed to that of the generator. Most micro and mini systems have the generator/alternator rotating at the same speed as the rotor and do not need a gearbox.

3.2.6. Battery

Almost all electrical energy used today is consumed as it is generated. This poses no hardship in conventional power plants, where the fuel consumption is varied with the load requirements. The wind, being intermittent sources of power, cannot meet the load demand all of the time, 24 hours a day, and 365 days of the year. The energy storage, therefore, is a desired feature to incorporate with renewable power systems, particularly in stand-alone plants.

A Battery is a device that store energy and supply electricity when the wind is not adequate. It is a combination of electrochemical cells that can store chemical energy that has the potential to be directly converted into electric energy. It is recommended that batteries be connected in series.

Connections in parallel may cause damage because of different states of charge among the individual battery cells.

Lead-acid battery is the most common type of rechargeable battery used in today's stand-alone power systems because of its maturity and high performance over cost ratio, even though it has the least energy density by weight and volume. It is available in small to large capacities in various terminal voltages, such as 6 V, 12 V and 24 V. The lead-acid battery found in two versions. The shallow-cycle version is used where a short burst of energy drawn from the battery is in need (applicable in automobiles). The deep-cycle version, on the other hand, is suitable for repeated full charge and discharge cycles of 80% and used in renewable energy applications.

For steady-state electrical performance calculations, the battery is represented by an equivalent circuit shown in figure 3.7. The battery works as a constant voltage source with small internal resistance.

Figure 3.7: Equivalent electrical circuit of the battery showing internal voltage and resistance

The open-circuit (or electrochemical) voltage E_i of the battery decreases linearly with the Ampere-hours (*Ah*) of discharge, Q_d and the internal resistance R_i increases linearly with $Q_d$compared to E_o and R_o values in the fully charged state.

$$E_i = E_o - K_1 Q_d \qquad 3.13$$

$$R_i = R_o - K_2 Q_d \qquad 3.14$$

Where K_1 and K_2 are constants to be found by curve-fitting the test data.

The battery can deliver maximum power to a DC load when $R_i = R_L$, this gives the maximum power, P_{max}:

$$P_{max} = \frac{{E_i}^2}{4R_i} \qquad 3.15$$

The efficiency of the battery at any state of charge is

$$\eta = \frac{R_L}{R_L + R_i} \qquad 3.16$$

The efficiency decreases as the battery is discharged since it generates more heat.

With regard to the effect of temperature on batteries, the battery capacity drops at temperatures above or below certain range, and drops sharply at temperatures below freezing. The optimum working temperature range is between –10°C and 25°C. Battery *Ah* capacity drops to 50% at approximately -27 0C. At freezing (0°C), capacity is reduced by 20% [15].

3.2.7. Inverter

An inverter is an electrical device that converts DC power from battery or PV array into AC power at a desired output voltage or current for use in household appliances. In the conversion process, about 10 percent of energy is lost. There are different kinds of inverters. Light duty inverters (100 – 1,000 watts) are typically powered by 12 volts DC and are suitable for lights and small appliances such as televisions, radios and small hand tools. Heavy duty inverters (400 – 10,000 watts) can be powered by a range of voltages, 12, 24 or 48 volts DC, and can be used to run just about anything found in a home or small business [7].

Basically, there are three kinds of DC-AC inverters; square wave, modified sine-wave, and pure sine wave inverters. The square wave type is the simplest and least expensive, but it deliver poorest quality output signal. The modified sine wave type is suitable for many load types and is the most popular low-cost inverter. Pure sine wave inverters produce the highest quality signal and are used for sensitive devices such as medical equipment, laser printers, computers, etc.

The working principle of most inverters is to use a low DC voltage input and to first step-up the voltage to a level corresponding to that of the peak value of the desired AC voltage and then generate the desired AC voltage by using a full-bridge or half bridge electronic circuit configuration. The output voltage of the inverter is controlled by electronic circuitry.

3.2.8. Diesel Generator

During extended periods of low wind, a back-up generator is required if continuous power is needed. This generator may be fuelled with gasoline, diesel oil or propane, but the most common in hybrid wind system is diesel generator because of its low cost. The electricity generated is used directly where required, or indirectly after first charging the batteries.

An uninterrupted supply of power may require a “remote start” generator which will kick in automatically before battery power is exhausted. The start signal is typically provided by the system inverter. Not all generators can be remotely started and not all inverters support remote start.

Generators require not only up front capital expenditure, they also require fuel, periodic maintenance, rebuilding and even replacement. While they can be an important source of power, generators are also noisy, create pollution and require storage of flammable fuels.

The working principle of diesel generator is the same with that of electric generator which is driven by prime mover. An electrical generator is an electromechanical system that converts mechanical energy into electrical energy through the interaction of electromagnetic and electrostatic fields within the system.

Figure 3.8 shows the equivalent circuit of a synchronous generator driven by a prime mover. In steady state, the mechanical torque of the prime mover should balance with the electromagnetic torque produced by the generator and the mechanical loss torque due to friction and windage, or

$$T_{pm} = T + T_{loss} \qquad 3.17$$

Multiplying the synchronous speed (ω_{syn}) to both side of torque equation 3.17, one can get power balance

$$P_{pm} = P_{em} + P_{loss} \qquad 3.18$$

The electromagnetic power (P_{em}) is the power being converted into the electrical power in the three phase stator windings,

$$P_{em} = T\omega_{syn} = 3E_aI_a\cos\varphi_{E_aI_a} \qquad 3.19$$

Where E_a is the internal voltage generated, I_a is the armature current, and $\varphi_{E_a I_a}$ is the angle between phasors E_a and I_a.

For larger synchronous generators, the winding resistance is generally much smaller than the synchronous reactance, and thus the per phase circuit equation can be approximately written as

$$V_a = E_a - jX_s I_a \qquad 3.20$$

Where jX_s is the synchronous impedance and V_a is the load voltage

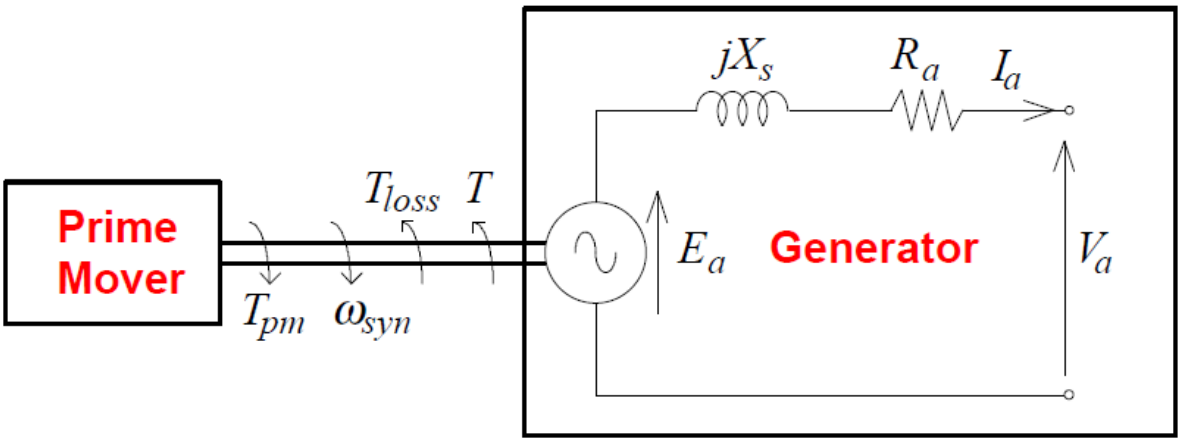


Figure 3.8: A synchronous machine operated as generator

Chapter Four

Ethiopian Energy System and Site Selection

4.1. Ethiopian Energy Mix

The main reason for Ethiopia's poverty is the insufficient use of commercial energy, until mid of 2009 the Ethiopian electric power generation capacity is about 715 MW, and less than 1.9 million tonnes of oil utilization annually. Electricity and oil are critical energy inputs in a developing economy as they contribute greatly to the production process. For economic and financial reasons, these modern energy sources have been made available largely to urban area which is 15% of the country population. Rural energy demands are mainly supplied by traditional energy sources (fuel wood, dung, crop residue and charcoal) [EEPCO, 2006 and IEA, 2009].

In general, Ethiopia's Energy consumption is predominantly based on biomass energy sources with 90.2 % of its primary energy consumption coming from renewable energy sources [IEA, 2007]. However, almost this entire large renewable share is exploited from non-commercial energy source (fuel wood, dung, crop residue and charcoal) used in rural and urban households. As a result, the overexploitation of the biomass resource in several regions of the country to satisfy the need of 90.2% energy demand has caused serious environmental destruction (soil erosion, top soil losses, reduced soil fertility, desertification). To overcome this serious problem, Ethiopian Government is working an intensive job to reach most of the rural area by electric grid and rural electrification. Rural electrification is developing by introducing modern energy saving stoves, biogas generation and small PV units. Also, Forestation is developing as a backup to decrease the environmental problems.

According to [IEA, 2007] as shown in figure 3.1, the energy mix of Ethiopia reveals that the country is more dominantly dependant on direct combustion of biomass which is increasing its demand yearly although the percentage share of biomass decrease from 95% to 90.2% share of total energy need. It is a major threat for deforestation in the country and needs to be decrease by significant amounts by replacing with commercial energy system. The main input for commercial energy in Ethiopia is a renewable source (wind, solar and biomass) which should be assessed to see the techno-economic feasibility particularly in residential community. Therefore, this thesis plays a major role to decrease the need of biomass which is directly converted.

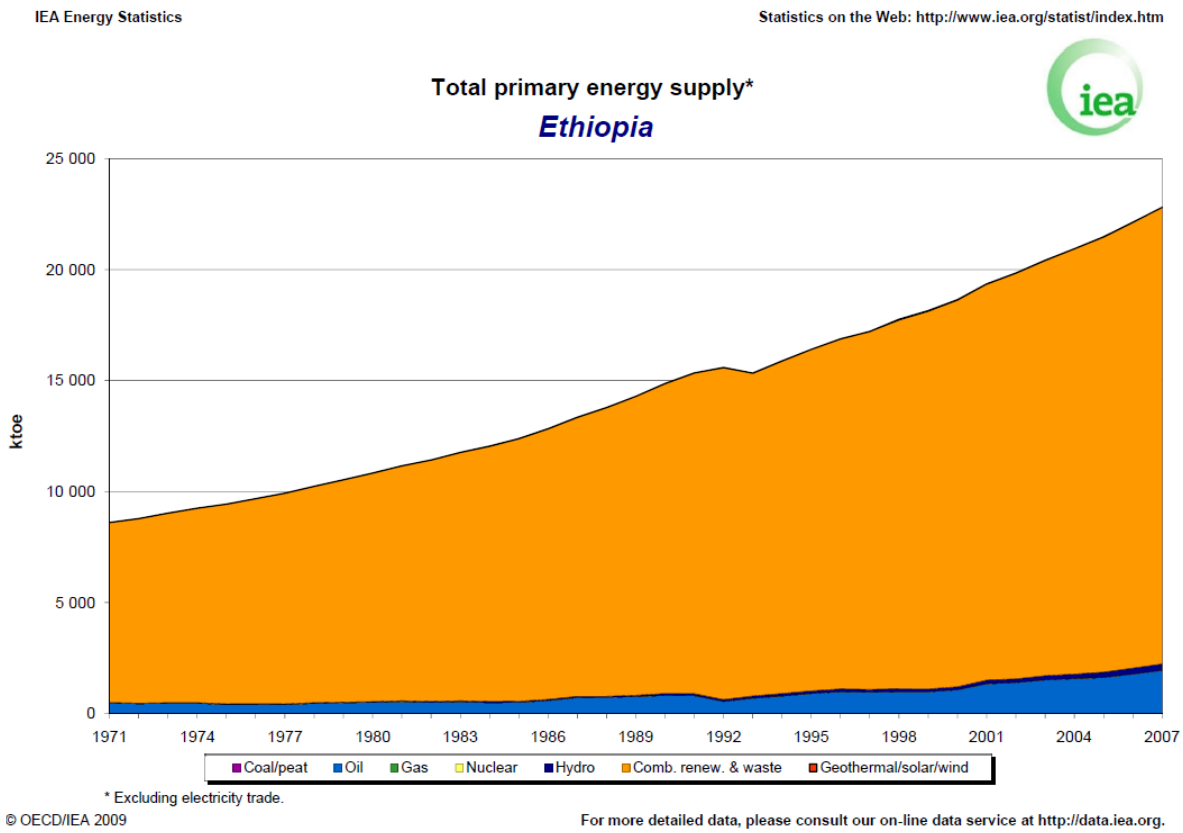


Figure 4.1: Total Primary Energy in Ethiopia [IEA, 2007]

4.2. Electricity Generation in Ethiopia

The electric supply of Ethiopia is only covering 15% of the population according to [EPCO, 2006] but this number will increase by considerable amount since the total electricity production is increased from 0.715GW to 1.895GW in the year 2010. According to EEPCO's survey in 2006, the demand increase in 12 years more than fourfold with an annual increase of 16%. To satisfy the demand, the Government has launched a universal electricity access program to be executed by Ethiopian Electric Power Corporation (EEPCO) with view to enhance the access to 50% by 2010 and this required considerable new generating capacity. Currently the three hydro power units (TEKEZE, GILIGEL GIB II and TANA BELES) are successfully included in the grid which is part of this program and the rest hydro power projects are under construction.

According to [IEA, 2007] as shown in Table 3.1, the Ethiopian Electricity generation is dominantly from hydro power around 97% of the total share and oil and other energy source take the rest. Although the country has high potential for hydro power and it is relatively less cost renewable energy sector, its installation takes longer time and it is dependent on rainfall source only. Because of the climatic change there may be a shortage of rain fall which cause temporary power shortage. Therefore, the power generation system has to be diversified to secure energy system. Wind and other renewable source can be taken as complement to the short come of hydro power, especially wind is the best complement since rainy season has low wind and dry season has high wind potential.

Table 4.1: Electricity Share in Ethiopia by fuel [IEA, 2007]

	Electricity in [GWh]
Electricity production from Oil	133
Electricity production from Hydropower	3369
Electricity production from Geothermal	Not known
Electricity production from Wind	Not known
Total known Electricity Production	3502
Distribution loss	330
Electricity used in energy sector	24
Net known Electricity Production	3148
Electricity used in Industry	1230
Electricity used in Residential	1085
Electricity used in Commercial and Public Services	788
Electricity used in Other Non-Specified	45

4.3. Pervious Study on Wind Energy potential in Ethiopia

There are few previous studies which provide substantial results regarding the wind energy potential of the country [18, 19, 20 and 21]. All studies are based mainly on data from the National Meteorological Services Agency (NMSA), and some of them included other source of data for the analysis purpose of wind potential.

Studies by Mulugetta and Drake[18] and Wolde-Ghiorgis[19] are used to identify the wind regimes in most areas of the country based on the wind energy potential estimate. However, the data used in the studies is relatively old and was probably meant to provide a general understanding of the country's weather conditions, for aviation purposes, or possibly for agricultural weather needs.

The most recent data used in the Wolde-Ghiorgis study was collected during the period 1968–1973 and was recorded only three times a day, at 6:00, 12:00, and 18:00 for 20 locations across the country. The rest of the data used was recorded during the period 1937–1940 and was likewise recorded three times a day at 8:00, 14:00 and 19:00.

Data used in the Mulugetta and Drake study was collected over a period of 5–10 years, 1979–1990 and the source is again the NMSA which was then called the Ethiopian Meteorological Service Agency (EMSA).The data was collected at 60 different locations across the country and the recording was carried out, according to the author, 4–7 times per day and at a height of 2 m but subsequently recalculated to a height of 10 m. The author also stated that he included data surveys from neighboring countries to compensate for the incomplete data from within Ethiopia.

In the study of [G. Bekele and B. Palm [21]], wind potential of four locations is investigated (Addis Ababa, Mekele, Nazret and Debrezeit). The data is from the same source, NMSA. The missing data has been replaced by the averages of the preceding and following readings. For verification purposes, the author used data from other sources for selected sites. The sources are a website known as Weatherbase[SM], data from Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ) particularly for mekele, software and satellite derived data obtained from the Meteonorm and NASA.

Compared to the studies by [18 and 19], the data used by [G. Bekele and B. Palm] are relatively recent, from 2000 – 2003, and it is data which has been recorded five times daily, at 6:00, 9:00, 12:00, 15:00, and 18:00, at a height of 10 meters, for three consecutive years. The data used in the previous studies only basis on the recording between 6:00 and 18:00 and that there is no recorded data for the period between 18:00 in the evening and 6:00 in the morning. However, in the study of [G. Bekele and B. Palm] further investigations have been carried out to compensate for the lack of nighttime data using four assumptions to come up with best result.

The study conducted by [R.Disasa, [20]] is used to investigate the potential of wind particularly in the five sites of Amhara region, namely Bahir Dar, Debre Markos, Debre Birehan, Kombolcha and Gonder. In this study, all the data are collected from the same source of the National Metrological Services Agency (NMSA) but the data are taken for different duration of time which is considered as drawback to compare the potential of wind among each site, by author. Compared to above all study, the data used by [R. Disasa] are relatively recent, from 2000 to 2006. The missed data at the day and the absence of data at nighttime is analyzed similar to [G. Bekele and B. Palm] approach.

4.4 Rough wind Energy Potential Assessment by Average wind Speed data for Current Study

In the current study different wind potential sites are investigated for 34 regions where the wind data is available in the same data source, called NMSA, for the feasibility of the data analysis. The data is recorded five times daily at 6:00, 9:00, 12:00, 15:00, and 18:00, at the height of 10 meters, for three consecutive years, which is the same as that of [G. Bekele and B. Palm] and [R. Disasa].

The wind potential is first assessed by taking yearly average wind velocity. The available wind data for 34 location is recorded from 1997-2005 but the number and year of data gathered is different for different location. As example, in one location the data is recorded for more than four years that ranges from 2001-2005 but in some other location it will be for three years which ranges from 1996-1999. This is one of the limitations to compare different location with average wind speed. Although the length of the time which the data recorded differs for different location it is a must at least to now the average yearly wind speed information to investigate further economic and technical assessment to implement a wind power plant. And the recommended average wind speed for power generation is greater than 4m/s in most cases [21]. Therefore, as a starting point, the average yearly wind speed is computed to select the potential areas which has a speed greater than 4m/s using Microsoft excel 2007. The missed row data here and there is filled by taking average of the first and the next recording. The average wind speed data corresponding to each region are summarized in table 4.2 for the entire 34 location.

Through analysis of average yearly wind speed data, six potential areas are identified which has an average wind speed of more than 4m/s. Those areas are namely, Addis Ababa, Nazret, Mekele, Mehalemeda, Moyale and Negele. The first three locations, namely Addis Ababa, Nazret and Mekele is not considered for further study in the current work because very recent study has been done by [G. Bekele and B. Palm] to investigate the potential of wind in those areas. Since the objective of this work emphasizes the study of techno-economic assessment of wind power for 100 households who are found in rural areas, the current study primarily concerned with regions which are located in rural area according to Ethiopian geographical division. Therefore, further wind potential investigation is done for three regions namely, Mehalemeda, Moyale and Negele because they are situated in rural part of the country and has relatively high average wind speed.

Table 4.2: The average wind speed data for selected 34 locations in Ethiopia

station	latitude	longitude	Wind speed, m/s
Addis Ababa	9.02	38.45	4.7
Arbaminch	6.05	37.38	1.60
Awassa	7.08	38.48	1.56
Bahir dar	11.36	37.25	2.53
Dire Dawa	9.36	41.51	3.62
Gode	5.9	43.58	3.88
Gore	8.16	38.05	1.48
Gonder	12.51	37.408	1.18
kombolcha	9.36	37.3	2.36
Mekele	13.3	38.17	4.79
Metehara	8.52	39.54	2.1
Negele	5.33	39.57	4.06
Nekemt	9.05	36.37	1.87
Moyale	3.31	39.34	4.71
Nazareth	8.33	39.17	4.25
yabelo	4.53	38.06	2.91
Adwa	14.1	38.54	2.29
Jijiga	9.2	42.47	3.53
Asosa	10.01	34.31	3.64
Dupti	11.45	41.06	2.14
Endesilase	14.06	38.16	2.53
Gewane	10.09	40.38	2.81
Hagermariam	5.38	38.14	2.16
Kibremengist	5.52	38.58	1.07
Debremarkos	10.2	37.4	2.01
Mega	4.05	38.2	3.15
pawe	11.09	36.03	1.25

Debrezit	8.44	38.57	2.68
Gimbi	9.1	35.47	1.97
Bilate	6.45	38.04	3.23
Harar	9.18	42.1	3.2
Sholgebya	9.03	39.2	2.86
Mehalemeda	10.15	37.26	4.61

In a figure 4.2, the geographical location of 34 regions is plotted in relative to their longitude and latitude using SURFER software. As we can see from the figure, both Moyale and Negele is far from Addis and it is costly to get power from the main central grid. Therefore, the investigation of this wind potential will promote an implementation of wind power to cut the unnecessary cost incurred to transport power, in addition to promote environmental friendly power source.

SURFER is a powerful contouring, gridding, and surface mapping program for scientists, engineers, educators, or anyone who needs to generate maps quickly and easily. It is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid. Grids may also be imported from other sources. The grid is used to produce different types of maps including contour, vector, image, shaded relief, 3D surface, and 3D wireframe maps. Maps can be displayed and enhanced in Surfer, allowing any one to produce the map that best represents his data [23].

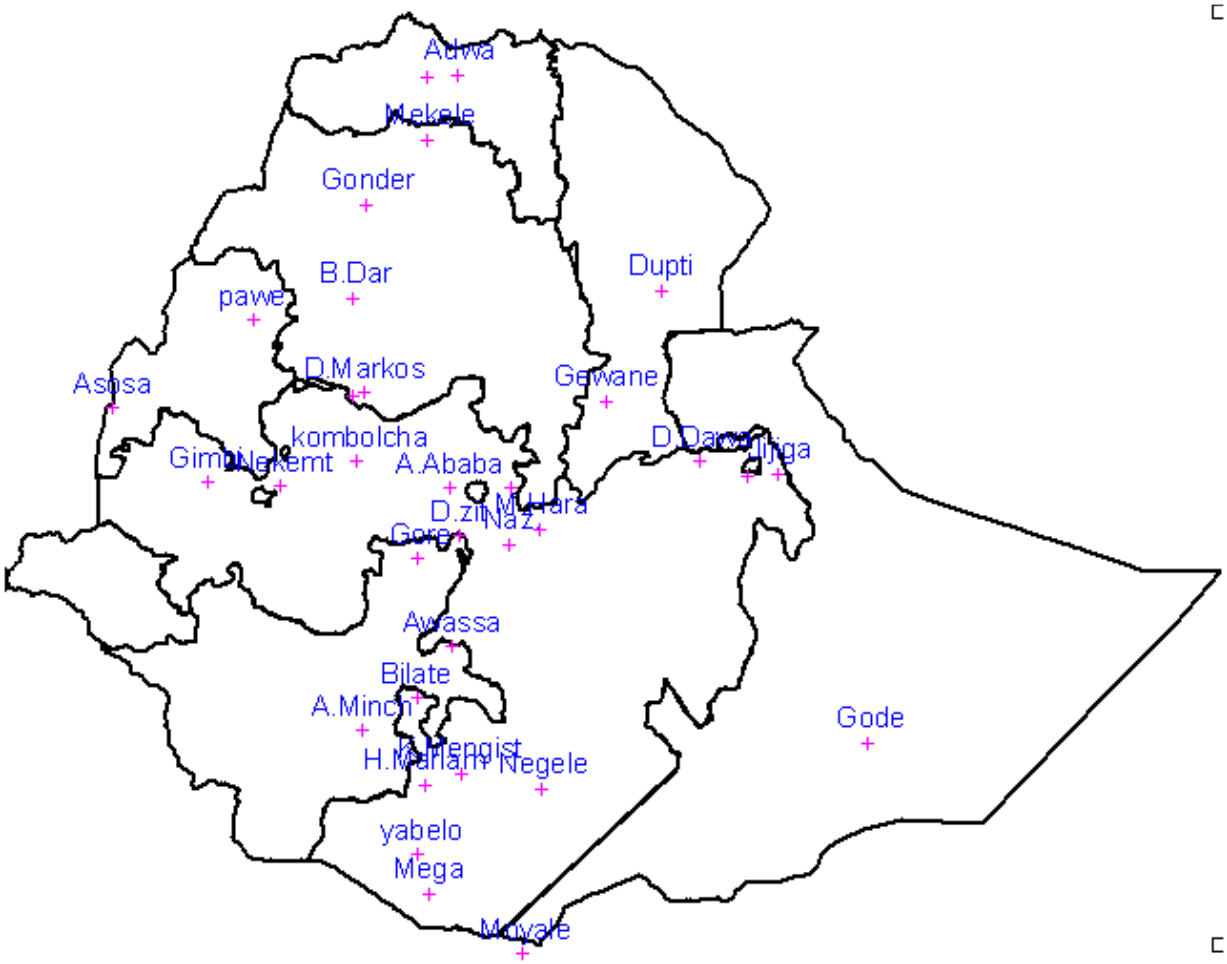


Figure 4.2: The location of selected 34 regions in Ethiopia

Figure 4.3, also shows the estimated average wind potential zone of the different geographical location which is created by taking 34 regional wind speed using SURFER software. The value indicated in the figure shows the average yearly wind speed in meter per second. The wind speed for the regions bounded by two lines considered as average value of the values indicated on both lines. For example, the region Gewane is found in between contour line 2.8 and 3, therefore its wind speed is assumed to be average of both values which is 2.85m/s. But in real data analysis for the recorded wind speed as indicated in table 4.2, the average yearly speed of Gewane is around 2.81m/s. Although the number of data taken to come up with conclusion of wind potential of the entire Ethiopian regions is minimum, the generated contour (figure 4.3) which shows the average wind speed will help as starting information to those who will further

investigate the potential of wind power in the recommended zone that has more than 4m/s averagely wind speed.

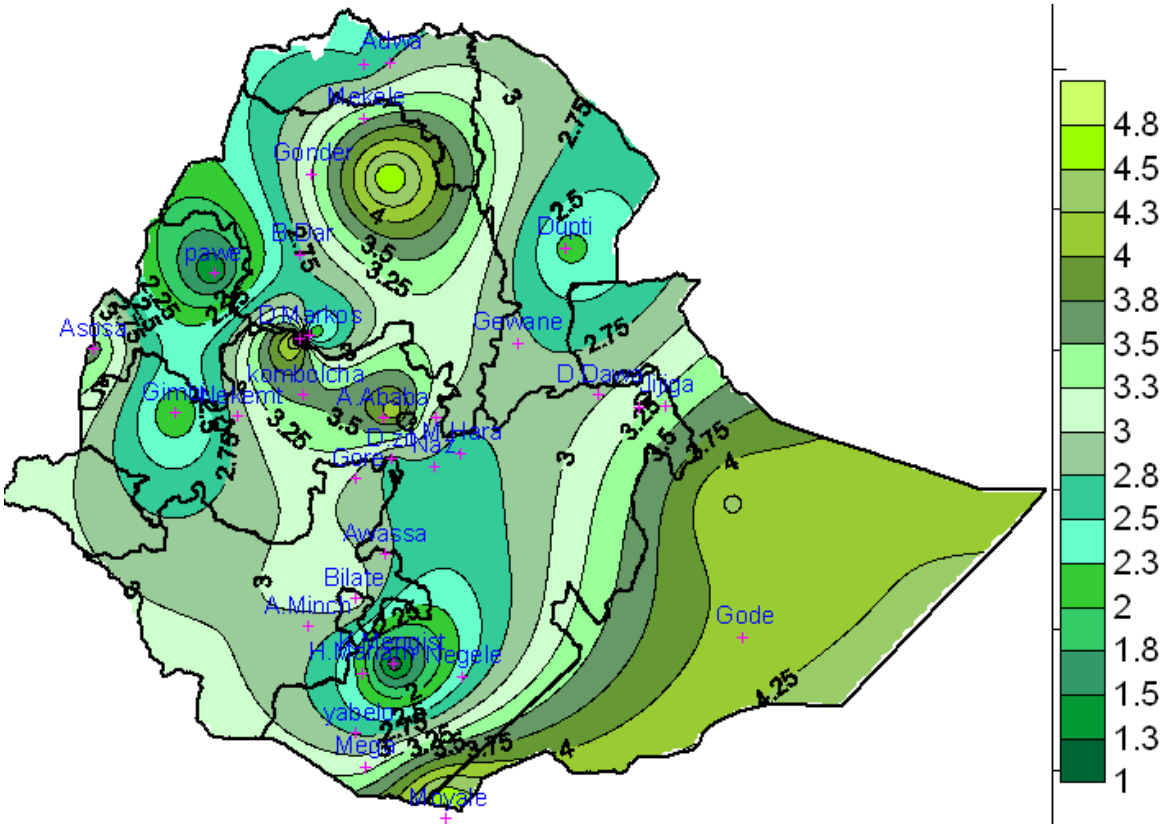


Figure 4.3: The estimated average regional wind speed

4.5 Determination of Wind Energy Potential for Pre-selected Three Sites

The three sites which are selected for further study are Mehalemeda, Moyale and Negele. The respective average values of wind and their geographical locations are tabulated in table 4.2. The data used for the investigation of the speed is found from National Metrology Service Agency (NMSA). In Ethiopia, the wind speed and direction has been measured by using Lambrecht cup anemometer (model No. 1440, 1450, 1464). The wind vane also used as the wind direction measuring device which is balanced in vertical axis, so that it does not tend to settle in any particular direction [18]. The rotation rate of the device is measured by counting mechanically the number of rotation.

There are some limitations with cup anemometers. First, due to inertia, the device does not register lower wind speeds at starting. Second, there is an over speed effect because the

anemometer caused by aerodynamic effect, reacts quicker to increase wind speed than to decrease. Lastly, since the reading is taken mechanically the recorded data will be wrongly collected. These limitations can lead to over and under estimation of the mean wind speed.

4.5.1. Data Source and Data Analysis

In this study, all data are collected from the same source of National Metrological Service Agency (NMSA) for the purpose of the feasibility of the data which used to investigate the wind potential for different location. These data are taken for different time for the pre-selected three sites. The data for Moyale are taken form (2001-2003), Negele (2001-2003) and Mehalemeda (2002-2004) have been considered, provided in Appendix A1. Even though the same time duration is most advisable to compare wind speed data for different location, it is hardly to find the same time gap data for different location. In this study, although the duration of time is different in one of the site, the length of the time is 3 years for each of the sites.

The manual recording data by NMSA has subjected to both missing data in day time and lack of the entire night time readings which make the investigation process of wind potential very difficult. Since this study is dealing with wind power potential, it needs through analysis of wind data using continuous data reading. To solve this problem of missed data different assumptions are analyzed by [G. Bekele and B. Palm] and the best approximation technique for missed night time data is proposed. Concerning the missed data here and there during the day time recording, the average value of the first and the next data is taken. For the missed data at night time, an assumption made by [G. Bekele and B. Palm] which is reducing scaling factor have been adopted for each sites and the most probable night time data have been estimated, with help of HOMER software.

4.5.2. Filling the Missed Night Time Data

As it stated above, the data obtained from NMSA comprises of only data for day time hours, which is at 6:00, 9:00, 12:00, 15:00 and 18:00. It means there is no data for night time from 18:00 in the evening to 6:00 in the morning. Although the night time wind speed differs from the day time because of weather variation, the assumption of reducing scale factor will provide a better approximation of night time data as shown below, as it has been proved well in [G. Bekele and B. Palm] work.

Filling the missed night time data by assumption of scaling factor

This assumption is done by finding a scaling factor which is well developed by using HOMER software for the pre-selected sites to estimate night time data. The version HOMER particularly used for current analysis is HOMER268Beta. Although HOMER software has wider application as described in chapter one, at this point it is used to determine the most potential wind area among pre-selected sites. Through the process of this software analysis different parameters are used as input. Those parameters are described as follows.

a) Weibull (k)

The weibull (k) value is an indication of the breadth of the distribution of wind speeds. HOMER fits a Weibull distribution to the wind speed data, and the k value refers to the shape of the distribution. The typical ranges of these parameters are (1.5-2.5). The first estimate of k value can be determined by using eqn. 4.1 and it is further developed by trial and error method while the generated day time hourly data confirms to measured day time data. For current study the k value of an average 2 is taken from the recommended range.

There is correlation between the Weibull factor value and the average wind speed; higher wind speeds correspond to higher Weibull values and vice versa. HOMER calculates the Weibull value automatically when the average wind speed is fed in to the software [HOMER268Beta].

$$k = \left(\frac{\sigma_V}{\bar{V}}\right)^{-1.086} \qquad 4.1$$

Where: σ_V is the standard deviation of the measured wind speed data and $\bar{V}$ is the mean wind speed value.

b) Autocorrelation factor

The autocorrelation factor is a measure of how strongly the wind speed in one hour depends on the wind speed in the previous hours, and can be calculated by equation 4.2. The autocorrelation factor is dependant on topography characteristics. Local areas with complex topography tend to have lower autocorrelation factor ranges from (0.7-0.8) while those surrounded by uniform topography have higher value (0.90-0.97). But the autocorrelation factor is independent of Weibull value. The Weibull value is a measure of the annual distribution of wind speeds while

the autocorrelation factor is a measure of how the wind speed varies from hour to hour. In this study, the selected sites are assumed to have moderately smooth topography although Ethiopia is characterized by variability of topography and an average value of 0.85 is considered [HOMER268Beta].

For a time series wind speed value of $V_1, V_2, V_3, \ldots, V_n$, the autocorrelation factor r_k can be define as follows.

$$r_k = \frac{\sum_{i=1}^{n-k}(V_i - \bar{V})(V_{i+k} - \bar{V})}{\sum_{i=1}^{n}(V_i - V)^2} \qquad 4.2$$

The value of r_k is the autocorrelation between any two time series wind speed values.

c) <u>Diurnal Pattern</u>

The diurnal pattern strength is a measure of how strongly the wind speed tends to depend on time of day. Because the wind is typically depends on solar radiation, most locations show some diurnal pattern in wind speed. The diurnal pattern usually obtained in the range of (0-0.4). In the current study an average value of 0.25 is considered [HOMER268Beta]. Equation 4.3 is used to determine the wind speed in any hour per day.

$$V_i = \bar{V} \times \left\{1 + \delta \times cos\left[\left(\frac{2\pi}{24}\right) \times (i - \varphi)\right]\right\}, i = 1,2,3 \ldots, 24 \qquad 4.3$$

Where δ is diurnal pattern strength, φ is hour of peak wind speed, V_i is wind speed in hour i and i is hour per day.

d) <u>Hour of Peak Wind Speed</u>

The peak hour indicates the duration of the day time that the wind speed usually get maximum. In other words, the hour of pick wind speed is the hour of the day that tends to be the windiest, on average. From the experience of previous study, mostly the duration of the peak hours vary from 15 to 16 hours. In the current study a peak hour of 16 is taken [HOMER268Beta]. The HOMER result of above four parameters is summarized in table 4.3.

Table 4.3: HOMER Generated Simulation Constants for the Selected Three-sites

Sites	**Mehalemeda**	**Moyale**	**Negele**
Scaled down average wind speed	>4 m/s	>4 m/s	<4 m/s
Weibull, K	1.98	2.02	2.0
Autocorrelation Factor	0.852	0.846	0.872
Durial Pattern	0.24	0.242	0.248
Hour of Peak Wind Speed	16	16	16

The principal input data required by HOMER to generate hourly data is the average monthly wind speed data. But in the current study, the author only found the measured data of daytime only. Because of this limitation, the generated hourly data using measured daytime of monthly average is not considered as a trust worthy data. To compensate this limitation, [G. Bekele and B. Palm] proposed five more assumption and after thorough analysis proposed a reducing scale factor to multiply the average daily measured daytime data to generate an hourly data. This method is applied in the current study to investigate potential of wind for the pre-selected sites.

4.5.3. Wind Potential Assessment for pre-selected three sites

According to Bekele and Palm, it is possible to estimate the nighttime wind speed data to be lower than the daytime data from practical observation. And this is due to orographic (formation of mountains and hills) influences which is very serious in Ethiopia topography.

To achieve an optimum model that can generate the measured daytime and thereby at the same time generate the most probable night time data, a scaling factor method is used. In doing so, the monthly average daytime data for the pre-selected sites of 3 year is taken, shown in figure (4.4, 4.5 &4.6) as (curve A).

The measured monthly average for the daytime (curve A) is used as input to HOMER software to generate hourly data. From the generated hourly data, the day time (6:00 to 18:00) data will be filtered out to get monthly average of daytime filtered out wind speed (curve B). Once both measured monthly average and filtered out monthly average is generated accordingly, a reducing scale factor is computed by taking an average deference of both monthly average data for 12 months. The reducing scale factor is summarized in table 4.4 for the pre-selected three sites.

Then the reducing scaling factor is applied to the daytime average measured data and a monthly average of this data (curve C) is generated to be used as in put in to HOMER to generate new hourly wind speed data. Finally the average monthly wind speed is determined from new hourly generated data (curve D). This procedure is shown in figure 4.4, 4.5 & 4.6 for the pre-selected three sites accordingly.

Table 4.4: Scaling factor for the pre-selected three sites

Sites	Mehalemeda	Moyale	Negele
Scaling factor for reduction of daytime daily average wind speed data	89.15%	89.20%	91.50%

As can be seen in figure (4.4 to 4.6), in all cases the scaled down daytime monthly average is well matched with measured monthly average by using the above table 4.4 scaling factors. Therefore, whilst it is not possible to get the actual wind speed precisely, the most likely wind speed in each of the sites is believed to be given by curve D, the monthly average of the hourly data generated by the software, based on the measured average of the daytime data, scaled down by approximate values given in table 4.4. And the average monthly wind speed data synthesized for all three pre-selected sites is summarized in figure 4.7.

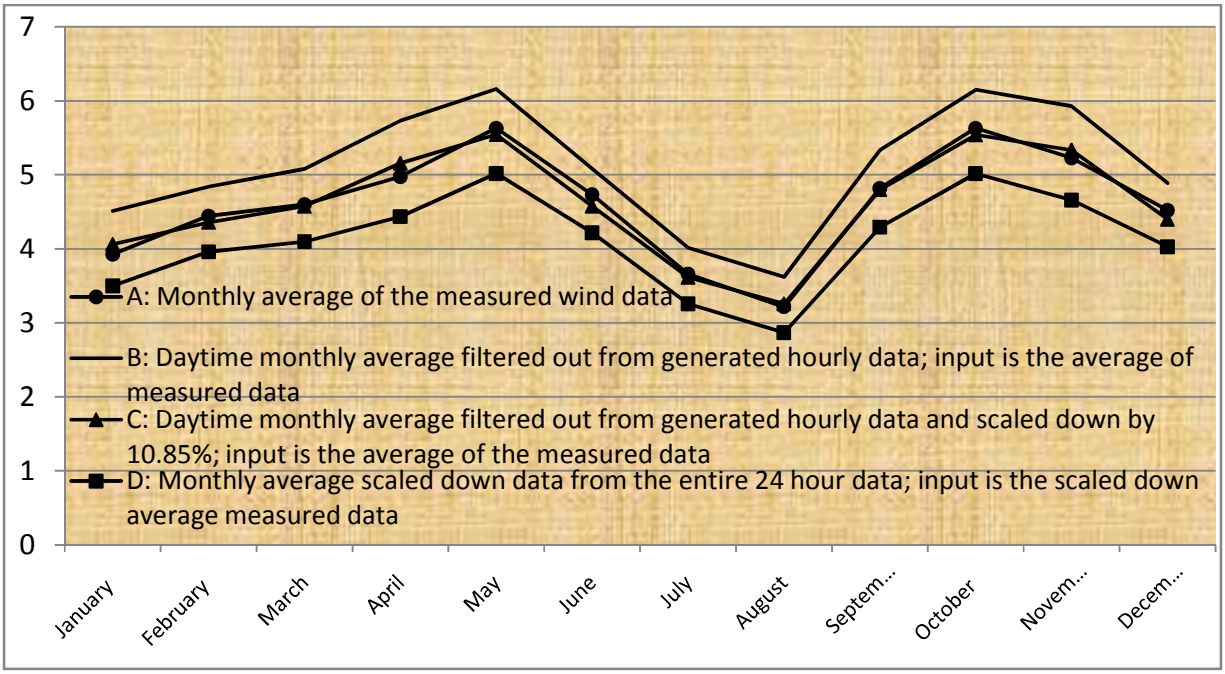


Figure 4.4: Comparison of the scaled down daytime to the measured average for Mehalemeda**.**

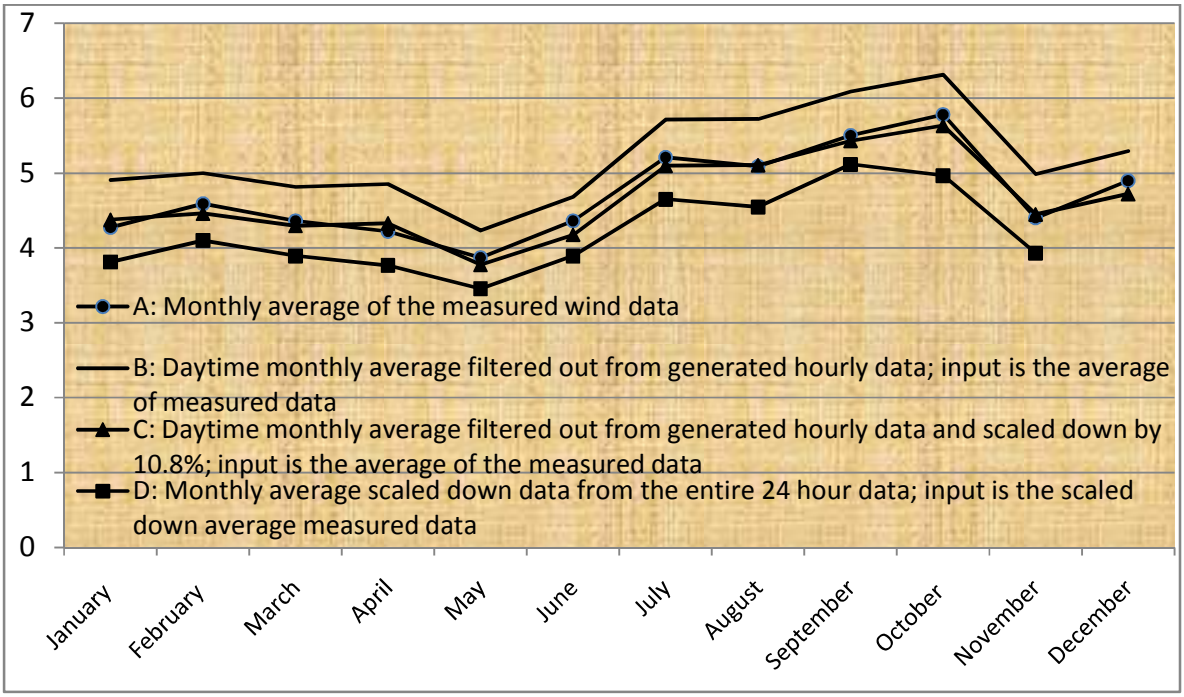


Figure 4.5: Comparison of the scaled down daytime output to the measured average for Moyale

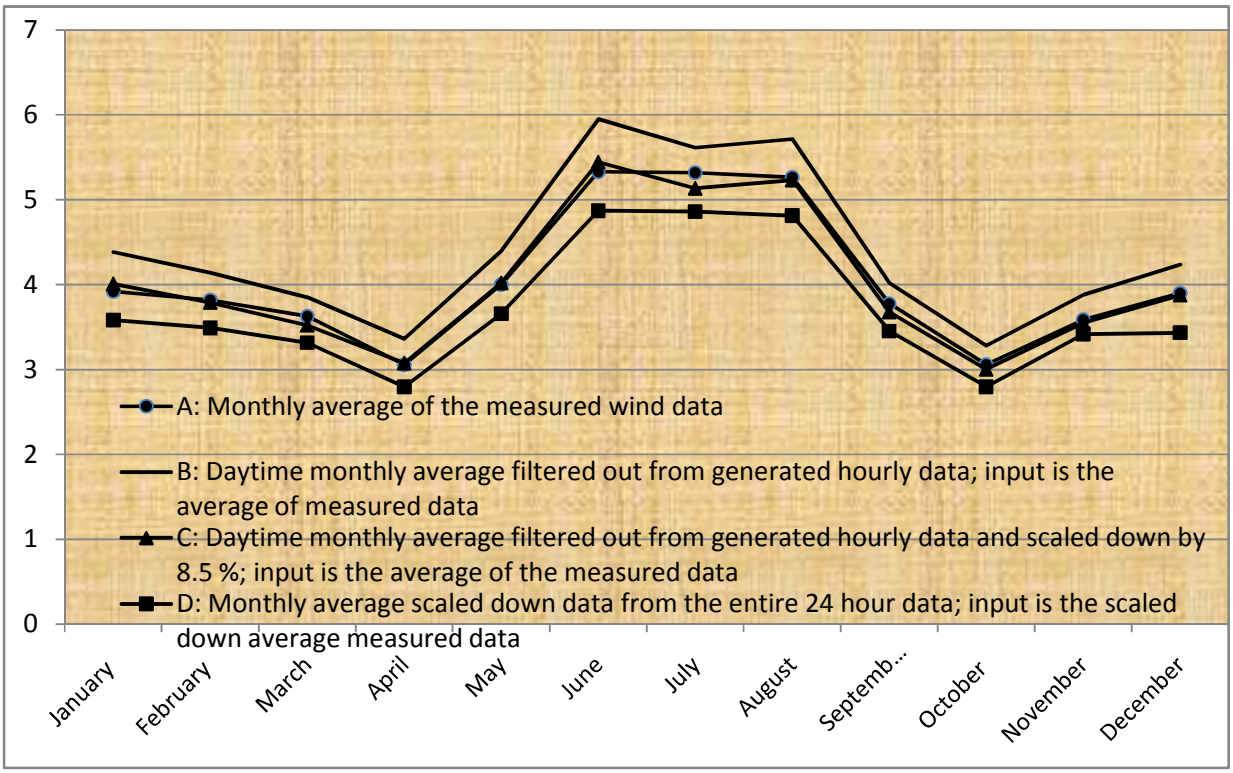


Figure 4.6: Comparison of the scaled down daytime output to the measured average for Negele

4.5.4. Methodology of selecting the most promising wind potential sites among Pre-selected sites

Through the process of determining the wind potential of the pre-selected sites, average monthly wind speed of the entire 24 hour data has been generated. In addition, different important functions such as probability density function (PDF), cumulative density function (CDF), and duration curves (DC), and wind profile of 24 hours for each month as a design tools are analyzed. These important parameters are obtained using HOMER software for the pre-selected three sites and displayed in the result pages Appendix A2.

Therefore, to identify the most promising wind potential site the parameters like average annual wind speed, probability density Function (PDF), standard deviation of the raw data, comparison with standards of department of energy (DOE), Cumulative density function (CDF) and duration curve has to be compared for all three selected sites.

1. <u>Average Annual wind speed for the pre-selected three sites</u>

The annual average wind speed for the selected three sites is summarized in table 4.5 after reduction of a raw measured data by scaling factor for respective sites. As can be seen from table 4.5, Moyale site has relative high wind speed. In addition to annual average wind speed, the distribution of monthly wind speed shown in figure 4.7 which confirms that Moyale has relatively uniform average monthly wind speed throughout the year. But the other two sites, Mehalemeda and Negele show a sharp bend between higher and lower wind speed variation.

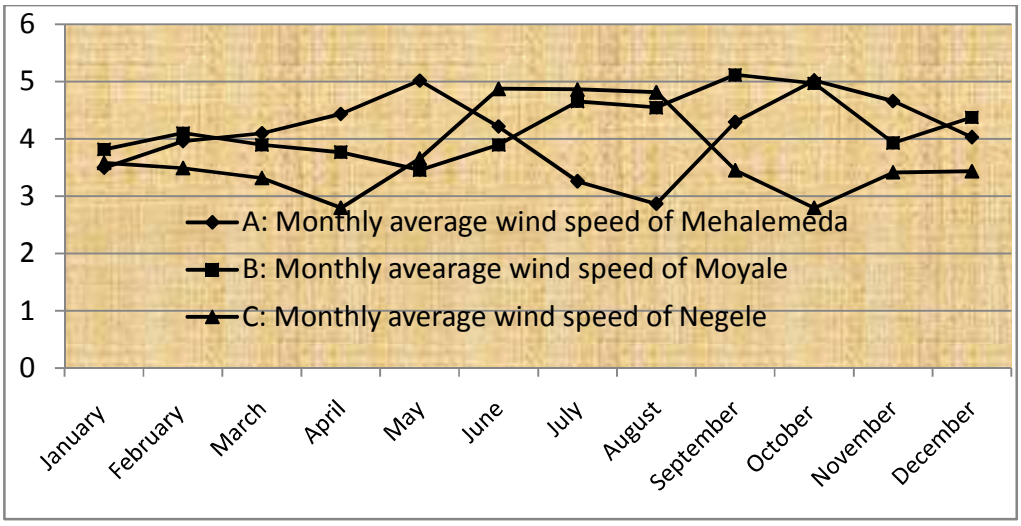


Figure 4.7: Comparison of the estimated probable average wind speed for the three pre-selected sites

2. Probability Density Function for the pre-selected sites

The probability density function (PDF) defines the frequency of occurrence of the respective wind speed. As can be seen from result page of appendix A2B, the most frequent wind speed for Mehalemeda is around 3.25, Moyale 3.5 and Negele is 3.0. The difference between annual average wind speed and the frequent wind is summarized in table 4.5. Therefore, the annual average wind speed in Moyale is more close to the frequent wind speed, as it observed from table 4.5 and PDF values. Although the deviation in case of Negle is the same with Moyale the annual average wind speed in Negele is less than the recommended average wind speed for Power production of wind turbine which is 4 m/s.

3. Standard Deviation of the raw data

The deviation of raw data defines how uniform is the recorded raw data. It means when the standard deviation value gets small the raw data is more uniform and vise versa. It is true that, the quality of wind power measured by wind speed data uniformity to harness a uniform power without much power fluctuation. In the current study the standard deviation is computed for the pre-selected three sites and summarized in table 4.5. Therefore, by comparing the value of standard deviation Moyale site has relatively uniform recorded data which produce more uniform wind power than other two remaining sites.

Table 4.5: Summary of different parameters to determine the most promising wind potential sites for the pre-selected three sites

Sites	**Mehalemeda**	**Moyale**	**Negele**
Annual average Wind Speed in [m/s]	4.11	4.21	3.71
Deviation of annual average wind speed and most frequent wind speed	0.86	0.71	0.71
Standard Deviation	1.075	0.856	1.062

4. Evaluation and Comparison of wind potential of selected sites according to the standard of Department of Energy (DOE)

In order to compare the wind potential class with that of standard by Department of Energy (DOE) the wind speed measured at 10m is converted to 50m. It is true that, the higher the elevation the higher the wind speed since ground level obstacles such as vegetation, buildings, and topographic features tend to slow the wind speed near the surface. And, the effect of this

obstacles decrease with height above ground; and wind speeds tend to increase. Then it is possible to convert the wind speed from certain height to the required height considering the wind shear (obstacles) effect by using logarithmic profile or power law profile equation. In the current study, the logarithmic profile equation has been given in equation 4.4.

$$\frac{v(Z_{hub})}{v(Z_{anemo})} = \frac{\ln\left({Z_{hub}}/{Z_o}\right)}{ln\left({Z_{anemo}}/{Z_o}\right)} \qquad 4.4$$

Where:

$v(Z_{hub})$ is wind speed at the required height (in the current case 50 m).

$v(Z_{anemo})$ the wind speed at measured height (in the current case, anemometer height is 10 m).

Z_o is the surface roughness length. For many trees and few buildings, the value of roughness is 0.25 taken as a surface roughness value since all pre-selected sites are in a country side and have no buildings and the village is rarely populated. But there are considerable trees. By using equation 4.2 the result is summarized in table 4.6.

Table 4.6: Classification of wind potential according to standard of Department of Energy (DOF)

Sites	**Elevation in (m)**	**Wind speed at 10 m (m/s)**	**Wind Speed at 50 m (m/s)**	**Wind Power Class**
Meahlemeda	-	4.11	5.90	Class 2
Moyale	-	4.21	6.05	Class 2
Negele	2,043	3.71	5.33	Class 2

The class 2 potential is considered marginally good for wind energy development while class 1 potential is not recommended [Bekele and palm]. Therefore, all the three sites are good for wind development because all of them are in class 2, according to DOE.

As can be seen, from all the above optimization steps, all the three sites are good for development of wind power. But among them Moyale is selected as wind development site for the further analysis with marginal difference. Since Moyale is situated at the border of Kenya, this wind potential assessment will benefit both Ethiopia and Kenya.

Chapter Five

Load Calculation

The next step, once identifying the potential area of wind energy for wind turbine design is determining the demanded electric load by the estimated population in the area. Then, this chapter deals with determination of electric load by a model community of 100 household, with five to six family members to each. During load calculation the nature of load has been thoroughly analyzed to come up with sustainable energy demand satisfaction since electric load is vary hourly, daily and seasonal bases. In addition to this fluctuation of power, the designer should also consider the wasting power during load calculation. As a result the daily energy demand of the site, the peak hours where peak load is necessary, peak load, and the seasonal variation of load is analyzed in the following sections.

The demand of the load can be satisfied by wind-generator-battery hybrid standalone electric energy supply. Although the nature of wind power is not constant because of wind speed variation, a thorough analysis of load calculation and optimization of the wind-generator-battery hybrid standalone power system needed to satisfy the demand of electric power for selected site of Moyale population. The optimization of this standalone energy system is done using the Hybrid Optimization Model for Electric renewable (HOMER) software, particularly the recent HOMER268Beta version is used for simulation purpose. In the proceeding chapter the optimization process to satisfy the demanded of electric load with better technology and minimum costs are analyzed.

The schematic diagram of wind-generator-battery hybrid standalone electrical energy system is shown in figure 5.1. The diagram also comprise invertors and power conditioning units such as AC-DC converters which is used to match the wind turbine generated voltage with that of bus voltage at DC centre, it is well defined in chapter three.

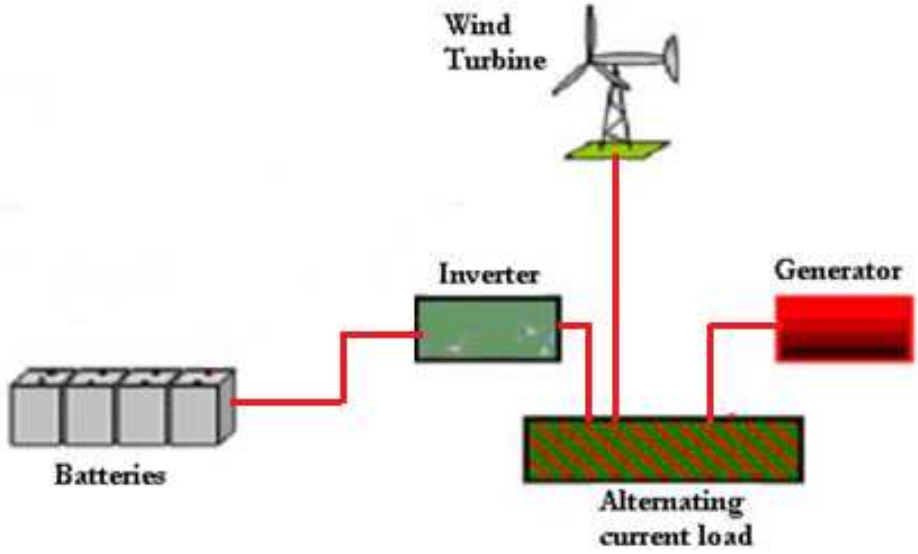


Figure 5.1: Schematic diagram of a standalone wind-generator-battery energy system

5.1. Methodology of Load Calculation

It is obvious that almost all of the rural people living standard of Ethiopia is very poor; people in rural area are using almost no electric appliance except lighting bulbs. But the current study uses a hypothetical electrical appliance by forecasting a better living condition in the future. Although the rural nations are not benefited from well organized public and government institution currently, hypothetical public institutions are considered during load determination. Then, the load is determined separately for house use electric appliance, public and government institutions and finally summed up to determine the total load required by 100 household populations in Moyale site. Those public and government institution that require an electric demand is designed considering a total population of 500 to 600 people since each household consists a family member of 5 to 6.

In addition to the total energy demand by the expected population, the peak hours have been estimated based on the experience of the people living style, when those electric appliances works most of the time in a day period. This is done by categorizing the electric load in broader division namely primary and deferrable loads. The primary load is the electric load that must be met at a specific time (e.g. lighting) and the deferrable load is the load that need not be met within a specified time but should be met within a certain time period (e.g. water pumping).

Finally, the estimated daily average energy is used as input to HOMER then the total energy on daily basis, the peak design load, and the variation of the load on seasonal basis would be obtained as a result, which is used as input for optimization of resources and cost in the proceeding chapter.

The software is designed to identify the proper timing of energy supplied to the components which are connected to the system while deciding the energy share of each component and the period when the components become active. For system which includes batteries and a diesel generator, the software can decide the times at which the batteries should be charged and when the diesel generator should be operated. It also gives the deferrable load a lower priority than that of primary load but higher priority than charging batteries. The battery and diesel generator is active when there is shortage in wind energy resource. If there is excess power in the system, the diesel generator serve deferrable load when it is producing excess power that a primary load require. But all power sources (wind turbine, diesel generator and battery) serve deferrable load when the storage tank is empty, here deferrable load is considered as primary load.

5.2. Electric Load

The electric load determine at this point satisfy the demand of 100 household which comprise a maximum of 600 people in the selected site. A hypothetical model of rural village which contains 100 household have the following institution in addition to house electric appliance which demands a supply of electric load. In some of the institution the load demand in the category of primary load and while in some other is deferrable load. The type of electric loads that are demanding for the institutions and organizations: lighting, water pumping and electric supply for some of clinic equipments.

In the current study, the type of electric load, the estimated number of electric appliances and its capacity and the required number of institution which is necessary for a model rural village developed based on near future economic status the rural populations. For the simplicity of the load calculation the institutions which require electric load in addition to household appliances are categorized as follows:

- One school which has 1-8 grades
- 5 mini-shops including 2 barbers

- Milling House
- One clinic
- One veterinary center
- Three government owned building which are used for offices

The load calculation approached in different ways but in the current study the locally available electric appliances which are required for the stated above institution identified in addition to household appliances, ignoring efficiency loss. Then, a considerable amount of electricity is expected to accommodate the loss of energy since the energy system is designed for very poor people which don't buy expensive most recent energy efficient appliances. The reason why the efficiency factors are not considered in the load calculation is, it is almost impossible and difficult to determine renewable energy system so as to satisfy the design load without production of excess electricity. So as to compromise the stated limitation instead of multiplying the calculated load by efficiency factor, allowing a considerable amount of excess electricity is preferred. It decreases the simulation time and energy during designing renewable energy system component size and quantities.

Appliances like electric clock, TV stereos and etc draw some amount of power even when they turned-off. In some other cases it accounts for system efficiencies including wiring and interconnection losses, as well as the efficiency of the battery charging and discharging cycles. These all stated looses are considered as major looses which needs efficiency factor while designing the energy system. But the current design ignores the efficiency factors and considers only an allowing considerable amount of excess electricity.

Every daily load is calculated and added to yield the daily average load which will give a total annual load. This is done by adding a wattage reading from the equipment specification. Then, the average daily load is multiplied by the number of hours which the equipments work per day to determine the daily load in KWh.

5.2.1 Estimating Appliance's and Home Electronic Energy Use

The first step in determining the household appliance load is deciding which equipments are mostly used in a moderate family considering the current and near future economic development of the nation where the electric energy system is designing. The current economic situation of rural Ethiopian population is below the poverty line and no need of luxury appliances. But the

current design of energy system considers a hypothetical model house which needs basic appliances for the better life. In the table 5.1, the required electric appliances which are applicable for house use is summarized with their wattage requirement and expected running time.

The formula which can be used to estimate an appliance's energy use:

- ✓ (Wattage * Hours Used per day)/1000 = Daily Kilowatt-hour (KWh).
- ✓ Annual Energy Consumption by each appliance's = (Daily KWh * Number of days that the appliance used).

[1 kilowatt (KW) = 1,000 watts]

Table 5.1: A typical Electric Appliances for single household and their running time [26]

Appliance	**AC/DC-Watts**	**Number of equipments**	**Run time (hr)/day**	**Watt-hr/day**
Light bulb	15	4	6	360
Refrigerator	200	1	8	1600
Television	110	1	8	880
DVD Player	25	1	4	100
Radio	30	1	4	120
Local Enjera Mitad (Stove)	2500	1	1	2500
Window Fan	55	3	6	990
Total				6550 **6.55KWh**

Some remarks on energy capacity and run-time of the appliances considered in table 5.1:

1. To estimate the number of hours that a refrigerator actually operates at its maximum wattage, divide the total time the refrigerator is plugged in by three. Refrigerators, although turned "on" all the time, actually cycle on and off as needed to maintain interior temperature [28]. But it is not known when exactly it turns on and off. For the sake of power security the peak load is calculated considering the refrigerator is working for entire 24 hours per day. This assumption project the daily household power consumption from 6.55KWh to 9.75KWh.
2. Currently in Ethiopia, the applicable type of light bulb is Compact Florescent Lamp (CFL) because of its energy saving capacity in comparison to Incandescent Lamp (IL).
3. Television may work in between 12:00-14:00 and at evening for 6 hrs.

4. Radio used mostly for head line news in a day.

The main constraining issue during a design of wind turbine is its initial investment cost. So as to reduce this cost an economic energy demand has to be developed first to satisfy the society energy need. The energy saving has lead to limit the unnecessary energy wastage while using different appliances. The appliances mentioned in a hypothetical household (table 5.1) are proposed considering the energy saving principles.

The calculated household load of 9.75 KWh/day is fairly economical as compared to that of urban household use in Ethiopia but the figure is greater than that of most African countries. There are two reasons why the daily household consumption of the Ethiopian is greater than that of most African daily power consumption of (3 - 5) KWh. First, in Ethiopia there is a traditional Enjera Mitad for baking of local food "Enjera" which is categorized as poor efficient appliance, around 25% efficiency. It takes 2.5KWh/day which is almost 26% of the entire need of power for a household. Second, currently the Ethiopian Government is planned five year strategic plan of increasing the life quality of rural people by constructing health centers, schools, road, and telephone accesses and electricity supply. So, the current load calculation considered this five year strategic plan to satisfy the demand of electric supply for a hypothetical model village of having a moderate life quality. Besides, there is high rate deforestation in Ethiopia to get fire wood for baking Enjera. This all motivates the author to consider this inefficient appliance of Enjera Mitad for load calculation to get electric power.

The peak primary load of the house appliances is ~3.1KW and a total load of 9.75KWh/day per house. Therefore, the expected hourly load of the entire 100 household is assumed to be 975 KWh/day that of primary peak load is 310 KW.

5.2.2. Estimation of Energy needed for water pump

For the house, school, clinic, veterinary, milling house and shopping center use of water, it is recommended if the rural population use water pumps. Around three water pumps are assumed to deliver the water need. One pump used for school and clinic, buildings, veterinary center and milling house; and the remaining two used for house use. The selected type of water pump has a capacity of 150 W power rating, with a pumping capacity 10 l/m. The required amount of water needed per family is ~100 l/day, ~1700 l/day for school, health center, shopping center and milling house. Therefore, the total energy demand per day for house use is ~ 2.5kWh/day and

0.29 KWh/day for school, health centre, and building and milling house, totaling 2.79KWh/day is required. The peak load of the pump (rated power of the pump) for house use is ~0.3KW and ~0.15KW for school, health center, building and milling house. A sufficient water storage capacity of four day is assumed and the corresponding electricity for storage is ~10KWh/day for house and ~1.16KWh/day for school, health centre, building and milling house. The load calculated for supply of water by pump is assumed to be a deferrable type load since it is not constrained by specific time to deliver water.

5.2.3. Estimation of Energy needed for milling house

Traditionally, Ethiopian rural mothers are in charge of taking care of their family meal daily by doing very tiresome hard work like grinding. Currently in most of the rural areas diesel driven grinding mills are become popular but the cost is not reasonable and still manually grinding is preferred by most of poor peasant families. So the design of the electric system will cut this cost with significant amount and decrease the burden of the rural people. In the current study one milling house with three grain mills at a time is considered. The power required by each mill is assumed to be 10KW and its run-time is assumed to be 6 hr/day. Three florescent lamps with 15W are required for lighting purpose for night time work. The run time for lighting is assumed to be 2hr/day since the night time is mostly peak load time and the mill is recommended to work at day time. Therefore, the total power needed for milling is 180 KWh and that of lighting is 0.09KWh/day. The peak load of for milling house is 30KW which is considered as a primary load and 0.045 KW for lighting is also considered as primary load.

5.2.4. Estimation of Energy needed for the School

One school which comprise grade 1-8 is assumed to be enough for the population of 100 families. The member of single family is assumed to be 6 and obviously four of them are children. Therefore, the total number of pupils which the school can accommodate is around 400 and the number of room needed to accommodate this figure is assumed to be 10 (which mean 40 students per class). Additional two rooms for laboratory, one room for staff meeting and the other two rooms for administrative office is required, totaling 15 rooms is needed for school. The electric energy is needed for lighting for night teaching, laboratory equipments, office and laboratory computers and window fan. Therefore, the amount of electric load and the run time for school appliances are summarized in table 5.2.

Table 5.2: Estimated Electric Appliances and their run time for school

Appliances	**AC/Dc-Watt**	**Number of Equipments**	**Run –time per day**	**Total energy [KWh/day]**
Lighting bulb	15	30	4	1.8
Window Fan	55	45	6	14.85
Computers	100	50	8	40
Printer	100	2	1	0.2
Laboratory Equipments	~1000	5	8	40
Total				96.85

The load calculated for school is entirely primary load of total 96.85 KWh/day which comprise a peak load of 13.13 KW.

5.2.5. Estimation of Energy needed for both commercial and governmental building

In the commercial and governmental building the main type of eclectic appliances are lighting bulb, computer for administrative office work, razor for barberry shop, refrigerator for some beverage, widow fan and coffee/tea machines for cafeteria. The estimated run-time and number of appliances are summarized in table 5.3 to know the total electric load in the buildings.

Table 5.3: Estimated appliances and their run-time for commercial and governmental buildings

Appliances	AC/Dc-Watt	Number of Equipments	Run –time per day	Total energy [KWh/day]
Lighting bulb	15	20	6	1.8
Window Fan	55	15	6	4.95
Refrigerator	200	3	8	4.8
Coffee/tea machine	3000	2	10	60
Razor	100	5	10	5
Computer	100	10	8	8
Printer	100	5	2	1
cash machine	60	3	8	1.44
Others	250	2	4	2
Total				~89

Here also the assumption considered in case of household for refrigerator held true. The load calculated for both business and government building is 89 KWh/day but considering 24 hour

work of refrigerator the daily load from stated building is 98.56KWh/day with the peak primary load of 10.41KW.

5.2.6 Estimation of Energy needed for health centre

For the hypothetical model village both clinic and veterinary centre is proposed for the better life of the population there in Moyale. The load is also calculated for that particular institution in the same way as it has been done for other institutions. The possible appliances which demand an electric power are lighting bulb, computers, window fan, refrigerator to store drugs and laboratory test equipments. The estimated load and run time of the appliances is summarized in table 5.4.

Table 5.4: Estimated appliances and their run-time for health centers

Appliances	AC/Dc-Watt	Number of Equipments	Run –time per day	Total energy [KWh/day]
Lighting bulb	15	5	12	0.9
Window Fan	55	7	6	2.31
Refrigerator	525	2	8	8.4
Computers	100	2	8	1.6
Printer	100	1	0.5	0.05
Laboratory Equipments	~1000	2	16	32
Total				45.26

Here also the assumption considered in case of household for refrigerator held true. The load calculated for health centre is 45.26 KWh/day but considering 24 hour work of refrigerator the daily load from stated health center is 62.06KWh/day and the equivalent peak primary load is 3.81KW.

5.2.7 Thermal Load

Thermal load is not calculated as an additional load for current study because Ethiopian weather condition is very comfortable and the room temperature is almost uniform throughout the year. This will decrease the amount of load demanding and increase the feasibility of the proposed energy system with respect to economy. Ethiopia is known by “thirteen months of sunshine”.

5.3. Estimated Total Power Demand

The total power demand by each institution determined in above section and now it is summed up to get the rough total eclectic load required for the modeled hypothetical village. Based on the calculated values of load above, the daily power demand by each institution with its summed up vale is summarized in table 5.5.

Having the calculated peak load of both primary and deferrable type of each institution and using peak hour factor, HOMER will calculate the actual amount of load required for the village.

Table 5.5: Estimated Total Load of the corresponding Institute in the village

Institution	**Primary Power Demand [KW]**	**Deferrable Power Demand [KW]**	**Total Power Demand [KWh/day]**
House Use	310	0	975
Water Pump	0	0.45	2.79
Milling House	30.045	0	180.09
School	13.13	0	96.85
Building of both commercial and governmental	10.41	0	98.56
Health centre	3.81	0	62.06
Total	~367.4	~0.45	~1415.38

As can be seen from table 5.5, the electric load for the house use is by far greater than that of other institution listed there. Therefore, the main objective of this wind-generator-battery standalone energy system design is to satisfy the electric power demand by each household.

5.4. Peak Load, Base Load and Deferrable Load Estimation

The peak load is a load which is provided for the customer at specific time which is expected to be higher than average load supply for short duration of time. The peak load fluctuations may occur daily, monthly or seasonally in a year time. From experience, the peak load periods in Ethiopia are mostly between 18:00 to 20: 00 at the evening and particularly at lunch break (12:00 to 13:00). While base load is a load supplied during a minimum power requirement time by the customer which mostly recorded after mid night till to morning. The other type of load is deferrable load which is a load can be required by the customer at relaxed time. Then, the appliances which need a deferrable type load mostly work at base load period where the excess production power is expected at this time.

In the current study, the primary load and deferrable type of load is identified and calculated which can be used as input to the HOMER software to determine the actual peak and base load. The primary load can be divided into primary load 1 and primary load 2 for easy computation of the software analysis. The house use load which is categorized as primary load can be considered as primary load 1 and that of other loads of different institution can be considered as primary load 2. Therefore, in table 5.6 all the type of appliances categorized in primary load 1, primary load 2 and deferrable load is summarized.

Table 5.6: Summary of appliances under different load type category

Appliances	**Primary Load 1**	**Primary Load 2**	**Deferrable Load**
House Use			
Light bulb	X		
Refrigerator	X		
Television	X		
DVD Player	X		
Radio	X		
Local Enjera Mitad (Stove)			
Window Fan	X		
Other than House Use			
Water Pump			X
Milling House load			
Lighting bulb		X	
Window Fan		X	
Computers		X	
Printer		X	
Laboratory Equipments		X	
Refrigerator		X	
Coffee/tea machine		X	
Razor		X	
Cash machine		X	

There are some appliances loads which vary seasonal in a year are considered as primary load and deferrable load. Those appliances which are demanding seasonal variation of loads are water pumps and air-conditioning units.

In Ethiopia, air conditioning units are not applicable the whole year and it varies as follows:

- Season 1: February to May, very hot season which require the maximum potential of the air-conditioning capacity of the fan almost for six hours a day. Two hours in the morning and 4 hours in the afternoon.

- Season 2: October to January, Moderately hot season which needs a considerable amount of air-conditioning capacity of the fan for at most four hours in a day. One hour in the morning and three hours in the afternoon.
- Season 3: June to September is somehow cold season that needs less air-conditioning capacity of the fan, for almost half an hour.

Water pumps application also seasonal in Ethiopia. July and August are rainy months and the schools are not functionally at those period. January is also a semester break and no school at this time too. During the period of rainy time, there are various source of water like ponds and river which are available for the rural people. These all sum up and decrease the load required for water pump application at those period by considerable amount. For the specified period an approximate 30% decrement is assumed for further study. The seasonal variation for both primary and deferrable load is summarized in table 5.7 considering table 5.6.

Table 5.7: Monthly average daily electrical load in (KWh/day), calculated Load

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Primary Load 1	942	975	975	975	975	884	884	884	884	942	942	942
Primary Load 2	433	440	440	440	440	420	420	420	420	433	433	433
Deferrable Load	2.23	2.79	2.79	2.79	2.79	2.23	1.95	1.95	2.23	2.79	2.79	2.79
Total	1377	1417	1417	1417	1417	1306	1306	1306	1306	1378	1378	1378

The deferrable load variation per year and primary load variation per day are plotted in figure 5.2 and 5.3 to study both daily and seasonal variation of the respected loads. This plot used for rough estimation of peak load period in a day time and peak load months in a year. The table for the plot of figure 5.2 and 5.3 is provided in appendix A3.

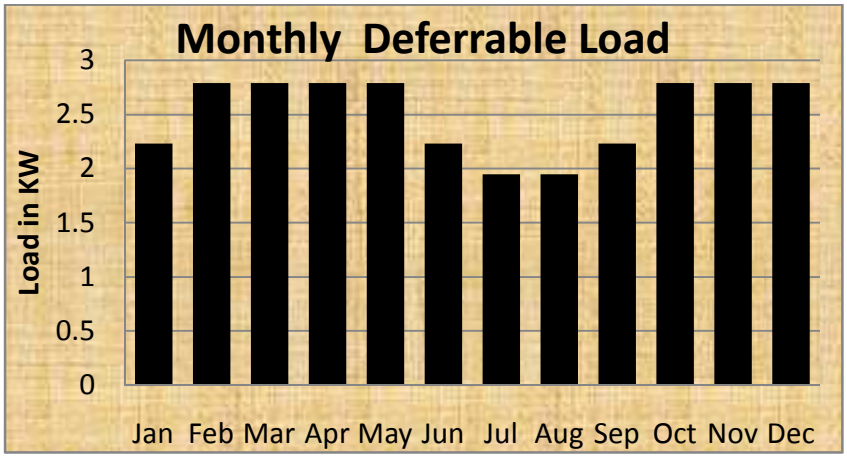


Figure 5.2: Monthly average Deferrable Load Profile

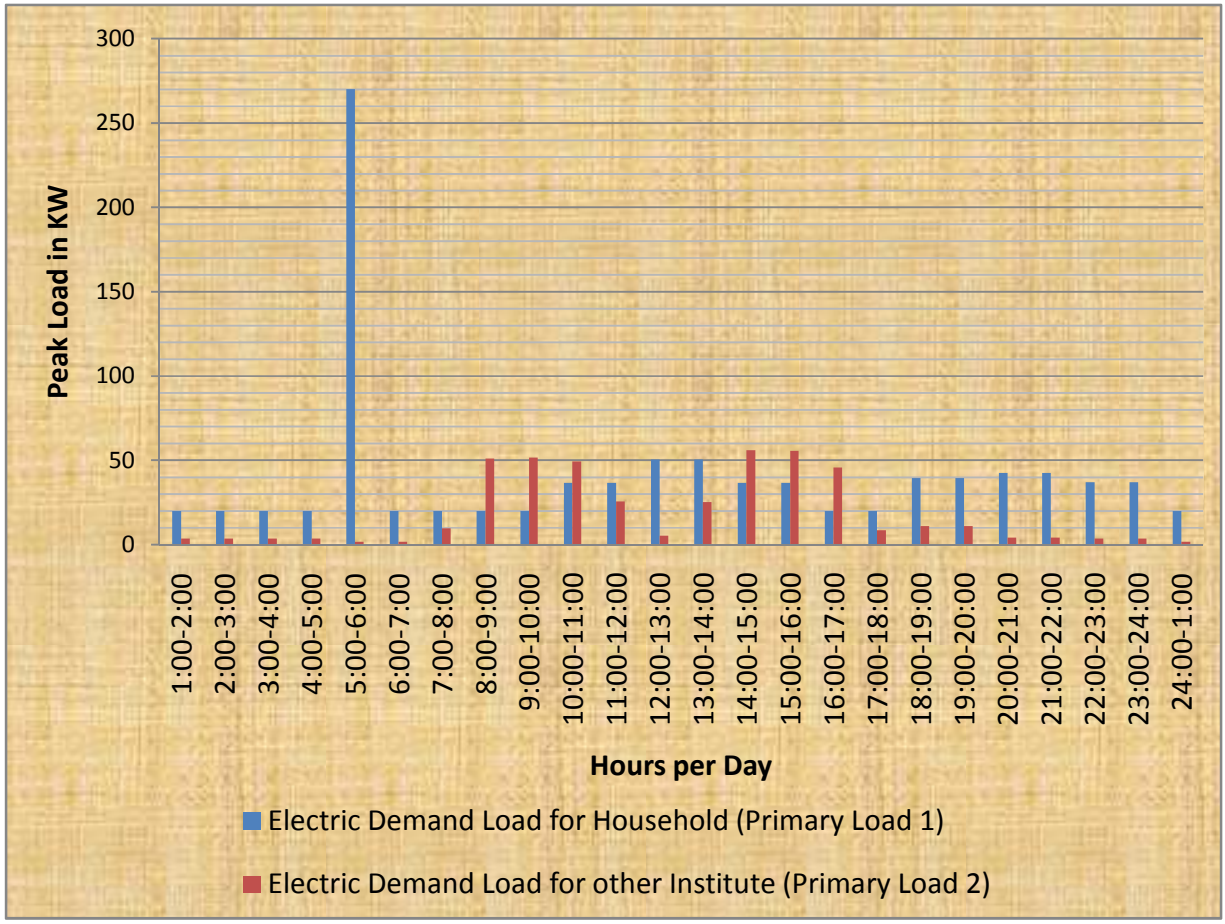


Figure 5.3: Daily Primary load profile of the village

Then, the average daily load by primary load 1, primary load 2 and deferrable type of load which are required for the entire hypothetical village is summarized in table 5.9. It is calculated by

using HOMER based on the input load of hourly per day of table provided in appendix A3. Those calculated values can be used as input parameters for HOMER software to determine a combination of economical wind-generator-battery energy system. In order to elaborate slightly how those input data are fed and how the results are obtained an illustrative figure has been given in appendix A5.

Table 5.8: Monthly average daily electrical load in (KW), HOMER generated

Months	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Primary Load 1	270	270	270	270	270	270	270	270	270	270	270	270
Primary Load 2	88.86	98.94	98.70	86.86	84.54	93.40	89.98	85.90	81.48	91.43	79.04	86.52
Deferrable load	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45	0.45
Total	359.3	369.4	369.2	357.3	355.0	363.9	360.4	356.4	351.9	361.9	349.5	357.0

Table 5.9: Result of HOMER estimated load per day

Type of Load	**Scaled Peak Load (KW)**	**Scaled Annual Average (KWh/day)**
Primary Load 1	270	975
Primary Load 2	99	440
Deferrable Load	0.45	2.5
Total	~369.45	~1417.5

Peak load is a load which is provided for the customer at specific time which is expected to be higher than average load supply for short duration of time. With this definition of peak load the calculated value of 270 KW for house hold (primary load 1) is a peak load which should be provided for the customer at particular time (5:00 to 6:00) which is for one hour time. The peak load is calculated considering the worst case, which is working of the expected appliance of all household at the same time. The same thing is true for primary load 2.

5.5 Control of Waste Energy

The design load is calculated with marginal factor of safety and the usage of the energy system for different purpose need a careful attention. The end user of this hybrid energy system has aware of the very nature of their appliances to decrease wastage of energy because of miss use.

As guide line the following suggestion is provided to decrease the wastage of energy for some selected appliances.

1. Refrigerator

Since refrigerator is used throughout the year, the energy saving potential is high for these appliances. The lower energy costs of more efficient refrigerators can replace even if existing ones are still in good service. But the replacement may incur additional cost and the rural people may not afford this, then suggestion for smart usage is proposed for existing refrigerators as follow:

- ✓ Keep the condenser coils at the rear of refrigerator clean. Dust and dirt on the condenser coils will reduce the working efficiency of the refrigerator.
- ✓ The compartment of the refrigerator should be kept to avoid unnecessary cold air loss on door opening.
- ✓ Arrange foods sparsely in the refrigerator to allow free air circulation.
- ✓ Always cool hot food before storing it in the refrigerator.
- ✓ Avoid frequent opening the refrigerator, or leaving the door open unnecessary.

2. Air Conditioning

Home air conditioning, which was once a luxury, is now becoming a necessity, or an affordable convenience to the middle income population, as air conditioners become cheaper and more energy efficient. The cheaper, window type air conditioners are now losing out to the "split" type, which have the advantage of separating the compressor from the cooling unit, thus reducing the noise level in the cooled room. The lower energy costs of the more efficient, newer air conditioners can often justify replacement even if existing ones are still in good service. Suggestions for smart usage:

- ✓ Do not block air conditioner vents with drapes or furniture.
- ✓ Roof, or ceiling insulation, and minimization of air leaks from under doors and through windows can help to reduce the cooling energy consumption.
- ✓ Glaze your window with heat reflective glass — some glazing has selective reflective coatings where heat is reflected but light is allowed in.
- ✓ On a hot day, close your curtains and blinds. This helps to keep sunshine heat away.

- ✓ Landscaping - trees and shrubs next to the house help in reducing the cooling load.
- ✓ Shade screens, glass tints, and window/wall awnings are another way of cutting down on heat gain.

3. Lighting

Suggestions for smart usage:

- ✓ Keep cleaning your light bulb once in 1 month or 2 increases the amount of light emitted.
- ✓ Use the compact fluorescent lamps because:

  i. Incandescent lamp

- Generate a high amount of heat and are typically used with a rating of 60 W. They are inefficient artificial light source.

  ii. Fluorescent lamps

- Generate bright light and are most often used with a rating of 12 W/15 W.

Chapter six

Optimization of Energy System components

In the current study, the proposed renewable energy system that is capable to give electric power for 100 household is mainly wind. Even though wind is primarily designed as power source, diesel generator and battery systems are also considered because of variability of wind speed and high cost of initial investment for wind turbine. Diesel generator is used as backup system while battery is used as storage of power during excess power is available because of wind fluctuation; Convertor is considered to change DC form of electricity to AC from battery. The schematic representation of standalone hybrid system of wind-generator-battery system provided in figure 5.1 is modeled by HOMER for analysis purpose as shown in figure 6.1.

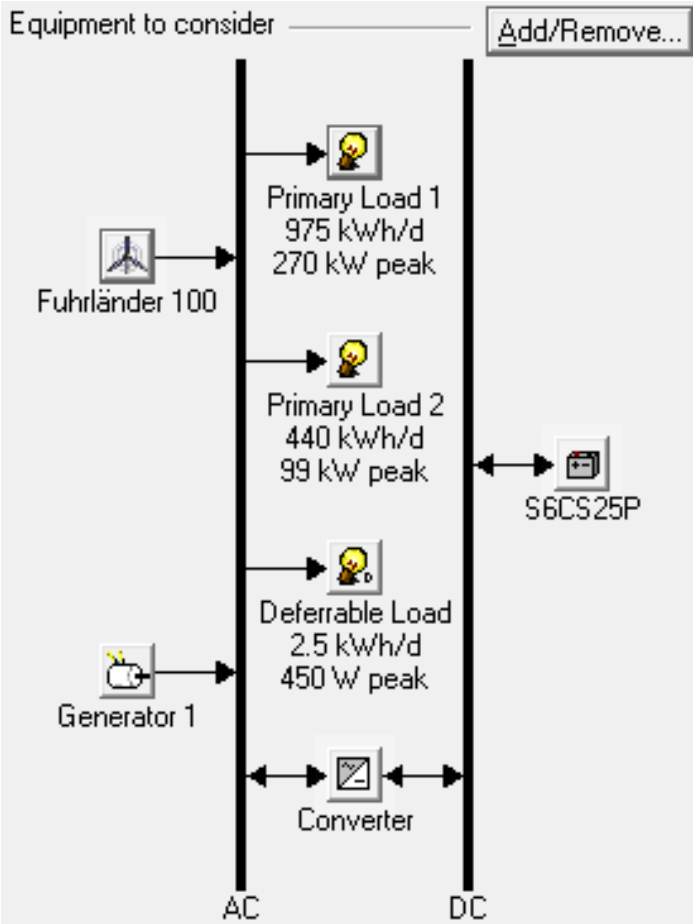


Figure 6.1: HOMER Representation of the Proposed Energy System for Optimization purpose

As it has been discussed in the chapter 5, the electricity demand of the selected site for the 100 household has been calculated by using HOMER, as it is tabulated in table 5.9. In this chapter, the parameters required for simulation work are analyzed which are input to the software. Then in the proceeding chapter the simulation work is carried out and results are discussed based on the calculated demand load and other necessary input to the software to select the best combination of energy system.

HOMER helps to find an economical combination of components that will meet a required load, based on hourly analysis of the input variables, such as wind data. The life cycle cost is also estimated by the software for the system that meets the yearly load.

The software also provides a feature for carrying out sensitivity analysis, which enables the evaluation of the economic and technical feasibility of several technology options. This feature can also be used when there is doubt over the exact value of a certain input, such as the annual average wind speed and diesel price, etc. The sensitivity analysis performs energy balance calculation on hourly basis for a year of 8, 7600 hours [24]. Then, it compares the electric load for each hour to that of energy of the system supply during that particular hour.

6.1. Methodology of Optimization Process

To select an economical alternative of a standalone renewable energy system, a HOMER analysis is implemented for simulation purpose based on different parameters. So as to bring the software output result, an input to the software is needed. Different inputs such as load, cost, sensitivity, component size options and etc are some of the inputs required by the software. Using variable input data, it is possible to iterate and select the best possible standalone energy system as a result of mainly based on economic feasibility and local availability. In addition to these primary factors there are other guidelines which help to optimize and select the best combination among different designed scenario of energy system. Therefore, the following parameters are used both as input and comparison criteria.

- Cost of the Energy System (Initial capital cost, Operation and maintenance (O&M), Total net present cost (NPC), etc).
- Renewable fraction (RF)
- Excess electricity production,

- Capacity Shortage factors, etc.

While designing a standalone renewable energy system the main threat is its cost although it is environmental friendly. Therefore, the cost of the energy system needs a special attention during design. The costs are initial investment cost, operation and maintenance cost (O & M) and replacement cost. In addition to these costs, penalties based on different country trend have been considered during cost analysis. Also, sensitivity analyses have been considered for various inputs during analysis regarding cost. The sensitivity case needs optimization since it may trade off the accuracy of the system and simulation period of the software may take long. In addition to sensitivity analysis, the renewable fraction (FR) is important factor for simulated results; a sensitivity case of 30% to 70% has been taken as the upper and lower limiting of the RF. The lower limit stands to consider environmental factor while the upper limit is for economy factor, it means the higher the RF value the higher will be the cost. Since for higher RF value the cost is very high and also increase the number of sensitivity case which cause the simulation period is so long, only the sensitivity case of RF (30-70) % is considered to shorten the period of computation.

Other limiting factor would be the amount of excess electricity, where higher excess electricity means there is much loss in resource. But HOMER is intelligent to constrain the system so that to simulate for different capacity shortage. In the current study, a capacity factor of 8 to 10 % is considered as sensitivity case for simulation purpose.

In addition to sensitivity case /variables/ stated above that can be used as input into the system simulation, there are a need of other simulation parameters like different sizes and quantities of different system components to optimize the energy system. In the current study, the components which vary in size (generator, and inverter) and quantities (batteries and wind turbines) are considered. Although, increasing the number of sensitivity variables within the range will increase the accuracy of the result, it will take longer computation period and even it may need a larger memory space of the computer. But HOMER is capable to handle this difficulty; the simulation can run first coarsely, minimizing the number of variables within the range. Then the result is refined by adding a greater number of variables within the range.

Since HOMER allow us to work with reasonable variable sensitivity analysis which may not take longer simulation time for better result, different scenarios of wind energy system is proposed to

satisfy the electric demand for the selected site. Therefore, for easy of the analysis the following three standalone wind energy systems are proposed for further study to select the best alternative.

- Scenario A: Wind energy system with diesel generator back up with battery storage
- Scenario B: Wind energy system with diesel generator back up without battery storage
- Scenario C: Wind energy system alone with battery storage

While simulating each of the above energy system scenarios, different size and quantities of the system components are considered. In the following section, the size range and number of components are provided in table 6.1.

For each scenario with different size and quantities of component, a HOMER simulation is conducted and result is displayed. For the evaluation purpose, the results are given as a list of feasible system configurations, sorted by life cycle cost. From the result, the least cost systems which are displayed in the first few rows of the list can be chosen for implementation. And, through the analysis of the feasible energy system, the other potential system is also reviewed from the result list in addition to the first rows based on the advantage and disadvantage of the setup against cost, renewable resource contribution (RF), future price trend of the components and excess electricity, etc. In addition to these all, the selection of best set up is done based on the comparison of current energy system of the Ethiopia, potentially Hydropower.

6.2. Factors that affect Optimization Process

6.2.1 Cost Estimation of Components

As it has been discussed above, the cost is the primary constraint while designing renewable energy system. Particularly, in developing country like Ethiopia cost reduction has got more priority than environmental impact of the energy system. In the current study, different scenarios are analyzed for their economic feasibility in addition to the renewability factors. As an input to the HOMER different component costs like initial investment cost, operation and maintenance cost and replacement cost has been assed based on current market. While as an output from HOMER simulation, net present cost (NPC), total initial capital and levelized cost of energy (COE) is used for optimization process to select best scenario in addition to other factors like renewable factor, etc.

a) Initial Investment Cost

The initial investment cost of a component is the total cost needed to install that component at the beginning of the project implementation period. The initial investment cost and related other costs of components are summarized in table 6.1 which can be used as input to the software.

b) Operation and Maintenance Cost (O&M)

The operation and maintenance cost is a sum up value of the annual cost which is needed for operation and maintenance of the system component. Here also the O&M cost is provided in table 6.1. But the fuel cost for the diesel generator is not considered as O&M cost, instead HOMER has different window for diesel cost analysis. In the current study, current fuel cost in Ethiopia is $1/L (April, 2011). Then the total cost of the fuel would be calculated using HOMER based on the sensitivity factors given for each case.

In addition to fuel cost, carbon dioxide penalty is also considered in the current study. Although there is no carbon dioxide penalty rule in Ethiopia yet it is expected that there will be a near future issue because currently Ethiopian prime Minster Meless Zenawi is working much on environmental protection and promoting environmental drawback of carbon dioxide on behalf of African nation. So, expecting the future penalty, an average value of $20/ t CO2 is considered based on IEA proposal and different countries experience. The proposal of IEA report to decrease CO2 emission is $50/t CO2 to decrease carbon dioxide of significant amount by 2050. But, the current penalty of different counties is less than what is proposed by IEA, as an indication European CO2 penalty is €25/t CO2 [26] which is approximately equals to $37/t CO2. Therefore, the estimated $20/t CO2 is fair value.

c) Replacement Cost

The replacement cost is cost needed for replacing of wear out components. It is different from initial investment because at end of life time of components only wear out parts need to change. Even the cost of component may get down from its current value because of alarming research work to decrease the investment cost of renewable energy system components. The other consideration while calculating cost, the entire system components may need replacement.

Based on the assumptions of European Wind Energy Association (EWEA) given in appendix A4, in its renewable energy roadmap, assumes that onshore wind energy cost ~€1350/KW in

2007 and ~€1230/KW in 2010. It assumes that costs will drop to €826/KW in 2020 and €788/KW in 2030. Assuming 75% of the component only replaced by 2030 after 20 year service life, the wind energy cost is €591/KW which is equivalent to $874.61/KW [26]. The reason why EWEA estimated considered in the current work is pervious similar work use the same assumptions [24]. The operating cost of wind energy at 2010 is ~€1230/KW which is equivalent to $1820/KW.

The replacement cost of diesel generator is assumed to be half the initial investment cost because from the experience most generators attain their service life without failure. Only few wear out parts need replacement. Replacement cost for inverter 100 % of its initial investment cost is assumed while for battery 66.7% of the investment cost is assumed to be replacement cost (two third of initial investment). In addition to these stated costs equipment life is also summarized accordingly for the system components in table 6.1.

6.2.2. Renewable Fraction (RF)

The renewable fraction defines how much energy is generated with contribution of renewable source of energy from the entire production of energy system. HOMER is designed to calculate the expected renewable fraction based on the equation 6.1.

$$\mathrm{RF} = \frac{\mathrm{E_{Ren}} + \mathrm{H_{Ren}}}{\mathrm{E_{tot}} + \mathrm{H_{tot}}} \qquad 6.1$$

Where, $\mathrm{E_{Ren}}$ is electricity production from renewable energy source, $\mathrm{H_{Ren}}$ is thermal heat from renewable heat source, $\mathrm{E_{tot}}$ is total electricity production from the entire system, and $\mathrm{H_{tot}}$ is total thermal heat production from the entire energy system. In the current study no heat load demand is considered for the selected site and it is neglected as it has been discussed in previous chapter.

As it has been discussed above the renewable fraction is considered in between 30 to 70 % to consider both the cost effectiveness and environmental cleanness of the system. Therefore, the simulation of HOMER work is done based on these limiting values so as to get different comparison result to select best energy system.

Table 6.1: Required Input Parameters to the HOMER Software (Source: EWEA Report of 2009 and HOMER268Beta)

OPTIMIZATION VARIABLE	**Wind Turbine**	**Diesel Generator**	**Battery 1156Ah**	**Convertor**
Type of components considered	FL250, FL100	Diesel generator	Surrette 6CS25P	
Capital ($)/watt	$1.82/watt	$0.3/W	1 Battery=$833	$0.7/W
Replacement Cost ($)/watt	$0.87/watt	$0.15/W	1 Battery=$555	$0.7/W
O&M Cost ($/yr)	1.5-2.5% of Initial Capital cost divide by the number of years	20-30% of the total initial cost/total hours	1 Battery=$15	0
Size considered (KW)		For FL250 0,44,88,176 For FL100 0,53,106,132, 176		For FL250 0,50,100,150 ,200, 250 & 300 For FL100 0,50,100,150 ,200, 250, 300 &350
Quantities Considered	For FL250 0,1,2,3 & 4 For FL100 0,1,2,3,4,5 & 6		For FL250 0,100,200, 300,400,500 &600 For FL100 0,100,200, 300,400,500, 600 & 700	
Life Time	25 years	15,000 hours	9,645KWh	15 years
Sensitivity input				
Diesel price ($/L)		0.8, 1, 1.15 & 1.25		
Hub height (m)	50, 60 &70			
Capacity shortage (%)	8, 9 & 10			
Interest Rate change (%)	6,8 & 10			
Renewable Factor (%)	30, 40, 50, 60 & 70			

6.2.3. Capacity Shortage and Excess Electricity

Capacity shortage stands for a shortfall between required operating capacity and the actual operating capacity of the system at a particular period. HOMER is intelligent to identify and calculate the shortfall of capacity (capacity shortage) in a year. In the current study a capacity shortage of maximum value of 10 % is considered because the design of the entire energy system is based on higher safety factors.

Excess electricity stands for an excess production of electricity which must be dumped because it cannot serve the load. The excess electricity may be caused by either excess resource of wind which is above demand load or the diesel generators minimum output exceeds the demand load and the batteries are unable to store the produced electricity. Then, one of the constraints while optimizing simulation result is low level of excess electricity production.

6.3. Summary about Input Parameters to HOMER Software

The input parameter for HOMER simulation is categorized in the following classification namely, resource input, electrical load input, equipments input, economic input, emission input and constraints (sensitivity value). Although, there are many variables required to design a quality of renewable energy system the stated parameters are main parameters which governs the design of current analysis.

6.3.1 Resource input (Wind Speed)

The total demand of electric load in wind –generator hybrid standalone energy system is satisfied from both wind and diesel generator source of energy. The share of wind energy calculated by HOMER once the hourly wind speed is imported to the software. Therefore, as an input parameters HOMER generated hourly wind speed based on scaled down daytime average monthly wind speed is provided as a resource for the calculation of wind load. The detail about potential investigation of a particular site is well discussed in chapter four. The excel sheet of HOMER generated hourly wind speed is documented in addition to this thesis report.

6.3.2. Load Input (Electric Load)

The main aim of the relevant energy system for particular village is to satisfy the demand of the population based on his/her current economic status. Then, knowing how much energy demand

is the first step to design system components size and its related costs. Therefore, the detailed analysis is done in chapter five to determine an electric load for selected site which is used as input to HOMER for further simulation purpose, and the summary of the total load is provided in table 5.9.

6.3.3. Equipments

The main category of equipments which are considered for current design of energy systems are wind turbine, diesel generator, battery and convertor. The quantities and size of each component has been feed to the software for simulation purpose. Different scenarios suggested above are simulated with variable size and quantities of those equipments to determine the best combination of the energy system. Through simulation of HOMER, the share of energy and corresponding costs are determined for each of the equipments.

a) Wind Turbine

The load calculated determined for the selected site is the main limiting criteria to select the type of turbine and its size. As calculated load is around 369.45KW then the contribution of wind turbine has to be large enough to ensure a significant amount of renewable fraction (RF). This can be made true by using either a number of small wind turbines or one big turbine. Since the optimization process is very iterative and it has to be limited to some few variables so as to converge to reasonable results with considerable time gap. Even though it is possible to iterate the simulation by considering various type of wind turbine, in the current study only two types of turbine are considered for further study.

In addition to load factor, cost is also a limiting factor to select a suitable type of wind turbine. Then having these constraining factors, wind turbines can be selected from different sources; the various wind turbine websites and those suggested by HOMER by itself. The type of electricity which a particular wind turbine generates and the minimum cut in wind speed are also other limiting factors so as to select the appropriate wind turbine.

Based on the stated factors above, the type of wind turbines considered for simulation purpose are Fuhrlander 250 (FL250) and Fuhrlander 100 (FL100) from HOMER library, to select an economical type of wind turbine after optimization based on the sated factors. The selected turbines can generate AC form of electricity to satisfy the need of AC form of electricity for each

household appliances and it can serve as off-grid system. Power curves of both FL250 and FL100 are shown in figure 6.2 (a) and 6.2 (b).

The rated power is about 250KW, attained around 15m/s, and cut in speed is 3m/s for FL250 while for FL100, rated power is about 100KW attained around 13m/s, cut in wind speed is 3m/s. Therefore, both turbines can work at low wind speed of minimum 3m/s. The detail specification about selected Fuhrlander turbine is given in appendix A6A.

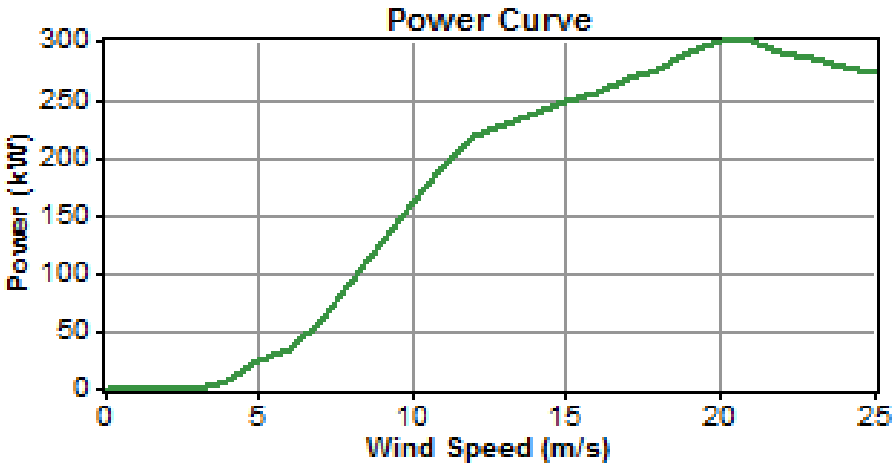


Figure 6.2 a: Power curve characteristic FL250 (Source: HOMER268Beta)

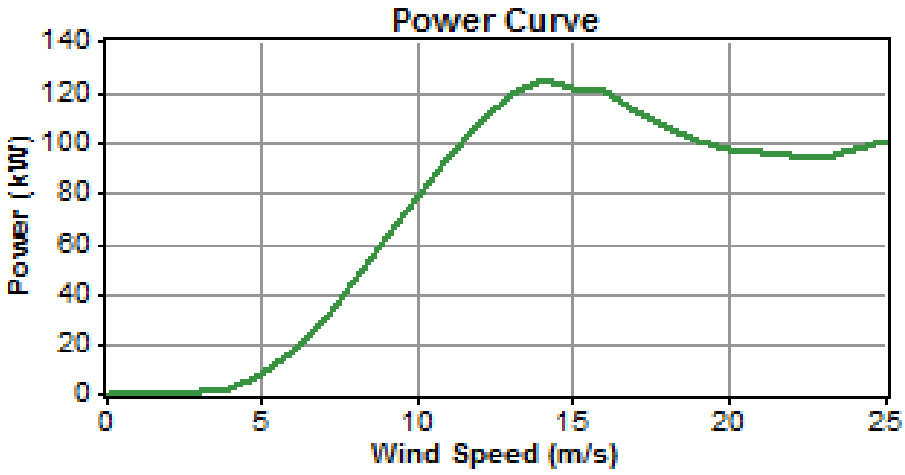


Figure 6.2 b: Power curve characteristic FL100 (Source: HOMER268Beta)

Once the type of turbine is decided accordingly, the forgoing step is to decide the cost of wind turbine (capital, replacement and O&M), quantities of turbines, service time and hub height. Different size variations have been considered while simulating energy system for both types of turbines, for FL250 (0, 1, 2, 3 & 4) while for FL100 (0, 1, 2, 3, 4, 5 & 6) are considered for

optimization purpose. The estimated service life of wind turbine in both cases is 25 which used HOMER to calculate the net present value. Three different hub heights are considered (50m, 60m &70m) for both cases which used HOMER to calculate different wind speed at different elevation based on logarithmic profile equation discussed in chapter four. The wind speed increases as hub height increases and this will decrease high investment cost. The resulting input is provided to HOMER for simulation purpose in both cases and the input parameters to each wind turbine cases are summarized in appendix A5B & A5C.

b) Generator

As it has been discussed for wind turbine, different parameters have to be input to HOMER in the category of diesel generator window. These parameters are size of generator, costs (capital, replacement, and O&M), and service time and fuel price. The input window in HOMER for generator is displayed in appendix A5D and A5E.

Since the size range of generators is one of the simulation variables, sizes of (0, 44, 88, & 176) KW are considered for generators working with FL250 wind turbine while sizes of (0, 53, 106, 132 & 176) KW are considered for generator working with FL100 wind turbine, based on the manufacturer catalogue. The size selection of a particular generator considers the constraint of both cost effectiveness and capacity of delivering the required power. Then, the appropriate size can be selected based on the simulation result which attains the most cost effective in terms of minimum net present cost and cost of energy (COE) as wells as size which provide less excess electricity.

The costs (capital, replacement and O&M) are calculated based on the information provided in table 6.1, and summarized in appendix A5D.The investment cost of generator which is provided in table 6.1 is determined based on the price of different manufacturer. In the current study, after a thorough analysis of different generator manufacturer, the type of generator considered is KOHLER diesel generator [27]. KOHLER is selected because of its low cost and applicability for standalone power generation. As an indication, a 160KW KHOLER diesel generator cost $33,609.00 which is equivalent to $0.21/watt but the price of generator per watt gets higher as size of generator is gets lower and vise versa. Considering this fluctuation of price, shipping and installing of the generator as well as future currency depreciation the investment cost of

$0.3/watt is considered, roughly. The fuel for selected generator is diesel oil. The details about the brand and type of engine for selected generator are summarized in appendix A6B.

In case of generator, fuel cost has to be input to the HOMER unlike other renewable source of power because the diesel is not free. Based on the current market of diesel price, the calculated cost is $1/L but other lower and higher price of fuel is considered in the current study so as to consider the world oil price fluctuation. The price considered as sensitivity case for simulation purpose are $0.8, $1, $1.15 and $1.25. Since the fuel is standard and its common properties like lower heating value, density and carbon content and sulfur content used are default values from HOMER library. The service life of generator considered is 15,000 hours. The minimum load ratio for generator is around 30% .Therefore, the separate input window from HOMER is displayed on appendix A5F based on the stated information so far.

c) Battery

As it has been discussed for both diesel generator and wind turbine, different parameters need to be considered while simulating the energy system which contains batteries. The parameters which used as input for HOMER are quantity of battery, costs (capital, replacement and O & M) and minimum service life. Different sources are consulted to select the appropriate type of battery for standalone renewable energy system. The main factors while selecting battery is its capacity of chagrining and discharging. Most of current ongoing battery banks have 50% discharging capacity but in research stage this figure is increased to 80% by using most quality of battery; these types of batteries are discussed in chapter three.

In the current study, Surrette6CS25P has been selected from HOMER library. This type of battery has been selected for similar analysis in previous study and it is commonly used in most application. The quantities of battery considered for both turbine cases are different, for FL250 (0, 100, 200, 300, 400, 500 & 600) and that of FL100 (0, 100, 200, 300, 400 500, 600 & 500). The service life and related costs for selected battery are summarized in table 6.1. The detail specification and input parameter to HOMER for battery is summarized in appendix A6C and A5G &A5H, respectively.

d) Convertor

A convertor is required in the system in which DC serve an AC load or vice-versa. In the current study different scenarios which comprise battery bank are considered and the form DC power from Battery has to be changed to AC form by use of convertor. Therefore, variable size ranges of convertor are considered for simulation purpose so as to provide an economical required form of electricity. The sizes considered for FL250 are (0, 50, 100, 150, 200, 250 & 300) KW and that of FL100 are (0, 50, 100, 150, 200, 250, 300 & 350) KW. Then, HOMER is intelligent to select the proper size of converter for the corresponding quantity of battery from given alternative input size of converter. The type of convertor considered for current case is taken from HOMER library which has a service life 15 years. The necessary cost parameters are also summarized in table 6.1. The detail of input window to the HOMER is also summarized in appendix A5I &A5J.

6.3.4. Economic Input

HOMER is also designed to have window for economic inputs in order to calculate the net present value of the proposed system. The input parameters needed to calculate the NPV are annual real interest rate, project life time, system fixed capital cost, system fixed O&M cost and capacity shortage penalty. The renewable energy project gets governmental subsidize which is funding at reduced interest rate than other projects. Annual interest rate of 8% considered for current thesis which is by 27% less than the current Commercial Bank of Ethiopia's rating of 11%. But considering the fluctuation of interest rate through time three different values are considered as sensitivity cases (6%, 8% & 10%). The project life is considered to be 25 years which is the same as that of component life. Both fixed capital and O&M cost considers the fixed cost regardless of size or architecture of the system. In this study, this value is taken to be zero as there is no information about these issues. Since there is no regulation regarding capacity shortage penalty, it is considered as zero value.

6.3.5. Emission Input

Although different emission penalty and constraining amount of emission can be considered while designing renewable energy system with help of HOMER, in the current study carbon dioxide emission penalty of $20/t CO2 is only considered as it has been discussed before. Because in Ethiopia, there is no limiting and penalizing rule for emission and it is difficult to find the real data for corresponding parameters. Then, HOMER automatically calculates annual

production of CO2 from diesel input and multiplies with penalty factor to consider annual cost because of emission.

6.3.6. Constraints Input

HOMER is also capable to consider some sensitivity factor or constraints as it has been discussed above. In the constraint window the main parameters considered are renewable ratio and capacity shortage in which 30 to 70% (RF) and capacity shortage range for (8%, 9% & 10%) has been considered. Also diesel price which varies from $0.8/L to $1.25/L and an interest rate which varies from (6% to 10%) are considered as sensitivity analysis. Then HOMER simulates the proposed scenario based on these input sensitivity factors so as to find both technical and economical sound energy system components.

Chapter Seven

Optimization Result and Discussion

In this chapter, the simulation results are discussed based on the input parameters described in the previous chapter. As it has been stated in the objective, the aim of this thesis is techno-economical assessment of wind energy system for selected site (Moyale) of rural village. The load and necessary input parameters are determined for a hypothetical model village of 100 household populations. Then this input parameters used to generate simulation result using HOMER Software. Through the simulation work, three different scenarios are considered to increase the probability of finding the best energy system components. The specified scenarios are described in the preceding chapters. From the generated simulation results the combination of components which costs less (minimum total net present cost (NPC) and less cost of energy (COE)) is considered as selected energy system for each scenario analysis. Then, finally from different scenario analysis, still the least cost scenario is considered as the best energy system by comparing scenarios with the same design parameters.

In addition to main factors, minimum net present cost and low cost of energy, secondary factors are also considered to select an energy system which is sound both in technology and economy aspects. These factors are renewable factor (RF), excess electricity and least capacity shortage. Finally, the selected energy system electric tariff also compared with current ongoing energy system tariff of Ethiopia.

7.1 Simulation result of Wind energy system of different Scenarios

For all scenarios simulation, two different wind energy system assemblies are considered by varying type of wind turbines (FL250 &FL100), as a result a total of 540 sensitivity cases are considered for both case while 980 and 2240 simulations results have been generated by running HOMER, respectively. For each sensitivity analysis the first few least cost optimization results only displayed for comparison purpose of various sensitivity cases as it described above. The sensitivity variables comprise diesel price, tower height, interest rate, capacity shortage and renewable fraction (RF). The software generated the same number of results for number of input sensitivity cases but in this report the worst cases and the selected type of result only discussed.

Although HOMER analyzed different combination of energy system components, it only selects the cost effective scenario for farther analysis. In the current study, for the given model of scenario A (Wind +Generator +Battery), HOMER tried to optimize different size of generator and number of wind turbines combination only to find economical energy system of scenario B (Wind +Generator) while it analyzes for scenario A. It also optimizes the third scenario option (scenario C) of wind + Battery option while it analyze for scenario A so as to find least cost effective energy system.

Table 7.1: Comparison of three least cost effective scenario for wind turbine of FL250

Sensitivity variables

Diesel Price ($/L) 1 | FL250 Hub Height (m) 70 | Interest Rate (%) 8 | Max. Annual Capacity Shortage (%) 10 | Min. Ren. Fraction (%) 30

Double click on a system below for simulation results.

FL250	Label (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
1	44	200	150	$ 739,800	104,679	$ 1,857,229	0.359	0.61	0.10	85,694	6,577
3		500	250	$ 1,956,500	23,905	$ 2,211,685	0.427	1.00	0.09		
2	176			$ 962,800	206,323	$ 3,165,256	0.600	0.67	0.07	180,903	6,106

Table 7.2: Comparison of three least cost effective scenario for wind turbine of FL100

Sensitivity variables

Diesel Price ($/L) 1 | FL100 Hub Height (m) 70 | Interest Rate (%) 8 | Max. Annual Capacity Shortage (%) 10 | Min. Ren. Fraction (%) 30

Double click on a system below for simulation results.

FL100	Label (kW)	S6CS25P	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage	Diesel (L)	Label (hrs)
2	53	200	100	$ 616,590	107,187	$ 1,760,782	0.344	0.59	0.10	88,988	5,527
6		600	250	$ 1,766,800	27,373	$ 2,059,001	0.400	1.00	0.10		
5	132			$ 949,824	154,159	$ 2,595,436	0.505	0.76	0.10	135,466	5,838

7.1.1. Selection of an Economical Energy System Scenario

The least cost option of all scenarios in both wind turbine cases are compared in regard to stated factors of COE, NPC, capacity shortage and renewable fraction and excess electricity to select a techno-economically sound scenario as shown in table 7.1 and 7.2. The cost effective scenarios are compared for the current market condition of diesel price ($1/L), tower height of 70m, current interest rate of 8%, the worst case of capacity shortage of 10% and minimum renewable

fraction of 30% although the sensitivity cases vary for different diesel price, tower height, interest rate, capacity shortage and renewable fraction.

1. Cost of Energy (COE) and Total Net Present Cost (NPC)

As it can be seen from the above two tables (7.1 & 7.2), the total net present cost (NPC) of scenario A is lower than that of scenario B &C in both wind turbine cases. Also cost of energy (COE) for scenario A is lower than that of scenario B & C. From these two comparison parameters (less NPC and less COE) point of view, scenario A is best alternative among the rest.

2. Renewable Fraction (RF) and Excess Electricity

As a second comparison parameters renewable fraction and excess electricity is considered. It is obvious that scenario C has a renewable fraction of 100% which is by far greater than the other two scenarios A & B but as a result there is highest excessive electricity in case of scenario C (49.8% in case of FL250 and 47.1% in case of FL100). The renewable fraction of scenario A in case of FL250 (61%) is less than that of scenario B (67%) and in case of FL100, the renewable fraction of scenario B (76%) is greater than that of scenario A (59%) and the excess electricity of scenario A (13.7% in case of FL250 and 14.4% in case of FL100) is lower than that of scenario B (57.6% in case of FL250 and 61.1% in case of FL 100). The highest renewable fraction and lowest excess electricity is a desired factor while selecting an option of technologically and economically viable energy system components. Therefore, regarding excess electricity comparison constrained scenario A is the best option among the rest although scenario C has the highest RF value. The excess electricity production will cause an extra cost for not demanded load.

3. Capacity Shortage

As a third comparison constrained lower capacity shortage is considered. An energy system with lower capacity shortage is considered as a best energy mix because the availability of power per year is higher as capacity shortage gets lower. Capacity shortage of 10 % is recorded for all scenarios in case of FL100 but in case of FL250, 10% capacity shortage for scenario A, 7% for scenario B and 9 % for scenario C. As a result scenario B is good in case of FL250 because of the recorded lowest capacity shortage of 7%. But the capacity shortage variations are so marginal

in all scenarios for both wind turbine cases which ranges from 7% to 10% to select the best type of scenario in regard to capacity shortage.

Therefore, as a result of the above discussion, scenario A wins the highest rank among the rest scenarios based on almost all stated design constraint (least cost and less excess electricity). Then, wind-generator-battery and convertor combination (scenario A) is selected in both wind turbine cases further investigations.

7.1.2 Comparison Summary of Different Scenarios to select Cost Effective Energy System

As it has been discussed above different scenario analysis are discussed in depth so as to select the best cost effective energy system components. As it clearly stated, the proposed scenarios are three namely scenario A, scenario B and scenario C. Further optimization is done for all scenarios by varying type of wind turbine. So, in all cases the list cost effective simulation result is identified with corresponding values of NPC, COE, excess electricity and capacity factor. For the comparison purpose some design constraints kept constant to compare different result with the same datum values. The tower height is kept at 70m for all scenarios, the current diesel price of $1/L is considered for the corresponding scenario A & B. The minimum renewable fraction kept 30% for the same scenario situation considered in case of diesel price and 10% capacity shortage is considered in all scenario case since this value is the worst case. The renewable fraction of 100% is considered for scenario C. Then, based on the stated assumption the corresponding value of design parameters stated above summarized in table 7.3 for all scenario cases.

As it has been discussed above, a scenario with low NPC, low COE, low excess electricity, low capacity shortage, high RF and high capacity factor is considered as best energy system. So, as to ease the comparison process, the corresponding values of design parameters are plotted in figure 7.1 to 7.3 for the proposed scenarios. As it has been discussed above scenario A is selected comparing with scenario B.

Table 7.3: Summary of design parameters to select techno-economical energy system scenario

Scenarios	Total NPC ($)	COE ($/KWh)	Excess Electricity (%)	Capacity shortage (%)	RF (%)	Capacity factor of Wind turbine (%)	Capacity factor of generator (%)
Scenario A with FL100	1,760,782	0.344	14.4	10	59	21.5	56.5
Scenario B with FL100	2,595,436	0.505	61.1	10	76	21.5	25.5
Scenario A with FL250	1,857,229	0.359	13.7	10	61	18	64.9
Scenario B with FL250	3,165,256	0.600	57.6	7	67	18	24.6
Scenario C with FL100	2,059,001	0.400	47.1	10	100	21.5	-
Scenario C with FL250	2,211,685	0.427	49.8	9	100	18	-

As it can be seen from figure 7.1, scenario A with FL100 is the cheapest energy system among proposed scenarios while comparing the COE. Therefore, because of its less COE ($0.344/KWh) scenario A with FL100 considered as a cost effective energy system in regard to COE.

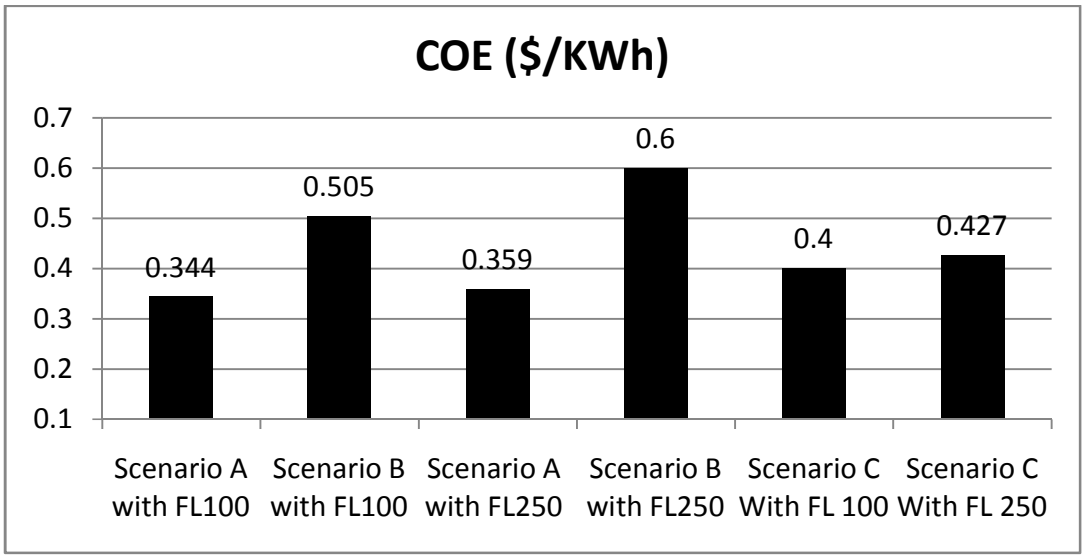


Figure 7.1: Comparison of Scenarios Based on Cost of Energy (COE)

The other design parameter considered while selecting cost effective energy system is total NPC. As, it can be seen from figure 7.2, scenario A costs less than other proposed energy systems.

As a third comparison parameter, design constraints of excess electricity, capacity shortage and capacity factor are considered. As it can be seen from figure 7.3, least capacity shortage is found for scenario B with FL 250 with value of 7% but it is not that much lower than that of scenario A with FL100 of 10%. Since scenario A took high credit than scenario B with regard to cost. While comparing with excess electricity because of its pure renewability scenario C generate highest excess electricity (49.8%) with FL 250 among other scenarios. Because of this excess electricity generation beyond reasonable level scenario C incur the highest cost. Comparing with excess electricity generation scenario A with FL250 takes highest selection rank among other scenarios with value of 13.7%. In addition to cost effectiveness, a considerable amount of excess electricity is needed while designing the energy system so as to answer the alarming increment of electricity demand in Ethiopian, which can be seen all over the country because of economic development of the country. Because of the sated reason and one discussed in chapter five, scenario A is considered as best energy system.

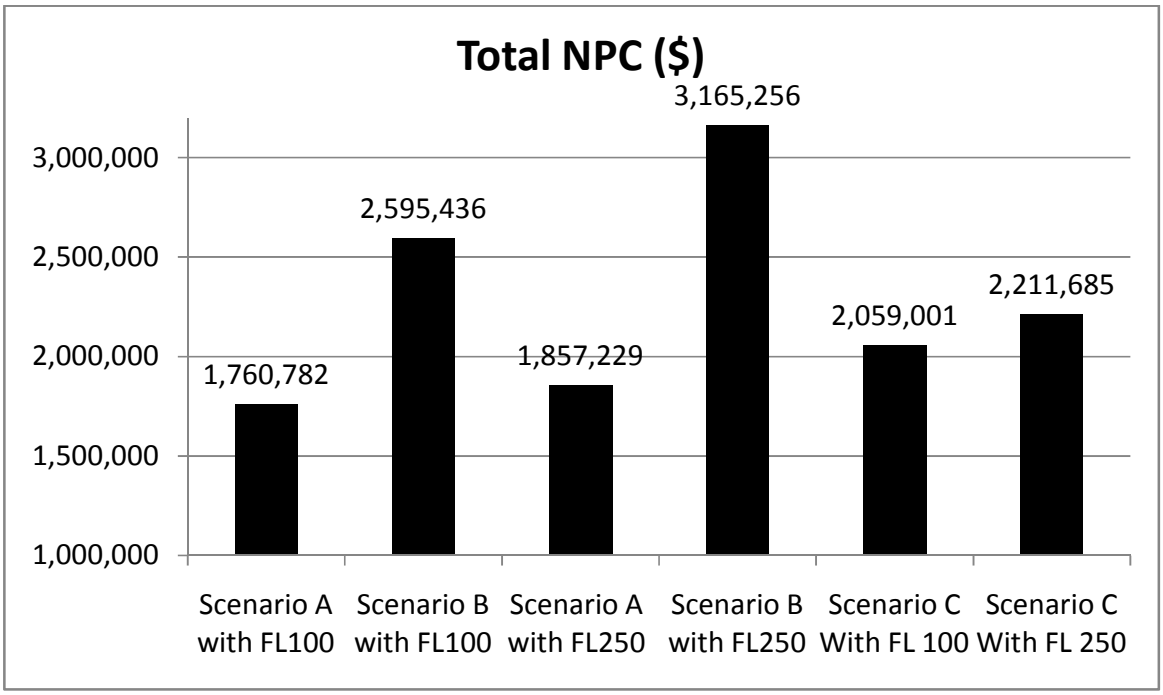


Figure 7.2: Comparison of Scenarios Based on Net Present Cost (NPC)

Since capacity factor is comparable with efficiency, high capacity factor is desirable value while designing a renewable energy system. Because of wind speed potential and its variability most of the time wind turbines are not that much efficient. As an indication shown in figure 7.3, the highest capacity factor of wind turbine (21.5%) is found in case of scenario A and scenario B with FL100. This 21.5% capacity factor is fairly good as compared to previous studies done with the similar data analysis. In one of the R.Dsasa [20] analysis, he found a value of 13.5% which is by far less than 21.5%. Similarly, as it can be seen from figure 7.4 the capacity factor for generator in case of scenario A with FL100 (56.5%) which is lower than that of scenario A with FL250 (64.9%). Therefore in regard to capacity factor still scenario A with FL250 took high selection rank than other scenarios.

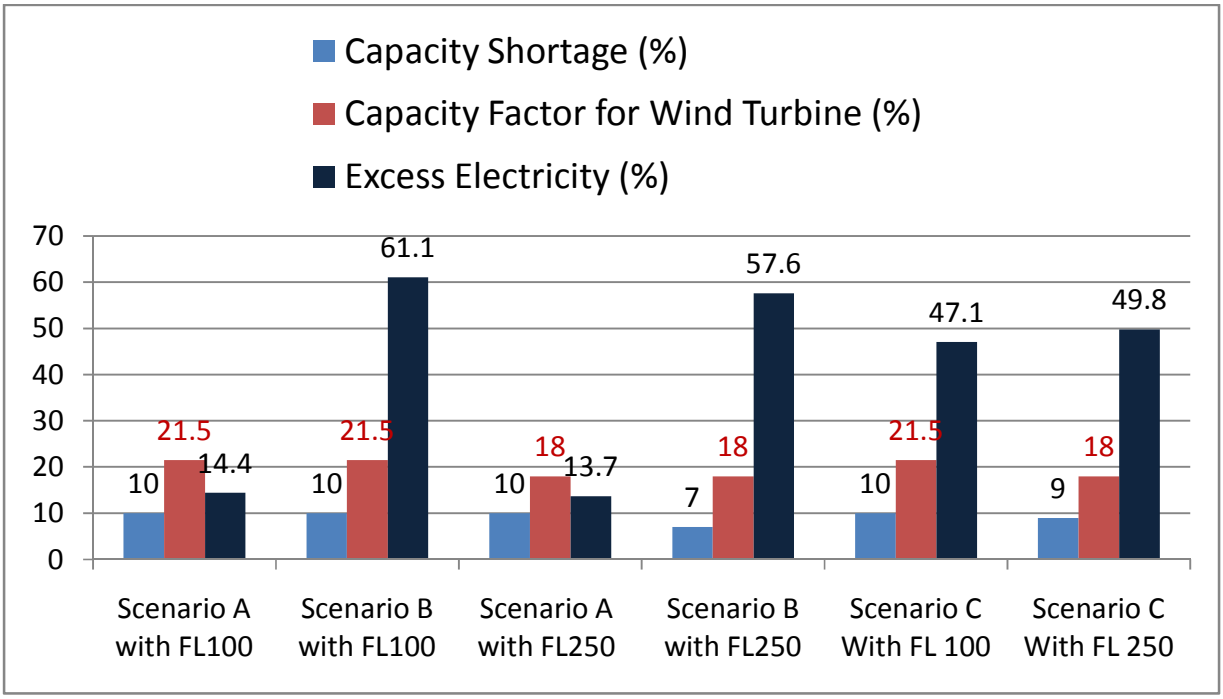


Figure 7.3: Comparison of Scenarios Based on capacity shortage, excess electricity and Capacity factor for wind turbine

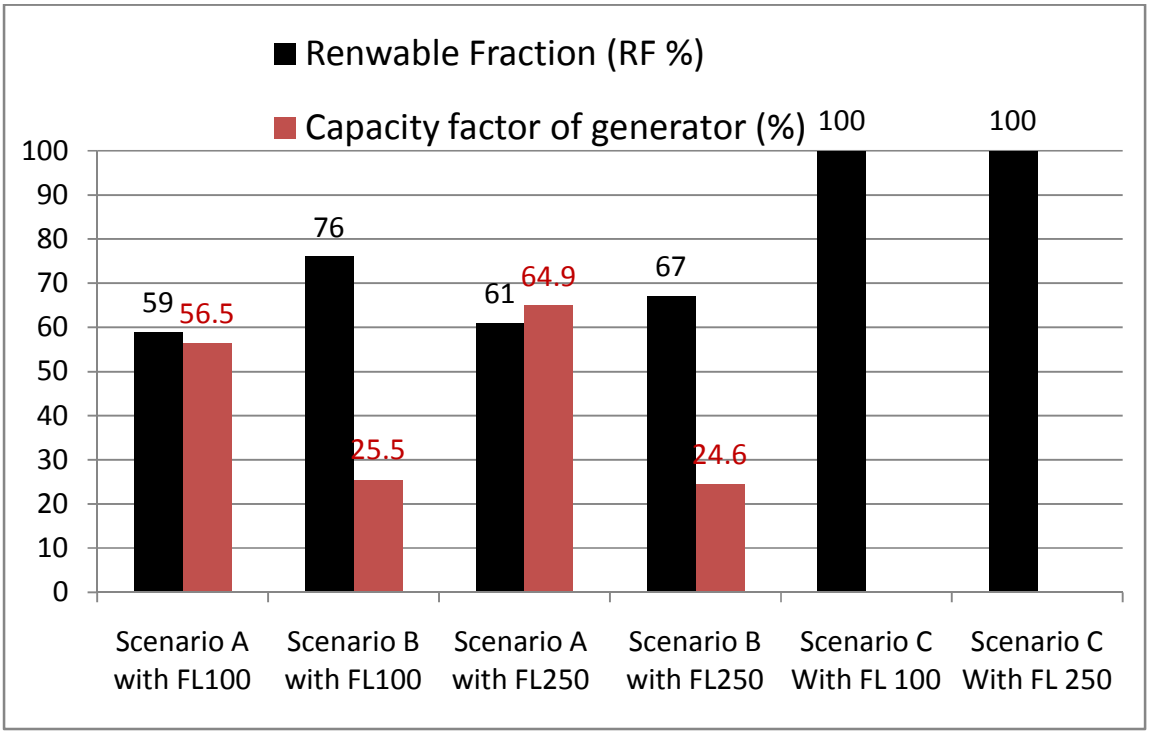


Figure 7.4: Comparison of Scenarios Based on RF and capacity factor for generator

As a final comparison factor, design criteria of renewable fraction are considered while designing a renewable energy system. In addition to cost effectiveness, high selection rank goes for energy system which has high RF because of its reduced carbon dioxide emission. As it can be seen from figure 7.4, scenario C has highest RF (100%) because it is designed from pure renewable source. But it incurs high investment cost, as a result the cost of energy (COE) is not affordable and the selection is made wisely so as to compromise both cost effectiveness and environmental cleanness. Therefore, scenario A is selected in regard to less cost and reasonable RF.

Therefore, based on the discussed economic feasibility, scenario A is selected as cost effective energy system. In addition to cost effectiveness, technological soundness also considered by comparing efficiency of the components and renewability fraction. Also, some design constraint like capacity shortage and excess electricity are considered during comparison so as to answer the current energy constraint of Ethiopian energy system. In addition to stated design parameters above, the selection of components (Wind Turbine, Generator, and Battery) while modeling the proposed scenarios also done based on their less cost and technological soundness in the current

market, as it has been discussed in chapter three and five. With almost all the stated design constraints and selected techno-economically sound components, scenario A has highest nobility to be selected as a techno-economically sound energy system alternative among proposed scenarios. Then, in the next section an evaluation of a type of wind turbine for selected scenario is done so as to design most economical energy system.

7.2. Selection of an Economical Energy system options (Types of Wind Turbines) for Scenario A

The second optimization step is selecting the best alternative among different energy system components which comprises different wind turbine types (FL250 and FL100) for selected scenario A. The comparison is also based on the constraint used before (less NPC, less COE, less excess electricity, less capacity shortage and high renewable fraction). To ease the selection of energy system components, some dependant parameters made fixed on the same value for both wind turbine cases.

1. Cost of energy (COE) as comparison parameter

For the specified capacity shortage of 10%, current interest rate of 8% and minimum renewable fraction of 30%, the simulation result is displayed for variable diesel price and hub height for both wind turbine cases of scenario A, as shown in figure 7.5 and 7.6. As it can be seen from result plots, the cost of energy (COE) varies for variable height of tower and diesel price which ranges from $0.321/KWh to $0.423/KWh in case of FL250 while $0.306/KWh to $0.410/KWh in case of FL100. The minimum COE is registered at high tower height and minimum diesel price while the maximum COE is registered at lower tower height and high diesel price in both wind turbine case. The current COE which is registered at current diesel price ($1/L) vary with respect to tower height, the variation with respect to tower height is depicted in the plot which is inversely proportional to hub height for both wind turbine cases. Therefore, the lower COE is recorded for wind turbine case of FL100 than that of FL 250.

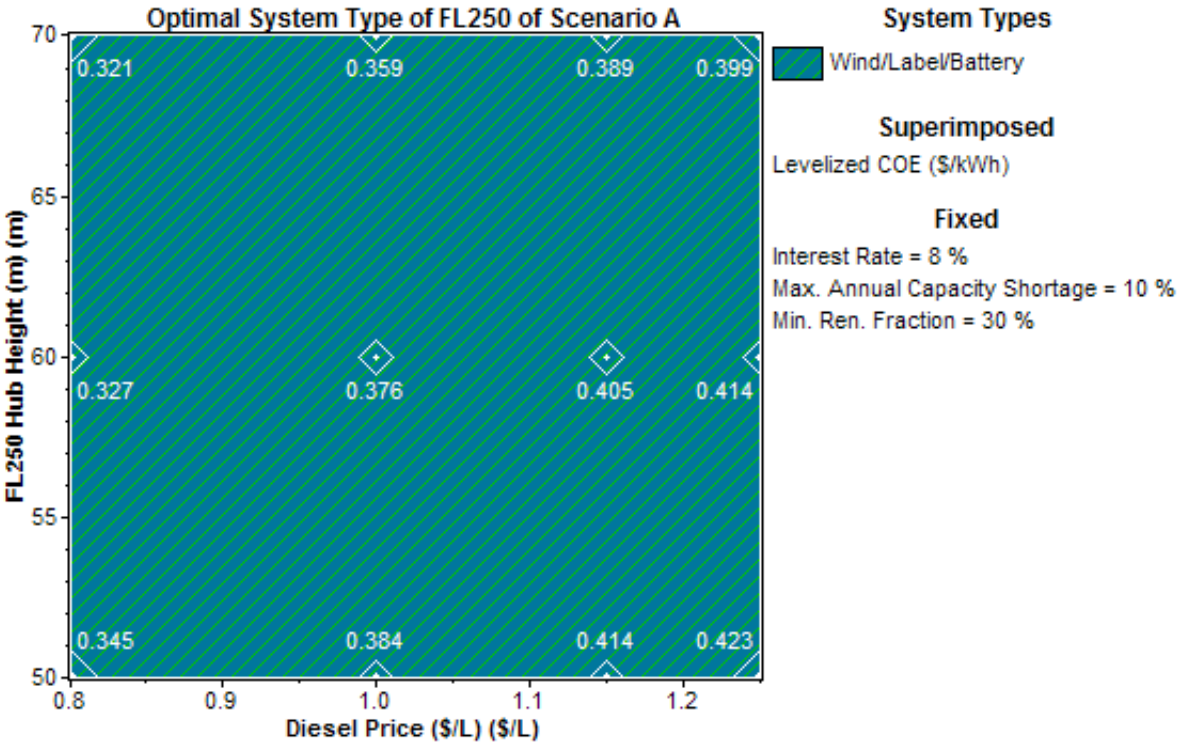


Figure 7.5: Simulation Result of wind energy system of Scenario A with FL250

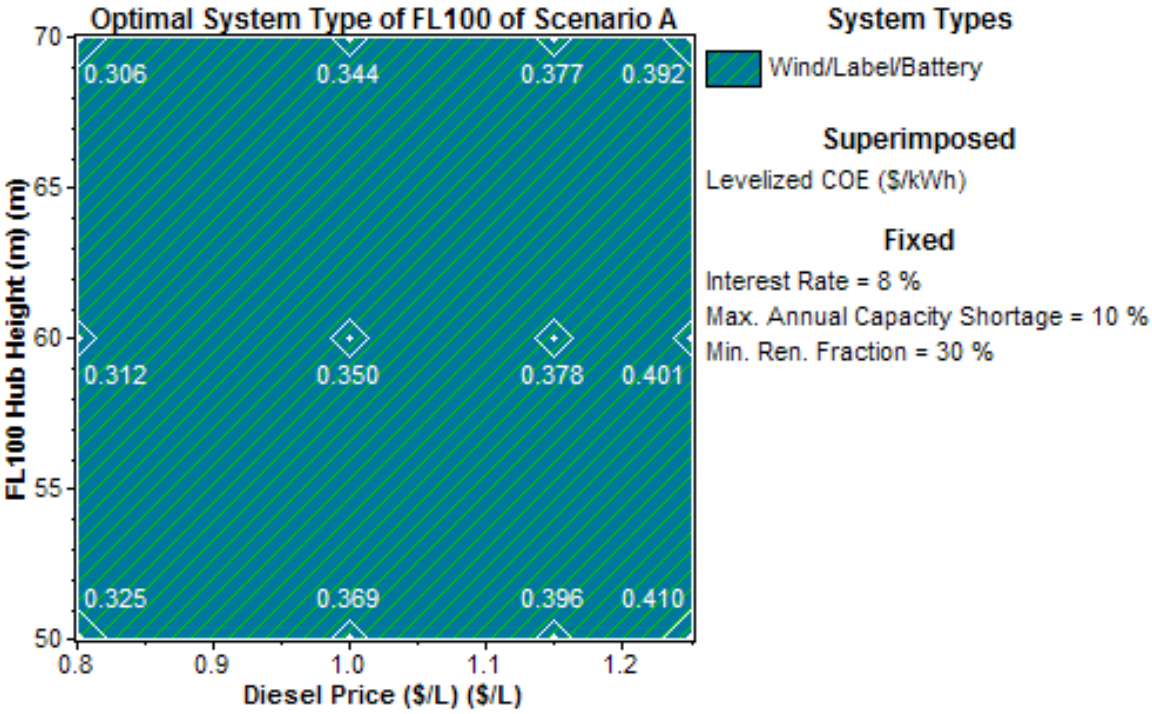


Figure 7.6: Simulation Result of wind energy system of Scenario A with FL100

2. Total Net Present Cost (NPC)

Similarly, for the specified capacity shortage of 10%, current interest rate of 8%, hub height of 70 m and minimum renewable fraction of 30%, the variation of net present cost (NPC) &COE with respect to diesel price is displayed in figure 7.7 and 7.8 for both wind turbine cases, as a result of HOMER simulation. For the case FL250, the NPC starts to increase from value of $1,671,698 at diesel price of $0.8/L linearly up to the diesel price of $1.25/L (NPC is equivalent to $2,053,136) with variable slope of increment. The same is true in case of FL100; the NPC starts to increase from value of $1,570,797 at diesel price of $0.8/L linearly up to diesel price of $1.25/L (NPC is equivalent to $2,016,872) with variable slope of increment. The wind turbine required in both case is constant with variation of diesel price. To have a better conclusive idea while selecting best energy components what are stated in graph and two paragraphs above is summarized in table 7.4.

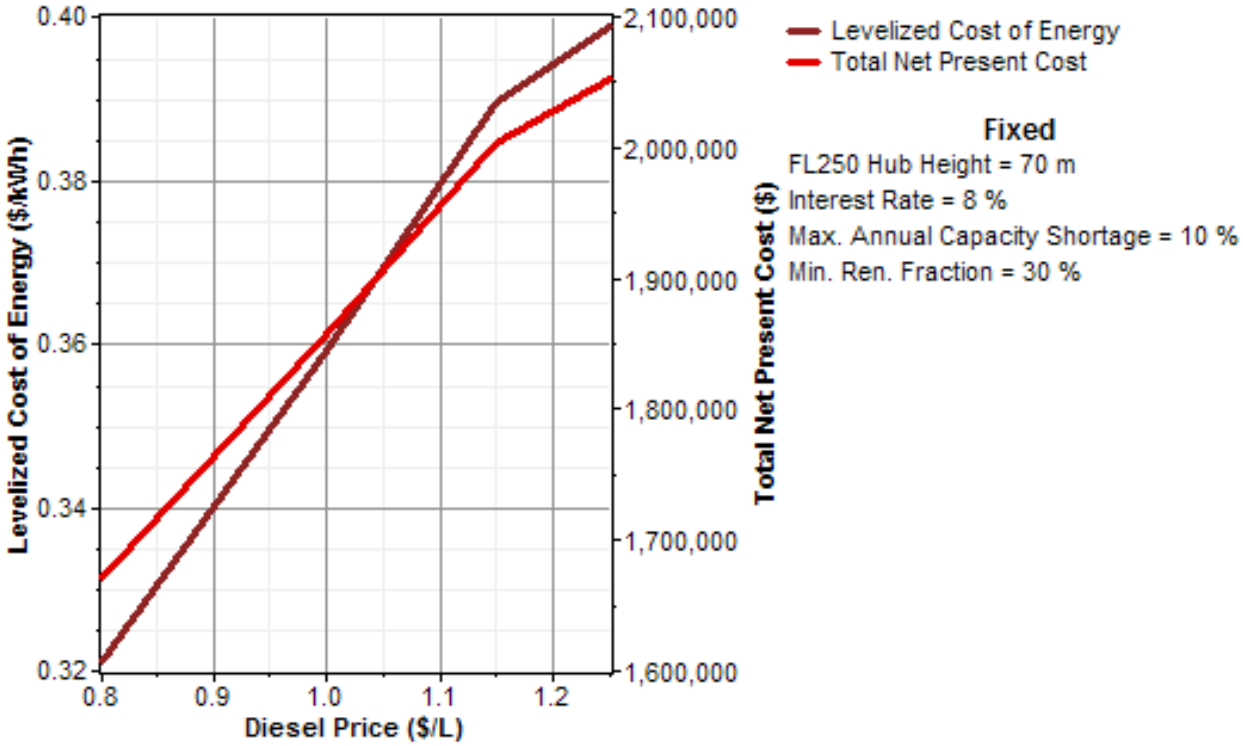


Figure 7.7: The variation of total NPC with respect to diesel price for scenario A with FL250.

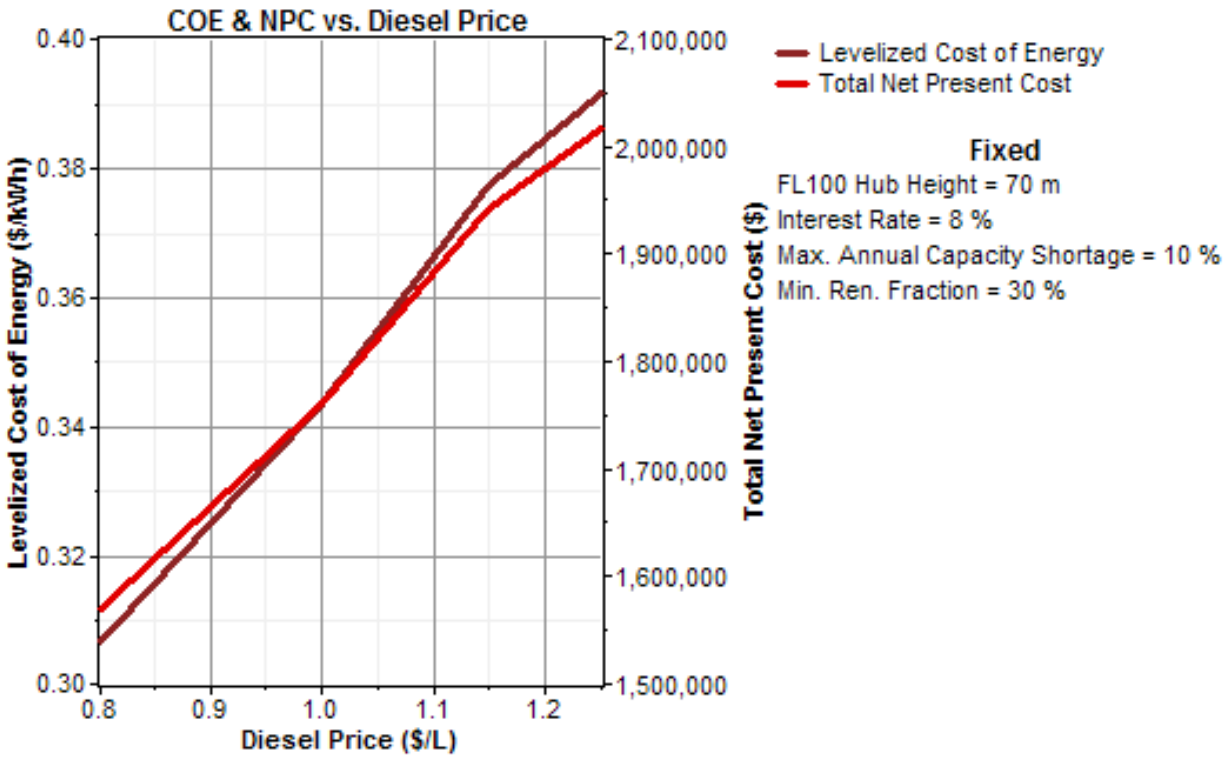


Figure 7.8: The variation of total NPC with respect to diesel price for scenario A with FL100.

Table 7.4: Summary of total net present cost (NPC) at hub height of 70 m with respect to diesel price variation for both FL250 and FL100

Diesel Price ($/L)	**0.8**	**1.0**	**1.15**	**1.25**
NPC for FL250 ($)	1,671,698	1,857,229	2,003,952	2,053,136
NPC for FL100 ($)	1,570,797	1,760,782	1,943,419	2,016,872
Change in total NPC for both turbines at each diesel price ($)	100,901	96,447	60,533	36,264

As it is clearly summarized in table 7.5, huge amount extra dollar is needed for wind energy system which comprise a wind turbine of FL250 than FL100 for the same energy production need to satisfy a given load. Concluding based on the stated hypothesis an energy system which comprises a wind turbine of FL100 needs low investment cost than that of FL 250.

In addition to the plot for COE in figure 7.5 & 7.6, the variation of COE at hub height of 70 m with respect to diesel price, is displayed in figure 7.7 and 7.8 for both wind turbine cases, as a result HOMER simulation. Similar to the previous parameter net present cost, COE also vary

with diesel price variations. For the case of energy system of FL250, the increment of COE goes linearly starting from value of $ 0.321/KWh at diesel price of $0.8/L up to a value of $0.399/KWh at diesel price of $1.25 with variable slope of increment.

Similarly, the nature of variation of COE for the case FL100 behaves the same way as FL250. But the minimum value starts with $0.306/KWh at diesel price of $0.8/L and goes to increase up to value of $0.392/KWh at diesel price of $1.25 with variable slope of increment. Similar to the previous NPC comparison case a summary of COE is provided in table 7.4 to select the best energy system component in regard to COE optimization parameter.

Table 7.5: Summary of cost of energy (COE) with respect to diesel price variation for both FL250 and FL100

Diesel Price ($/L)	**0.8**	**1.0**	**1.15**	**1.25**
COE for FL250 ($/KWh)	0.321	0.359	0.389	0.399
COE for FL100 ($/KWh)	0.306	0.344	0.377	0.392
Change in COE for both turbines at each diesel price ($/KWh)	0.015	0.015	0.012	0.007

As it has been discussed above and summarized in table 7.5, the less cost of energy (COE) can be assured by installing the wind energy system components which comprise FL100 wind turbine than FL250 for the same amount of energy delivered to the customer.

3. Capacity Shortage

As a third comparison parameter low capacity shortage is considered. The lower capacity shortage value took high selection rank while considering capacity shortage as comparison criteria. As it summarized in table 7.1 and 7.2, the capacity shortage for both wind turbine cases are the same (10%). In this case, capacity shortage is not helpful to select best energy system among two cases compared.

4. Renewable Fraction (RF) and Excess Electricity

As a final comparison parameters renewable fraction and excess electricity is considered. Higher renewable factor and lower excess electricity took high rank to select a best energy system among given two cases of FL250 and FL100. For both cases the renewable fraction is summarized in table 7.1 and 7.2, respectively. The final simulation result which also shows excess electricity is summarized in figure 7.9 and 7.10, respectively. The renewable fraction in

case of FL100 case (59%) is lower than that of FL250 (61%) by three percents only. Also, the excess electricity lower in case of FL250 (13.7%) than that of FL 100 (14.4%) by 0.7% which is marginal difference. Therefore, it is difficult to select a particular turbine type based on the low renewable fraction and low excess electricity because of their marginal difference.

As it has been discussed in the chapter six, considerable amount of excess electricity can be tolerated while designing a renewable energy system which is designed based on the marginal load calculation because there are some uncertainty conditions which may need high demand load than expected. Secondly, as it can be seen current Ethiopian energy statics, there is high growth rate of energy demand every year because of high rate of development in the country. So to provide a sufficient energy for consecutive increment of energy demand a considerable amount of excess electricity is allowed while designing the current energy system. Then based of the low NPC and COE, an energy system which comprises a wind turbine of FL100 has got high rank than that of FL250 with considerable amount of excess electricity.

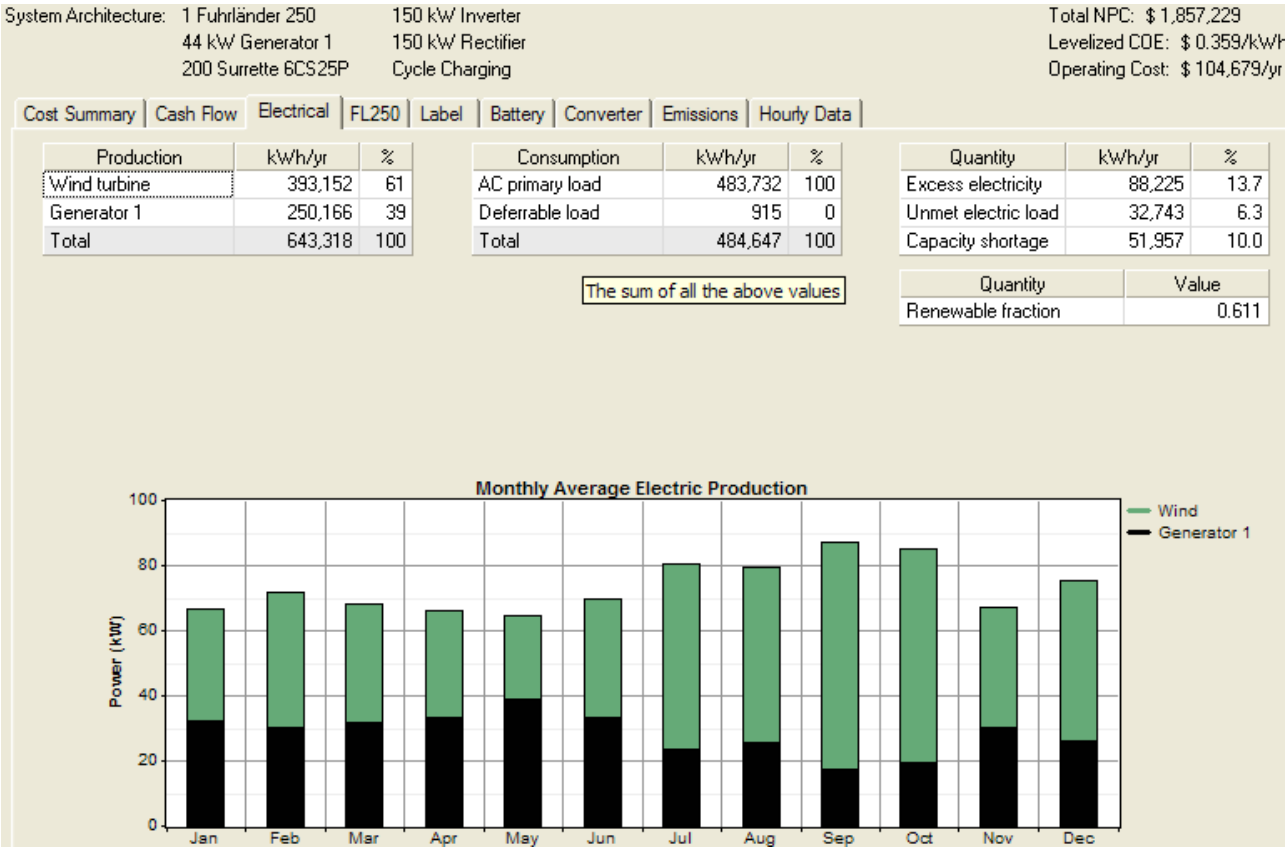


Figure 7.9: Simulation Result of Electrical Architecture for scenario A with FL250

Based on the overall comparison results discussed above, energy systems which comprise FL100 wind turbine has less net present cost (NPC) and less cost of energy (COE, and it also generate a considerable amount of electricity. So, FL100 wind turbine energy system is selected based on the sated advantages.

The three proposed scenarios (scenario A, scenario B and scenario C) are analyzed and compared based on the design parameters as it is discussed above. Based on the comparison, scenario A is selected because of its nobility in regard to almost all factors and further analysis has been done by varying type of wind turbines to find best cost effective energy system components. As a result scenario A with wind turbine of FL100 is selected as cost effective energy system comparing with FL250.

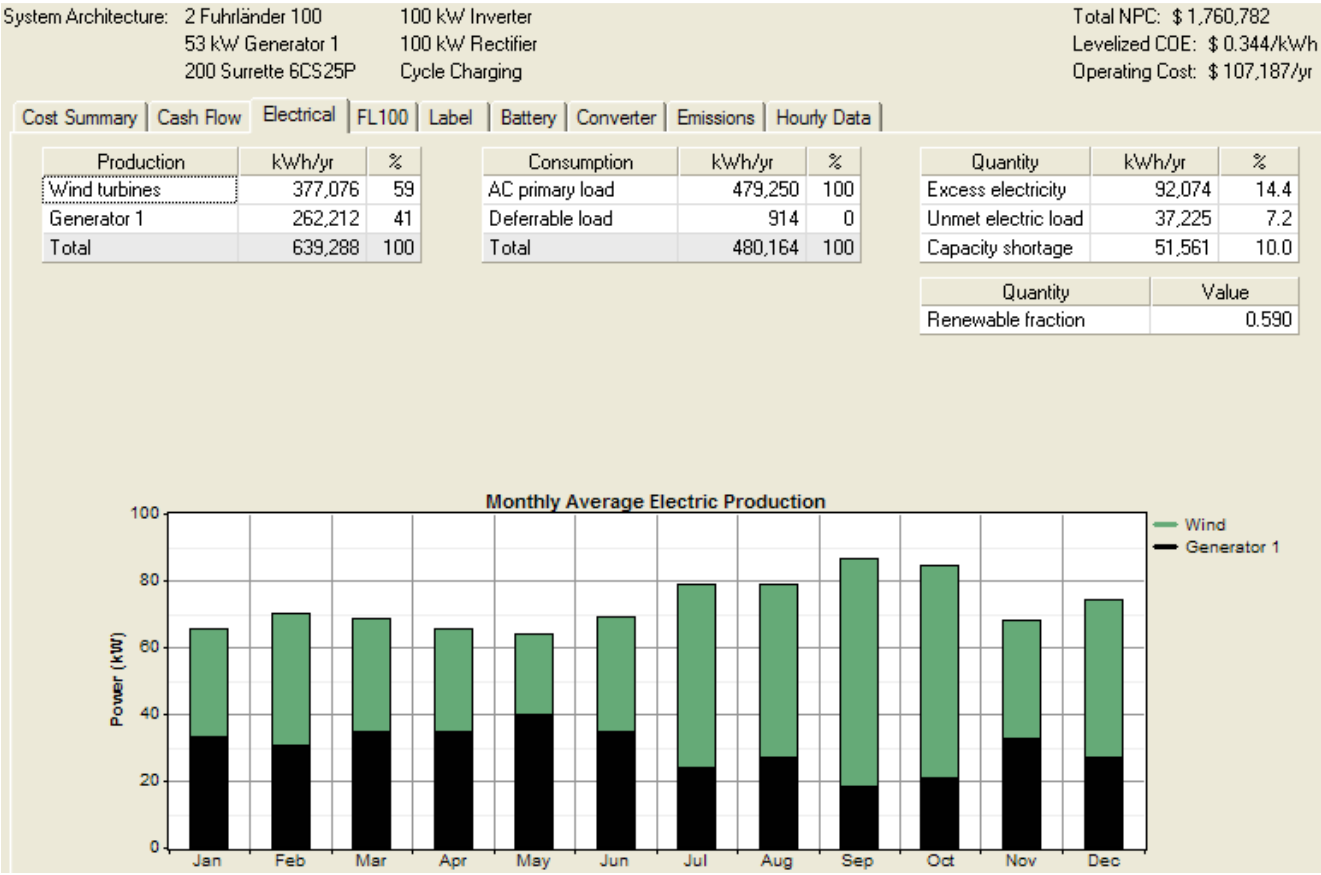


Figure 7.10: Simulation Result of Electrical Architecture for scenario A with FL100

7.3. Summary of the Selected Energy system Design (Scenario A with FL100)

While simulating scenario A with FL100 there are around 200 simulation results which are arranged from less cost to high cost for a given datum values of interest rate (8 %), hub height 70 m, capacity shortage (10%), current diesel price ($1/L) and renewable fraction (30%). The few least cost effective energy system options are displayed in table 7.6 which is used to study the techno-economical viability of the selected energy system among different combination of components used in case of scenario A with FL100.

From the selected few least cost effective simulation results summarized in table 7.6, five options are selected for further investigation of viability of techno-economical capability. For ease of the comparison purpose it is summarized in table 7.7. The pre-selection is done by observing low excess electricity and CO_2 emission although the first row in table cost less. So as to check technological viability of the selected options in addition to low cost constrained.

Table 7.6: Summary few least cost effective simulation result for selected scenario A with FL100

FL100	Label KW	Surrette 6CS25P	Converter KW	Total NPC, $	COE $/KWh	RF %	Cap. Shortage %	Excess Electricity %	CO2 Emission tones/yr
2	53	200	100	1,760,782	0.344	0.59	8.07	14.4	234.33
2	53	300	100	1,831,921	0.357	0.60	8.11	10.6	222.82
3	53	300	100	1,833,371	0.356	0.74	6.61	25	181.23
2	106	200	50	1,848,701	0.359	0.57	7.27	19	260.39
4	53	200	100	1,859,710	0.361	0.81	5.45	40.3	173.06
3	106	200	50	1,866,854	0.360	0.70	5.69	34	223.4
4	53	300	100	1,875,663	0.362	0.83	5.19	37.4	149.61
2	106	100	50	1,880,491	0.366	0.56	7.3	21.6	291.02
2	53	200	150	1,882,381	0.356	0.57	5.43	13.9	251.57
3	53	400	100	1,887,212	0.366	0.76	6.47	22.4	166.08
3	106	100	50	1,896,539	0.367	0.69	5.68	35.9	254.69
3	53	100	150	1,901,179	0.369	0.69	6.28	34.2	236.99
2	53	400	100	1,908,451	0.372	0.61	8.14	8.33	212.65
3	53	200	150	1,908,857	0.361	0.71	4.69	27.9	215.34
4	53	400	100	1,918,717	0.370	0.84	5.09	35.4	132.11
2	106	300	50	1,927,201	0.374	0.58	7.34	17.9	251.03
3	53	300	150	1,938,290	0.365	0.73	4.38	23.8	194.75
3	106	300	50	1,943,582	0.375	0.71	5.75	33.1	213.51
3	53	100	200	1,945,194	0.377	0.69	6.23	34.2	236.94
2	53	300	150	1,946,095	0.368	0.59	5.59	9.91	238.45
4	106	200	50	1,946,270	0.374	0.78	4.55	45.2	200.11

5	53	200	100	1,957,295	0.378	0.85	4.33	49.2	153.85
3	106	300	100	1,962,464	0.367	0.71	3.6	25.7	208.03
3	106	200	100	1,964,230	0.368	0.69	3.6	29	234.77
5	53	300	100	1,964,365	0.378	0.87	4.16	46.9	128.42

The energy system options which are shown by red color in table 7.6 are summarized in table 7.7. The amount of excess electricity decrease from option 1 to 4 but a considerable amount of excess electricity is required while designing an energy system because the load calculation is done without considering power loss. Therefore, considering a considerable amount of excess electricity constrain, option 4 is best option among other with excess electricity of 8.33% but it cost an extra $147,669 of NPC and $0.028/KWh than option. Among selected five options, low CO_2 emission is recorded in option 1. Therefore, at the current diesel price of $1/L, hub height of 70 m and interest rate of 8% option 1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

Table 7.7: Summary of five selected energy system options comparisons

Option	**FL100**	**Label KW**	**Surrette 6CS25P**	**Conv. KW**	**Total NPC, $**	**COE $/KWh**	**RF %**	**Cap. Shortage %**	**Excess Electricity %**	**CO2 Emission tones/yr**
Opition1	2	53	200	100	1,760,782	0.344	0.59	8.07	14.4	234.33
Opition2	2	53	300	100	1,831,921	0.357	0.60	8.11	10.6	222.82
Opition3	2	53	200	150	1,882,381	0.356	0.57	5.43	13.9	251.57
Opition4	2	53	400	100	1,908,451	0.372	0.61	8.14	8.33	212.65
Opition5	2	53	300	150	1,946,095	0.368	0.59	5.59	9.91	238.45

In addition to table 7.7, the summary of five selected options of energy system is summarized in figure 7.11 to 7.14.

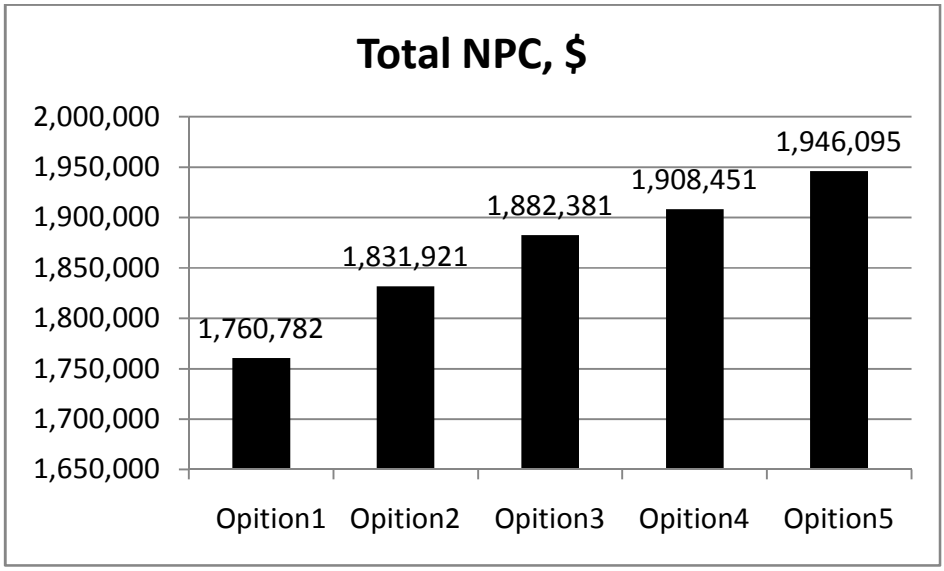


Figure 7.11: Comparison of Scenario A option based on total NPC

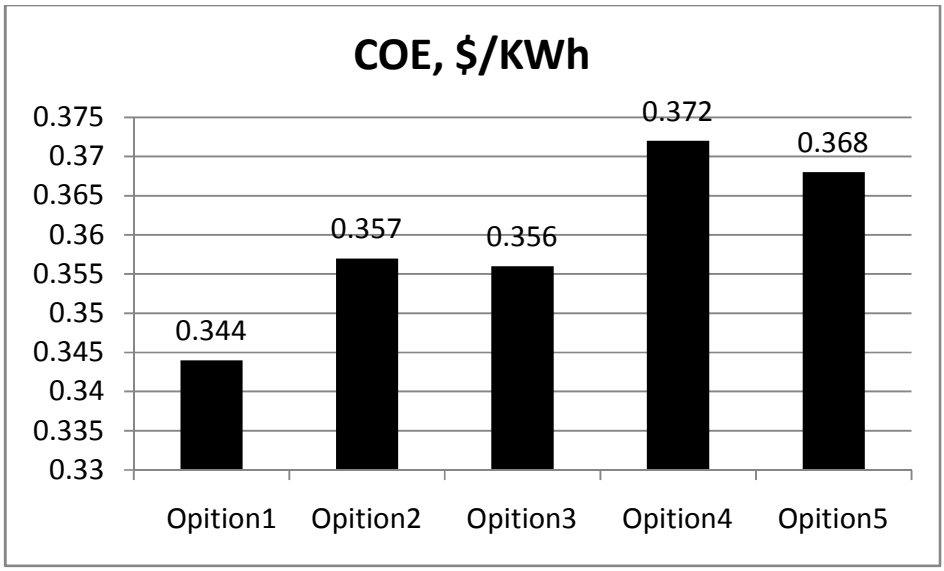


Figure 7.12: Comparison of Scenario A options based on total COE

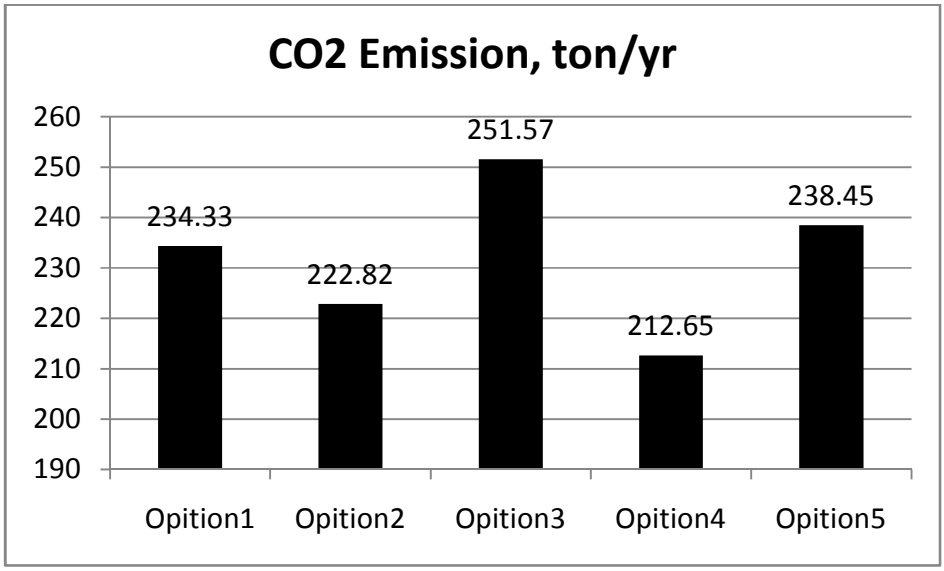


Figure 7.13: Comparison of Scenario A options based on CO2-Emission

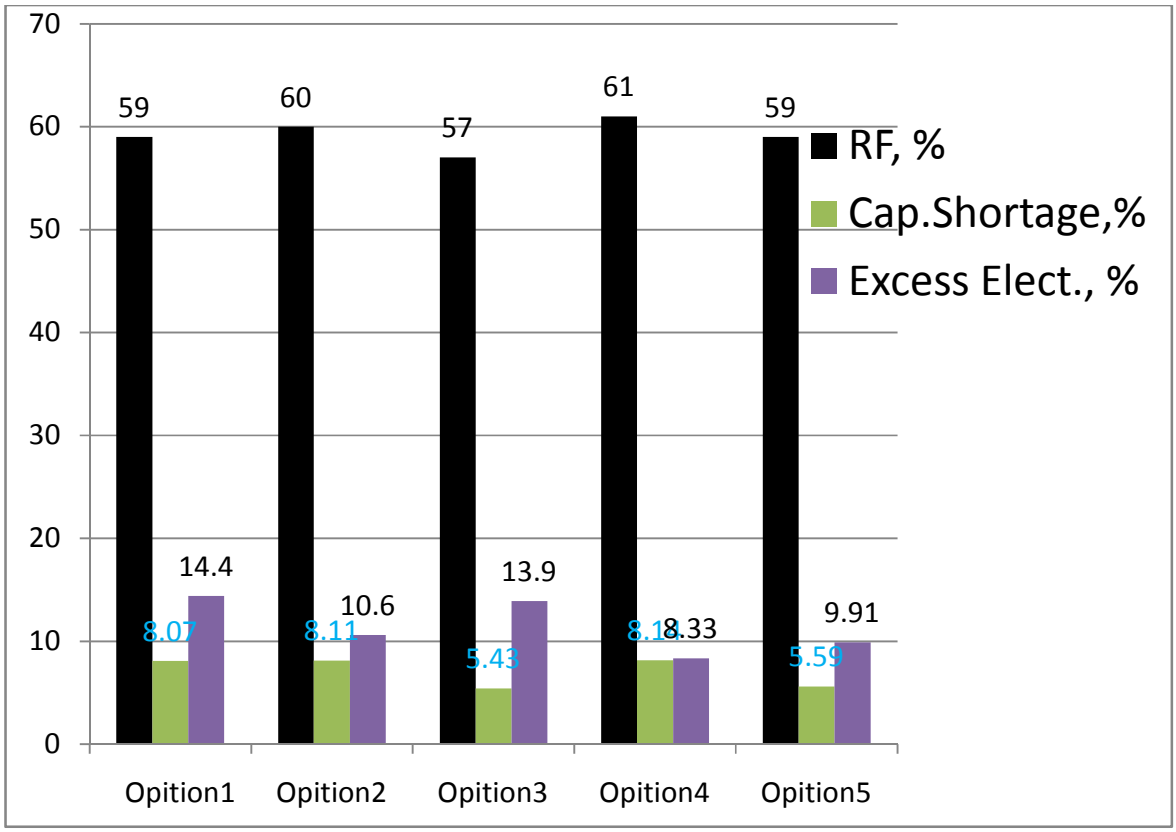


Figure 7.14: Comparison of Scenario A options based on RF, Excess Electricity & cap. shortage

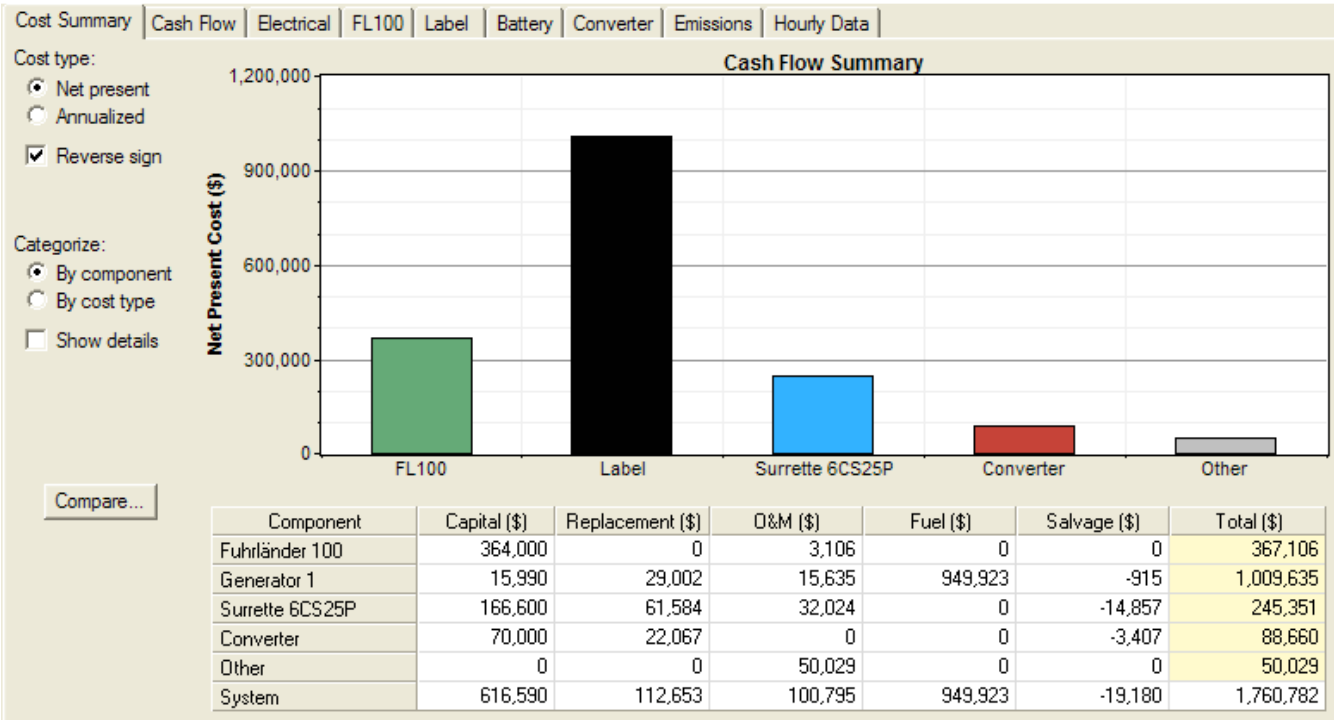
With similar analysis above, for diesel price varying from $ 0.8/L to $1.25/L at hub height of 70 m and interest rate of 8% , an energy system option1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

Similarly, for interest rate variation (6% to 10%) at hub height of 70 m and current diesel price of $1/L , an energy system option1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

Similarly, for varying hub height (60 m to 70 m) at current diesel price of $1/L and interest rate of 8% , an energy system option1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

Concluding from above discussion, in all variation of diesel price, hub height and interest rate, an energy system option1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

The final summary of the HOMER simulation results are displayed in figure 7.10, 7.11 and 7.12 for the selected energy system scenario A with FL100 of option1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter). The summary contains different type of costs, electrical architecture, and equipments performance, emission results.



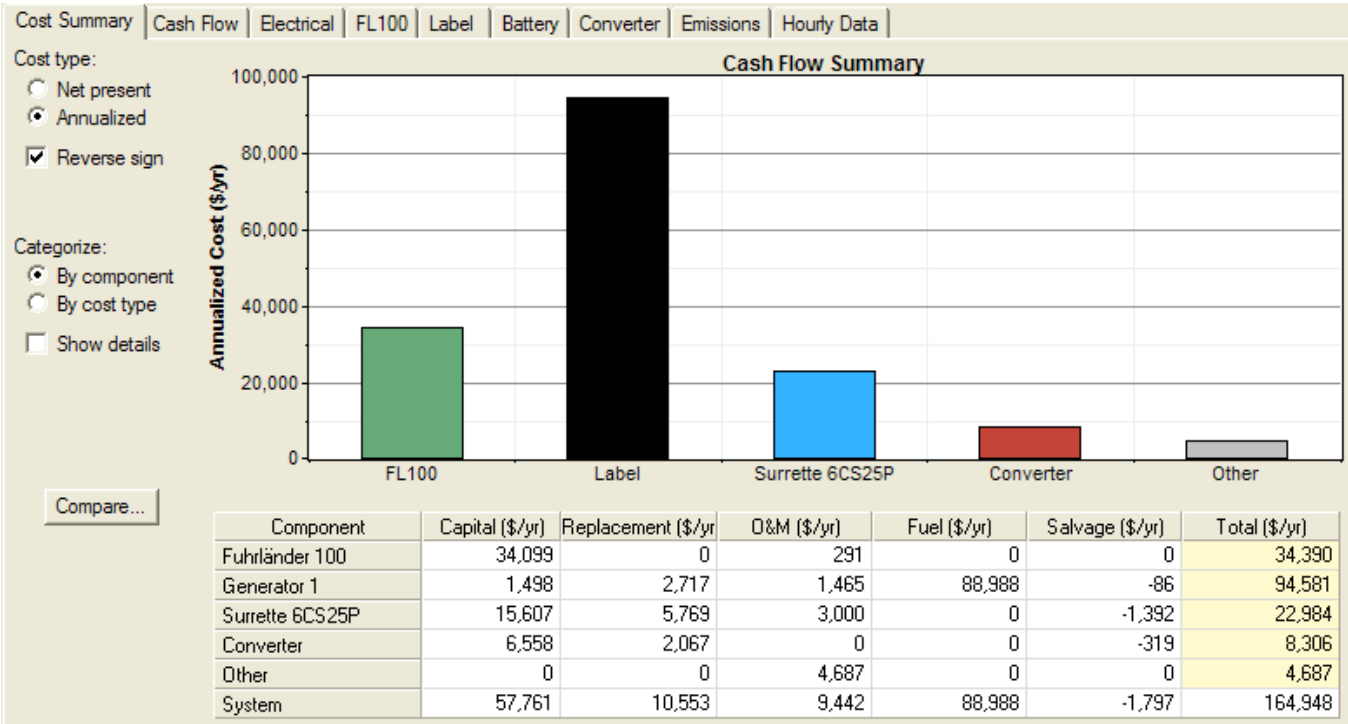
Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Fuhrländer 100	364,000	0	3,106	0	0	367,106
Generator 1	15,990	29,002	15,635	949,923	-915	1,009,635
Surrette 6CS25P	166,600	61,584	32,024	0	-14,857	245,351
Converter	70,000	22,067	0	0	-3,407	88,660
Other	0	0	50,029	0	0	50,029
System	616,590	112,653	100,795	949,923	-19,180	1,760,782

Figure 7.15: Summary of total cost for selected scenario A with FL100

As it is displayed in figure 7.15, the cost break down is given in different forms. The total NPC for the entire component of the system is $ 1,760,782 which is the lowest capital cost from different optimization results. As a result, the total initial capital and O &M cost are $616,590 and $100,795 respectively. Also, the annualized initial capital and O&M cost is also summarized in figure 7.16 with corresponding value of $57,761/yr and $9,442/yr respectively. The total annualized cost is $164,948/yr which include 8% interest rate. With all these costs the estimated COE for selected energy system will be $0.344/KWh.

HOMER also optimizes the share of both total NPC and annualized cost by component and cost type. As an indication a share of total NPC by both component and cost type is depicted in figure 7.17 and 7.18. The cost of diesel generator takes larger portion than other component by 57% and the cost of fuel take higher share by 53 % than other cost type. Parallel to share of cost by each component, an electricity production of wind turbine is higher than that of diesel generator (59% from wind turbine and 41% from diesel generator). As it can be seen from share of total cost, an introduction of generator cause high investment cost because of fuel usage. Therefore, this situation triggers an optimization of energy system which is purely renewable (scenario C) to see the feasibility of investment cost. But as it discussed above because of unnecessary excess

electricity production there is high investment cost and as result there is also high cost of energy (COE) in case of pure renewable energy system of wind turbine..



Component	Capital ($/yr)	Replacement ($/yr	O&M ($/yr)	Fuel ($/yr)	Salvage ($/yr)	Total ($/yr)
Fuhrländer 100	34,099	0	291	0	0	34,390
Generator 1	1,498	2,717	1,465	88,988	-86	94,581
Surrette 6CS25P	15,607	5,769	3,000	0	-1,392	22,984
Converter	6,558	2,067	0	0	-319	8,306
Other	0	0	4,687	0	0	4,687
System	57,761	10,553	9,442	88,988	-1,797	164,948

Figure 7.16: Summary of annual cost for selected scenario A with FL100

The selected energy system simulation result of HOMER is displayed in figure 7.10 which shows an entire designed architecture parameter of the designed system. It comprise 2- FL100 wind turbine, a 53 KW- diesel generator, 200 Surrette 6CS25P batteries, 100 KW inverter and 100 KW rectifier, which are selected after a thorough analysis to get cost effective energy system component size and numbers. The renewable fraction (RF) is 59 % which is fairly renewable for the given sensitivity case of (30-70) % renewability factor. For the country like Ethiopia, any energy system which needs high share of generator is not recommended because of diesel price. The current renewable share of 59 % is fair enough based on current market situations of diesel price.

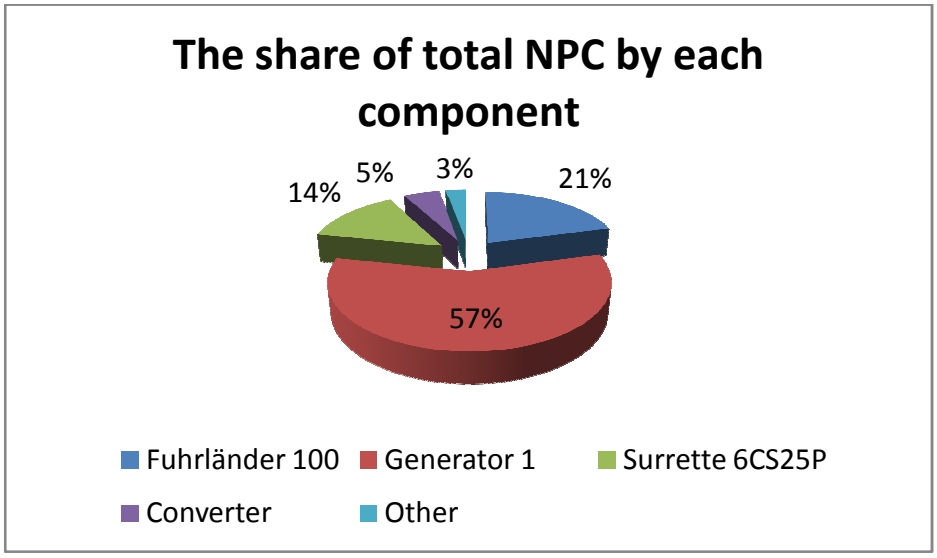


Figure 7.19: The share of total NPC by energy system component

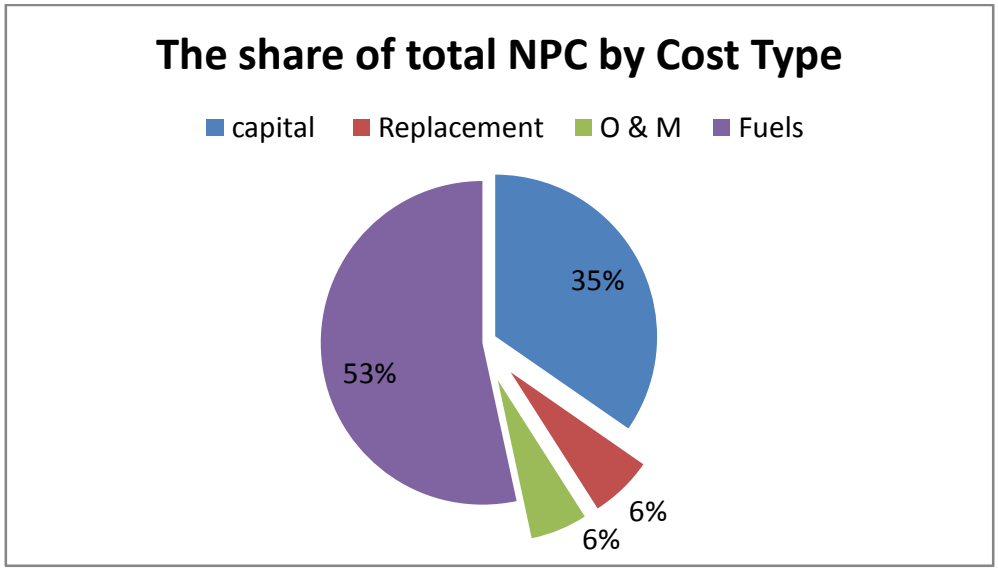


Figure 7.20: The share of total NPC by Cost Type

The share of total electricity production from the two turbines is around 59 % of the total electricity generated by the system, they are capable to produce a total of 200KW power at their maximum rated power. The capacity factor of combined wind energy share is 21.5% which is dependent on wind speed and the current value is fairly good as it has been discussed above. As it can be seen from figure 7.10, the maximum production of electricity from wind turbine is seen in September which is about 69KW although the full power of combined wind turbine could

generate around 200KW. This limitation is mainly depending on the wind speed potential. As wind speed goes lower the expected power from wind turbine get lower, as a result a low electricity generation is recorded in may which is approximately 22KW power. Since the need of diesel generator is as complement to wind turbine, electricity generated from generator will compensate the low generation of wind turbine. Therefore, electricity generated from diesel gets high at low wind speed season. As an indication, the generated electricity from generator becomes high in May which is around 40KW and gets low in September which is around 19KW. Off course the capacity factor of generator is fairly high because it is not dependant on weather variation. For the selected scenario, generator capacity factor becomes 56.5% and the total hour of operation is 5,527 hour/year. Since capacity factor is comparable to efficiency, the generator capacity factor of 56.5% is very good while wind turbine capacity factor is low but the value 21.5% is fairly good since it is not possible to control the variation of wind speed so as to increase capacity factor.

The current selected energy system of scenario A with FL100 is designed by considering the worst case of capacity shortage of 10% and minding considerable excess electricity because of the stated reason in chapter five. Then obtained result of capacity shortage of 8.07 % and excess electricity of 14.4 % is fairly good achievement.

The hourly profile of AC primary load, Wind and diesel power generation, unmet load and battery state of charge is depicted for arbitrary taken date of January 28 in Appendix A7 for the selected scenario A of opition1 (2-FL 100, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter). Also, the daily wind speed variation is displayed in appendix A7E and the highest wind speed which is (> 3m/s) is possible for longer time of a day from 9:30 to 24:00.

As it can be seen from the result display on appendix A7A, the pick-load period in day time is from 10:00 to11:00. The power generated from wind is largely vary from 6:30 to 23:30 and it seems constant for the rest while that of diesel generator constant from 4:30 to 15:30 and somehow vary from 15:30 to 23:30, as it has been depicted in appendix A7B.

Similarly, for the selected energy system of Option-1, the diagrams of HOMER simulation result is displayed in appendix A7 for the selected variables of Ac primary load, renewable penetration, total renewable power output, unmet load, total electrical load , excess electricity

and/ or battery Maximum Charge power. But the values of selected parameters are summarized in table 7.8.

Table 7.8: Summary of selected simulation results for selected scenario A with FL100

System components with share electricity generation	**Costs**	**Emissions (tones/year)**	**Electricity Production KWh/yr**
2 Wind Turbine (FL100) with rated capacity of 100 KW, generate 59%	COE =$0.344/KWh	Carbon dioxide = 234.33 Carbon monoxide =0.578	Wind Turbine = 377,076 Diesel Generator =262,212 Total = 639,288
53 KW diesel generator, generating capacity 41 %	Total Capital Cost = $616,590	Unburned hydrocarbons = 0.064	Excess Electricity =92,074 Unmet Electric Load =37,225 Capacity Shortage =51,561
200 Surrette 6CS25P Batteries (cycle charging)	Net Present Cost (NPC) = $1,760,782	Particulate matter =0.044	Ac-Primary Load =479,250 Deferrable Load=914
100 kW Inverter		Sulfur dioxide =0.471	
100 kW Rectifier		Nitrogen oxides = 5.161	

It is true that the emission of carbon dioxide will decrease by increasing the share of renewable energy source. As it is summarized in table above, 234.33 tones of CO_2 is emitted in year because of 41% electricity production share of diesel generator. The total CO_2 emission, if the entire energy system is designed from diesel generator, will be 571.54tones/year. Therefore, because of a 59 % share of wind turbine, 337.21tones of carbon dioxide emission to the environment is blocked per year. The investment will be pay back after 25 years (appendix A8).

Chapter Eight

Conclusion and Recommendations

8.1 Conclusion

At present, implementation of renewable energy system is not cost-competitive against conventional fossil fuel energy or grid connected power sources. However, the need for clean power source and alternative energy technologies create good potential for widespread use of renewable energy systems.

In addition to environmental issue, independency from imported oil and related political conflicts force renewable energy system design as a promising energy compliment.

In most developing countries like Ethiopia, hydro electric power is still the most dominant form of energy among all renewable energy technologies. However, its application is limited by the need of high investment for erection of dam and seasonal variation of rain fall. Therefore, an implementation of cost effective standalone hybrid wind energy system is a best complement for the limitation of hydropower.

Although, the cost of energy (COE) from standalone wind energy system is higher than that of grid connected hydro electric power, it is an ideal alternative for rural electrification with reasonable initial investment cost.

In the current study, a techno-economic analysis of wind energy system has been done considering the most cost-effective wind energy components (wind turbines, power conditioning units and battery) so as to reduce cost of investment and cost of energy.

The entire country wind potential is estimated by taking 34 sampling regions annual wind speed with help of surfer software. From the estimated wind potential map the three regions of highest wind speed (>4m/s) is selected for further investigation. The selected potential regions are Moyale, Mehalemeda and Negele.

Using scaling factor assumption made by B.Getachew and B.Palm and HOMER tool, Moyale site is selected as an ideal place to implement wind energy system. However, the other two sites also good to install wind energy system.

After a thorough analysis of different scenarios sing HOMER based on the design constraints of low (NPC), less COE, high RF, considerable excess electricity and high capacity factor of components, scenario A (Wind energy system with diesel generator back up with battery storage) is selected as a cost effective energy system.

For all varying cases of design constraint such as diesel price, interest rate and hub height a wind energy system option-1 (2-FL100 wind turbine, 53KW diesel generator, 200 surrette 6CS25P battery and 100KW-converter) is selected as best energy system component in regard to economy and technology.

The implementation of selected wind energy system of Opition-1 costs a total net present cost of $1,760,782 at current interest rate of 8%. At the hub height of 70 m and current diesel price of $1/L the selected wind energy system costs the customer about $0.344 per KWh.

Although the COE from wind energy system of $0.344 per KWh is not comparable with current hydro electricity tariff of Ethiopia ($0.063/KWh) it is a best alternative to get electricity at reduced initial investment of $616,590.

The designed wind energy system cuts 337.21tones of carbon dioxide emission to the environment per year because of 59 % share of wind energy system.

8.2. Recommendation and Future Work

There are two difficulties which the author faces while designing the current wind energy system. First, it is difficult to find night time data in Ethiopia while investigating the wind potential area. So as to compensate the missed night time data, a scaling factor proposed by B.Getachew and B.Palm is used to investigate the potential area. The proposed scaling factor is not trust worthy unless it has been verified by finding measured hourly data for entire 24 hour per year. Therefore, the future researcher has to verify the scaling factor assumption to fill the missed night time data by comparing with that of the measured hourly data. The day time measured data only considered in case of scaling factor assumption and then the generated hourly data from HOMER has to be compared with that of measured night time data to validate the assumption of scaling factor.

The second threat of the current study is finding a refined solution in short computation period for increased number sensitivity cases while simulating the proposed scenarios. It is obvious that the simulation result will be refined as number of sensitivity case increases but it needs high speed computer with large memory space. Therefore, to find a refined simulation result better if the future researcher work their optimization of such kind hybrid energy system analysis with high tech-computers. Through the increased number of sensitivity analysis it is possible to find results which can satisfy the calculated energy demand at reduced cost than achieved in the current wind energy system design. Also, it is possible to forecast the near future economic trend of the designed energy system with high accuracy in regard to interest rate and diesel price variation.

This thesis work will contribute the following facts

- Provides information about the Ethiopian wind potential
- used for initial study for rural electrification
- used as reference for other feasibility studies in other part of the country

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Appendix A1

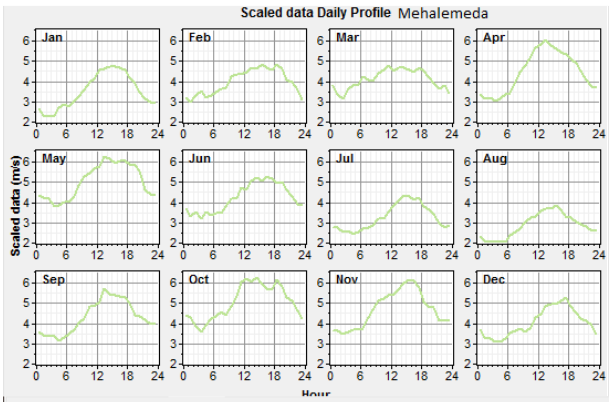
Raw Data from NMSA

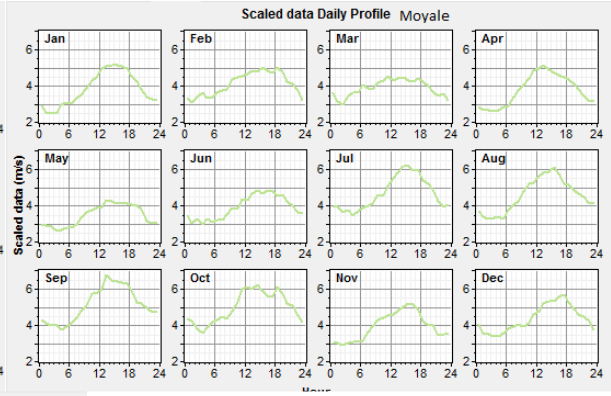
All data are collected from the same source of National Metrological Service Agency (NMSA) for the purpose of the feasibility of the data which used to investigate the wind potential for different location. These data are taken for different time for the pre-selected three sites. The data for Moyale are taken for (2001-2003), Negele (2001-2003) and Mehalemeda (2002-2004) have been considered. This has been given in separate Microsoft excel sheets.

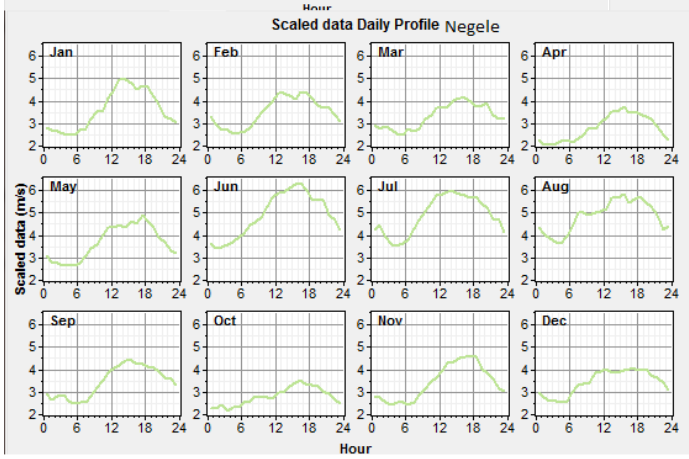
Appendix A2

Result pages for wind Potential Assessment

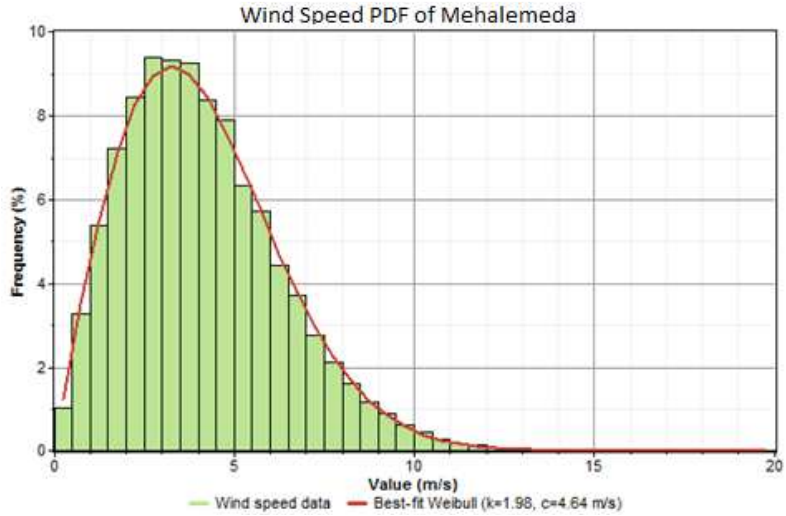
A) Daily Wind Speed profile in a month for the three selected sites

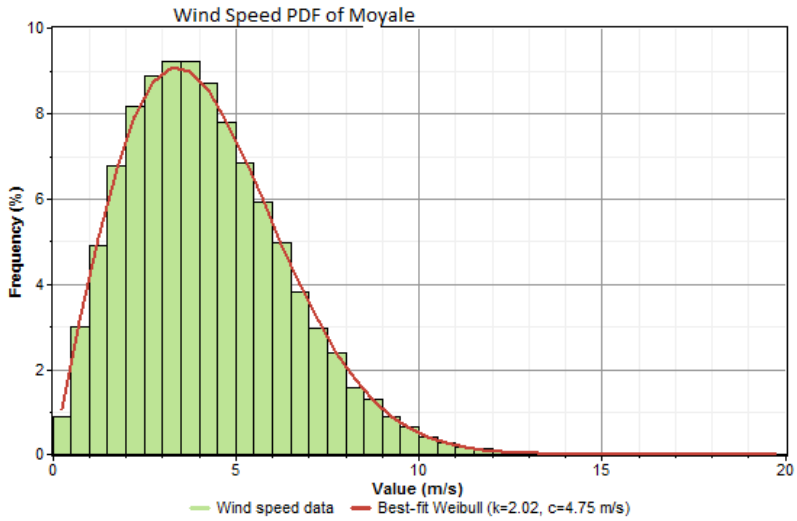


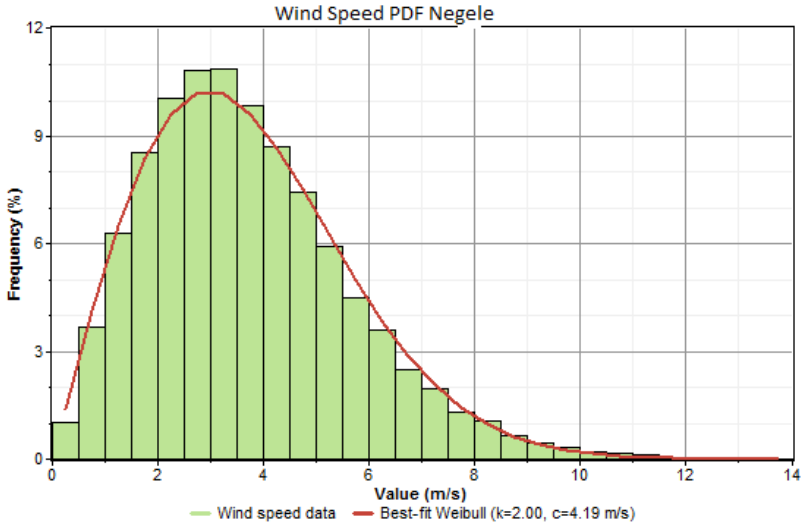




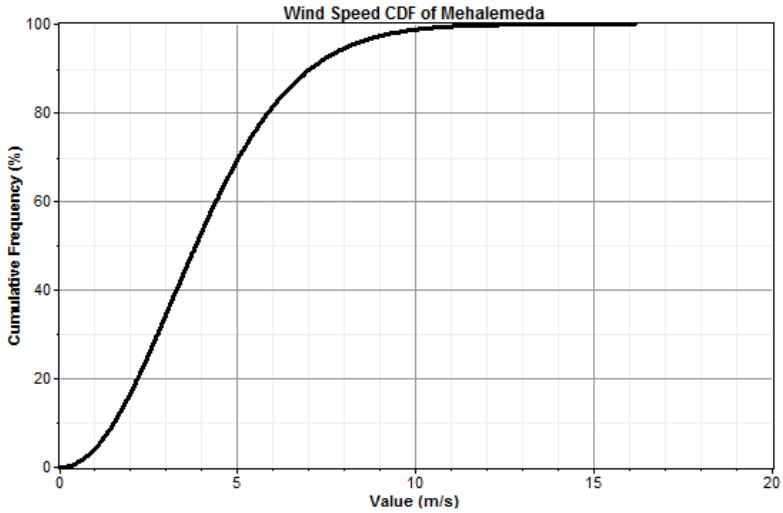
B) Wind speed Probability Density Function (PDF) for the selected three sites

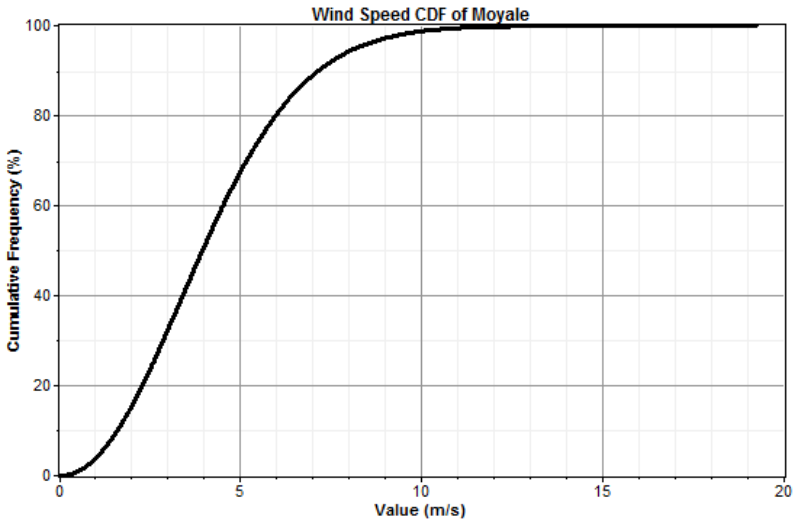


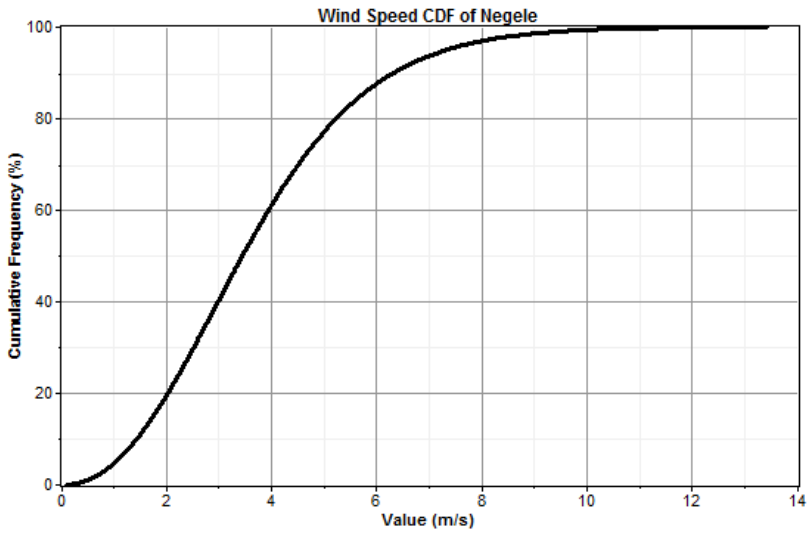




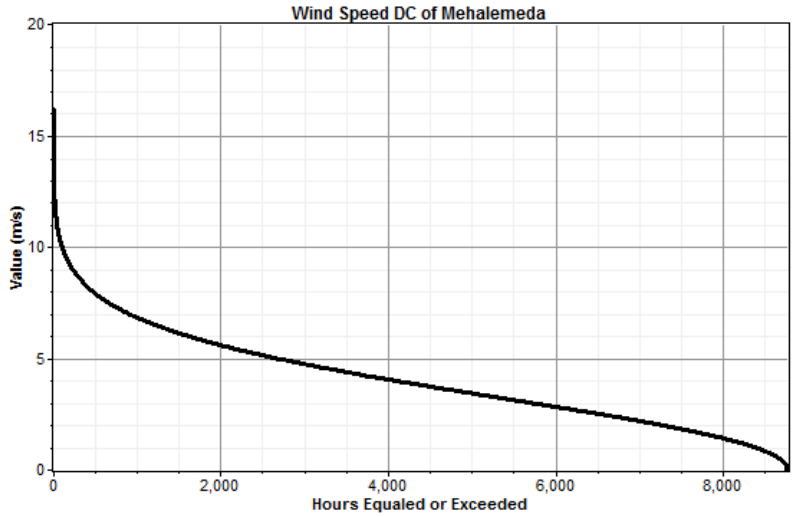
C) Wind speed Cumulative Density Function (CDF) for the selected three sites

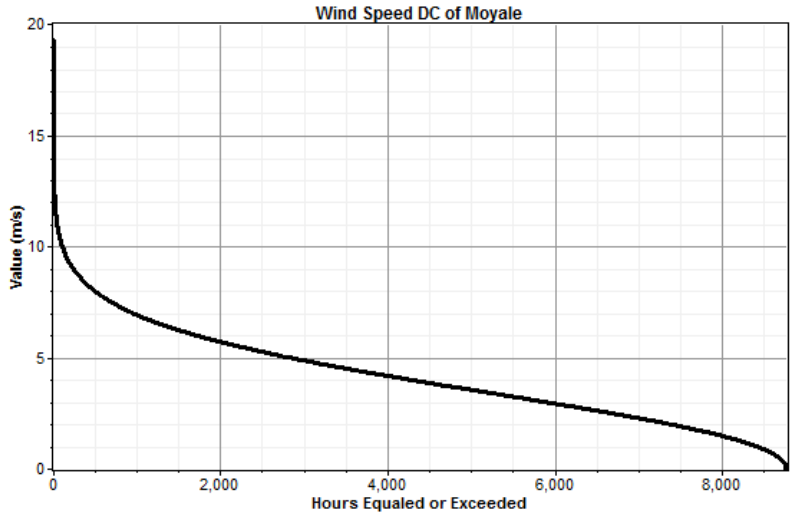


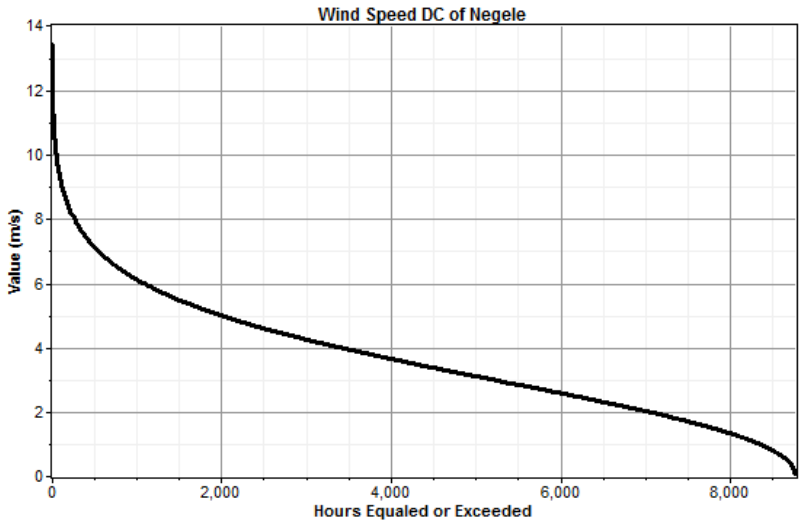




D) Wind speed Durial Curve (CD) for the selected three sites







Appendix A3

Peak Load Calculation for Both Primary Load 1 and Primary Load 2

A) Primary Load 1: hourly variation of load

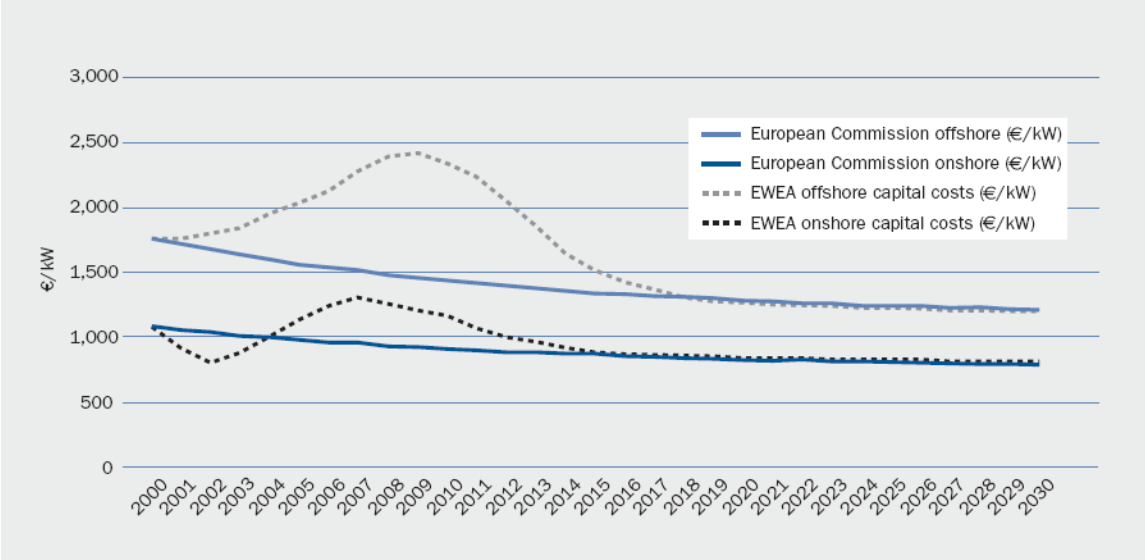
primary load 1								
Hours/day	Light Bulb	refrigrator	TV	DVD Player	Radio	Ele.Mitad	Widow Fan	Total
1:00-2:00		0.2						20
2:00-3:00		0.2						20
3:00-4:00		0.2						20
4:00-5:00		0.2						20
5:00-6:00		0.2				2.5		270
6:00-7:00		0.2						20
7:00-8:00		0.2						20
8:00-9:00		0.2						20
9:00-10:00		0.2						20
10:00-11:00		0.2					0.165	36.5
11:00-12:00		0.2					0.165	36.5
12:00-13:00		0.2	0.11		0.03		0.165	50.5
13:00-14:00		0.2	0.11		0.03		0.165	50.5
14:00-15:00		0.2					0.165	36.5
15:00-16:00		0.2					0.165	36.5
16:00-17:00		0.2						20
17:00-18:00		0.2						20
18:00-19:00	0.06	0.2	0.11	0.025				39.5
19:00-20:00	0.06	0.2	0.11	0.025				39.5
20:00-21:00	0.06	0.2	0.11	0.025	0.03			42.5
21:00-22:00	0.06	0.2	0.11	0.025	0.03			42.5
22:00-23:00	0.06	0.2	0.11					37
23:00-24:00	0.06	0.2	0.11					37
24:00-1:00		0.2						20

B) Primary Load 2: hourly variation of load

primary load 2											
Hours/day	Light Bulb	refrigrator	Computer	Printer	Lab equp	tea machine	Milling	Razor	cash machine	Widow Fan	Total
1:00-2:00	0.075	1.65			2						3.725
2:00-3:00	0.075	1.65			2						3.725
3:00-4:00	0.075	1.65			2						3.725
4:00-5:00	0.075	1.65			2						3.725
5:00-6:00	0.075	1.65									1.725
6:00-7:00		1.65									1.65
7:00-8:00		1.65			2	6					9.65
8:00-9:00		1.65	6.2		7	6	30		0.18		51.03
9:00-10:00		1.65	6.2	0.2	7	6	30	0.5	0.18		51.73
10:00-11:00		1.65	6.2	0.1	7		30	0.5	0.18	3.7	49.33
11:00-12:00		1.65	6.2	0.5	7	6		0.5	0.18	3.7	25.73
12:00-13:00		1.65								3.7	5.35
13:00-14:00		1.65	6.2		7	6		0.5	0.18	3.7	25.23
14:00-15:00	0.3	1.65	6.2	0.5	7	6	30	0.5	0.18	3.7	56.03
15:00-16:00	0.3	1.65	6.2		7	6	30	0.5	0.18	3.7	55.53
16:00-17:00	0.3	1.65	6.2		7		30	0.5	0.18		45.83
17:00-18:00	0.3	1.65				6		0.5			8.45
18:00-19:00	0.87	1.65			2	6		0.5			11.02
19:00-20:00	0.87	1.65			2	6		0.5			11.02
20:00-21:00	0.525	1.65			2						4.175
21:00-22:00	0.525	1.65			2						4.175
22:00-23:00	0.075	1.65			2						3.725
23:00-24:00	0.075	1.65			2						3.725
24:00-1:00	0.075	1.65									1.725

Appendix A4

Cost of onshore and offshore wind (€/kW) European Commission/EWEA assumptions

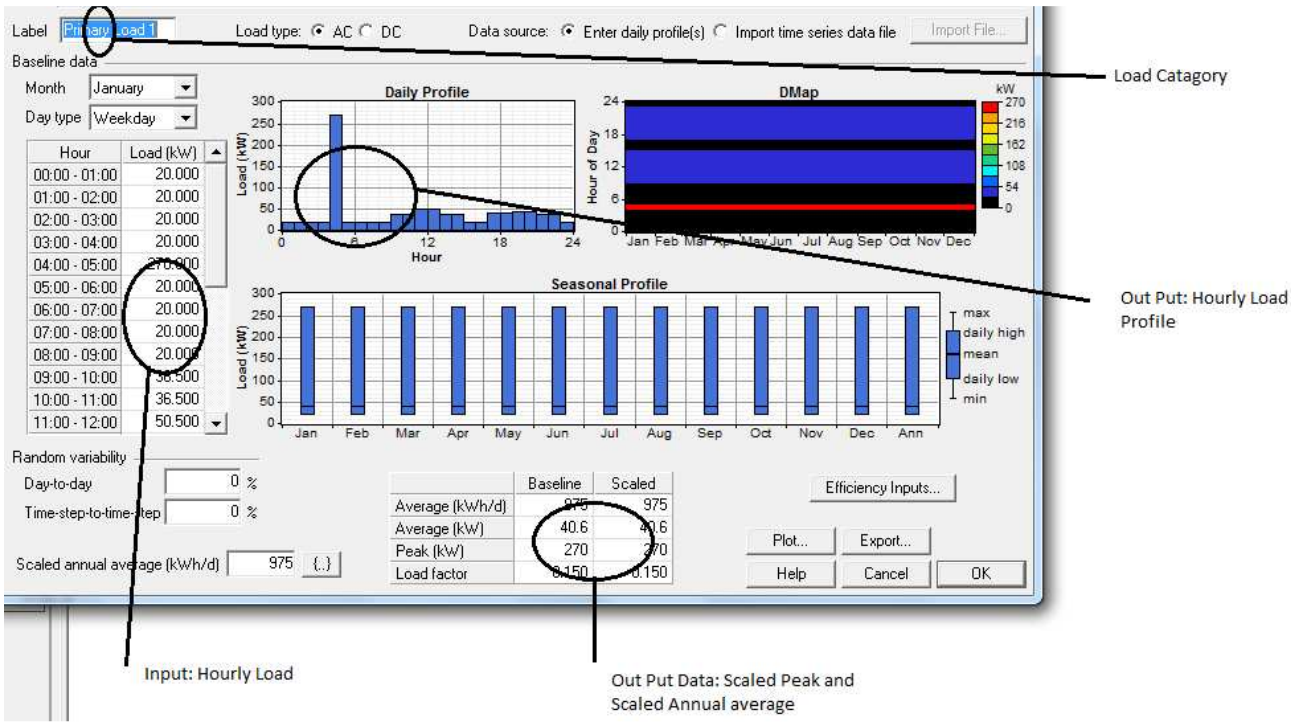


Source: EWEA, 2007

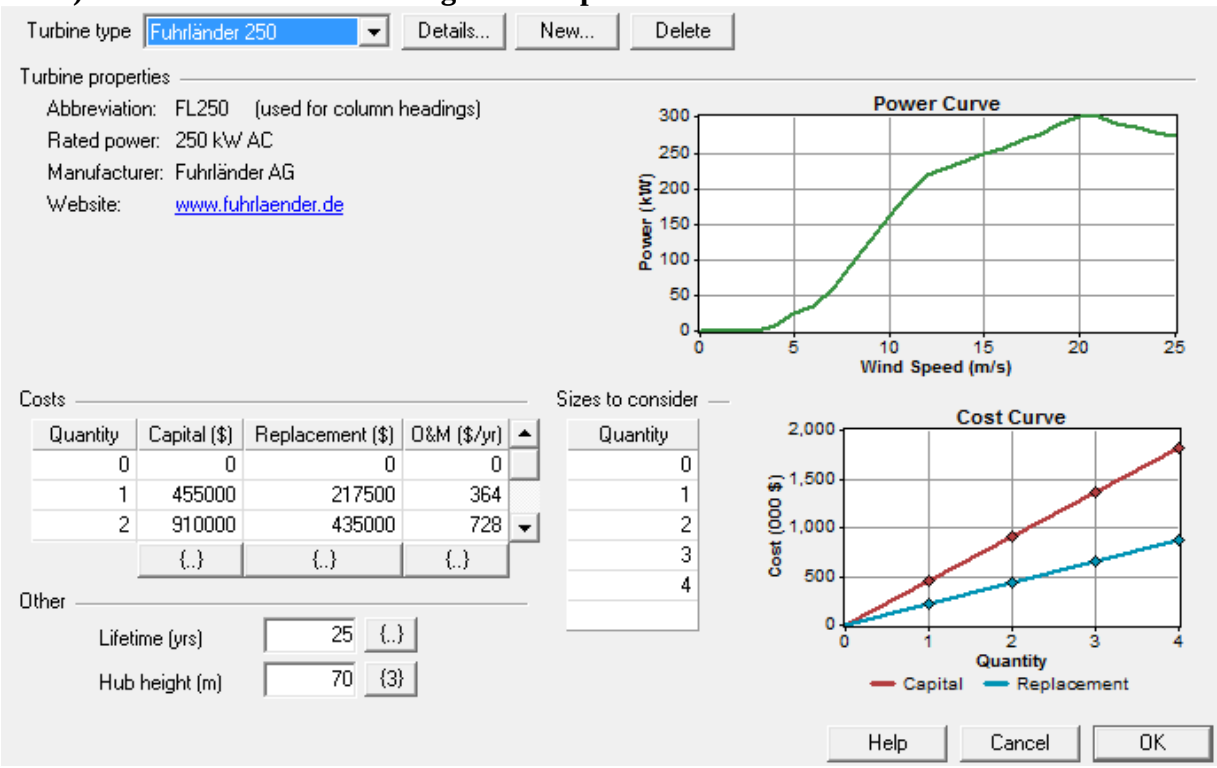
Appendix A5

Input Data Illustrations

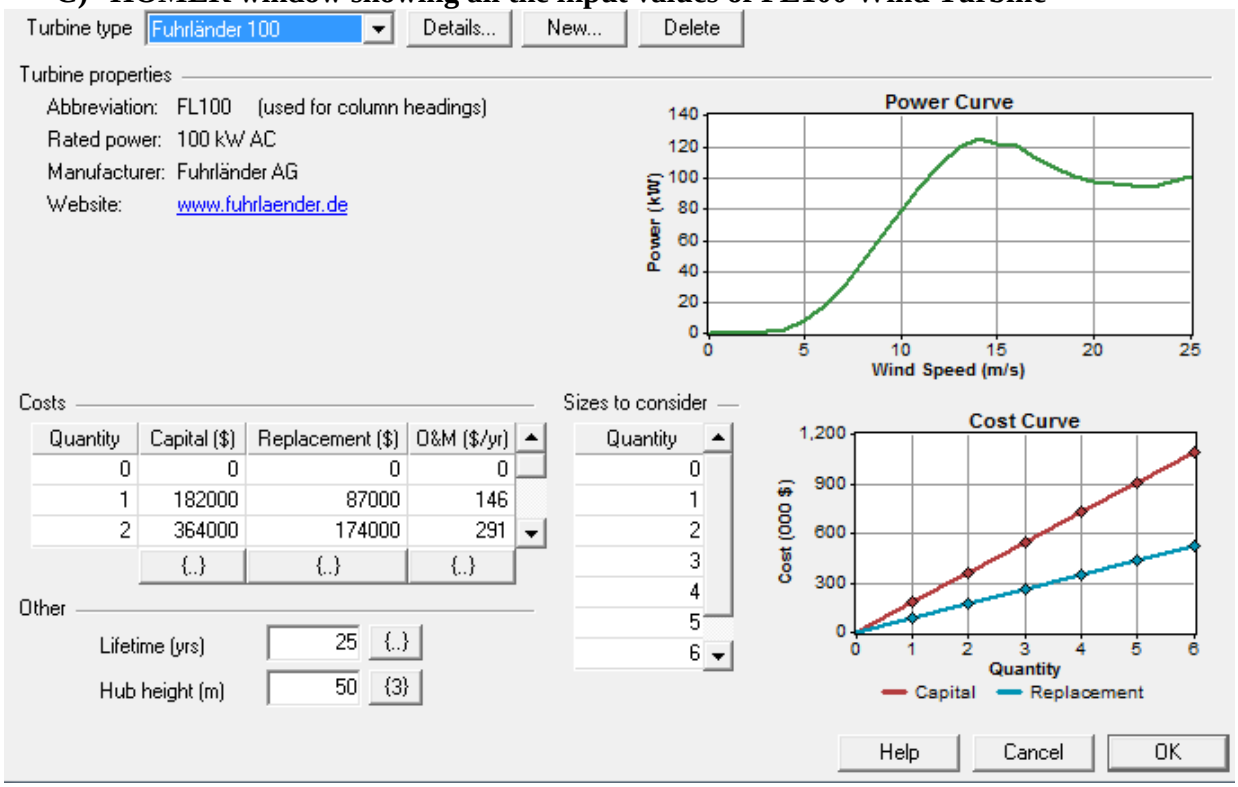
A) **Load Input Window of HOMER by taking Primary Load as Sample**



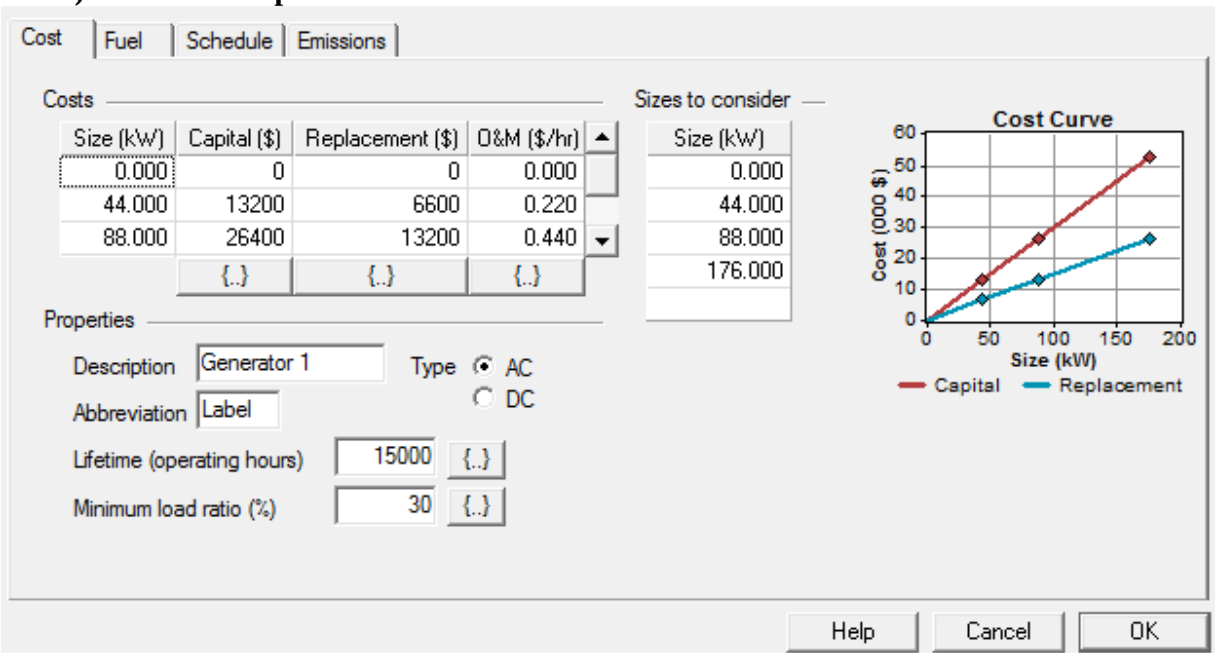
B) HOMER window showing all the input values of FL250 Wind Turbine



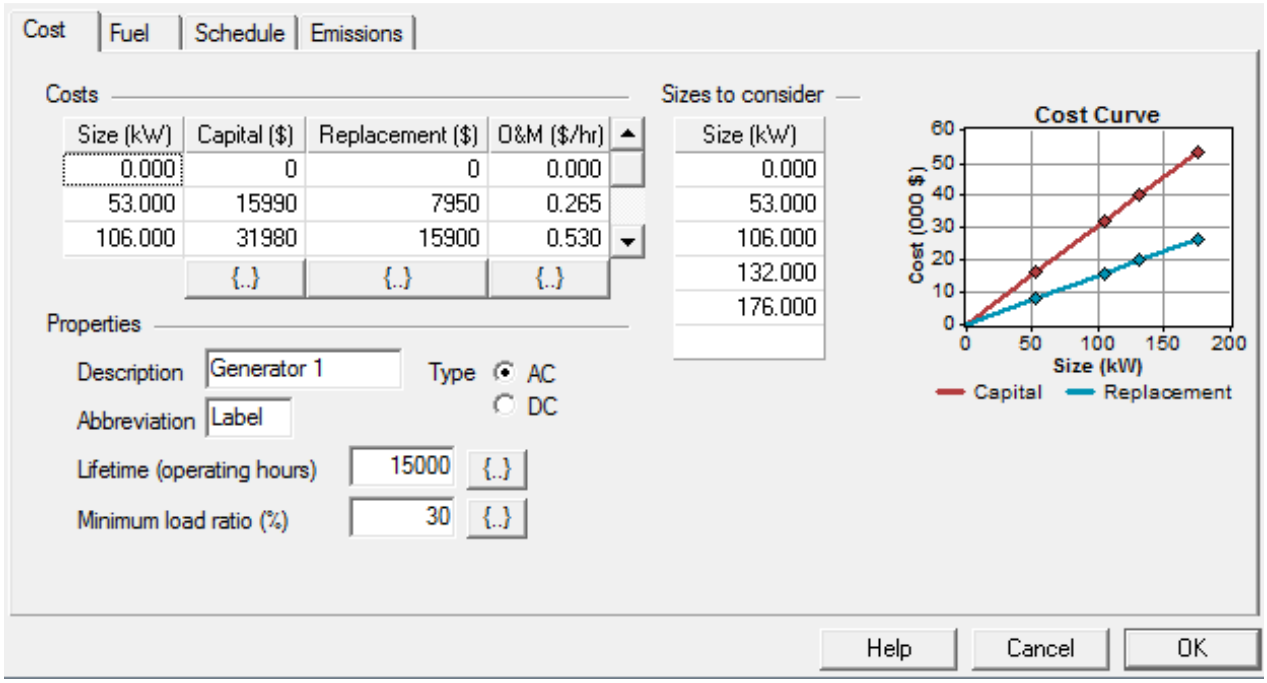
C) HOMER window showing all the input values of FL100 Wind Turbine



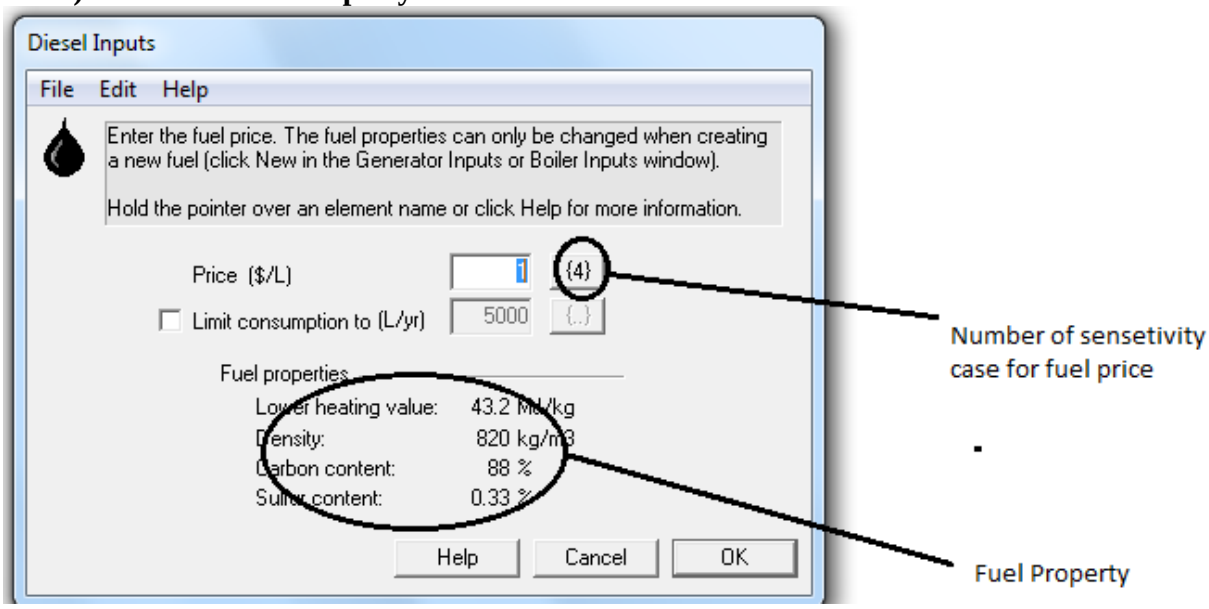
D) Generator Input Variables on HOMER window with FL250 Wind Turbine



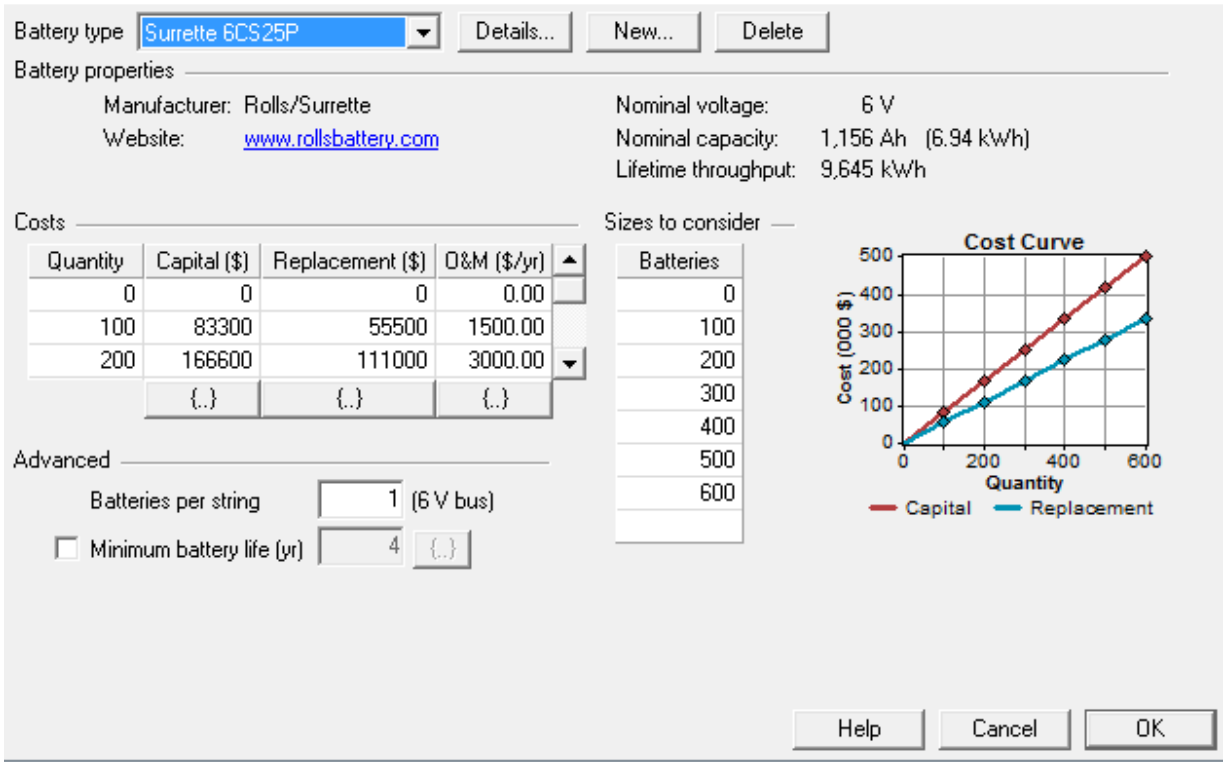
E) Generator Input Variables on HOMER window with FL100 Wind Turbine



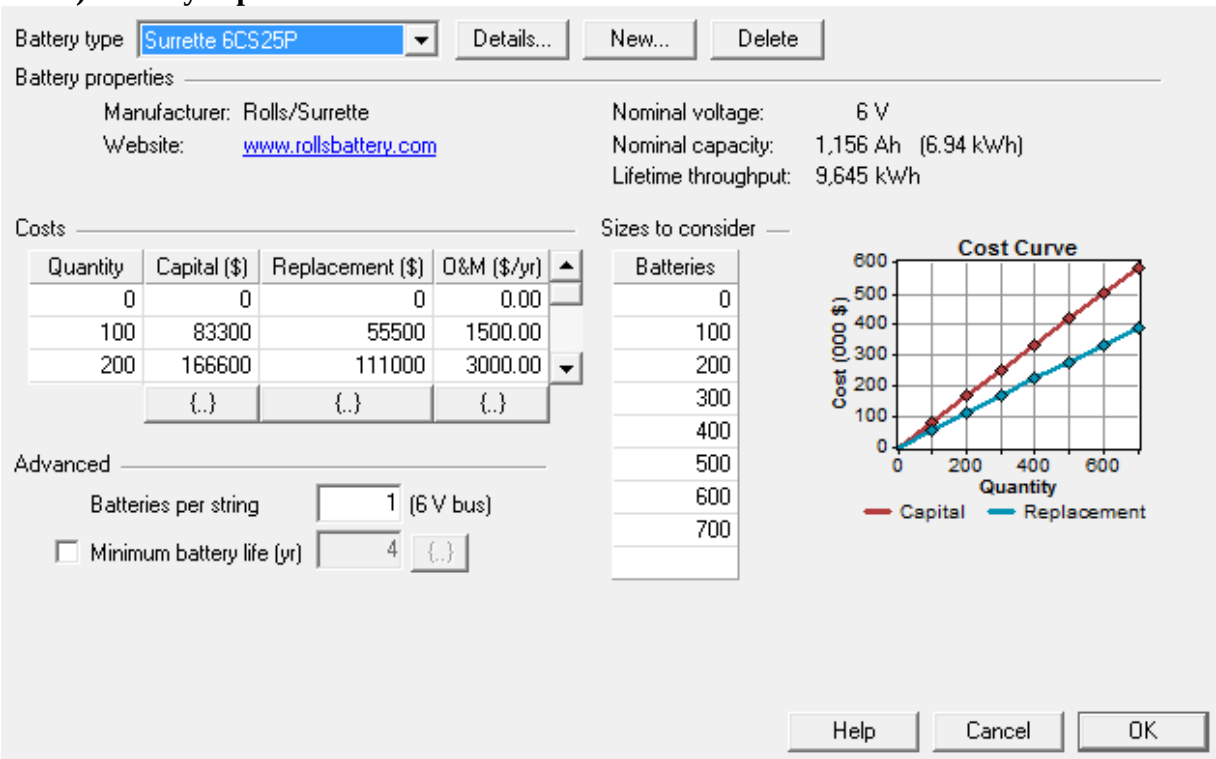
F) Fuel Cost and Property



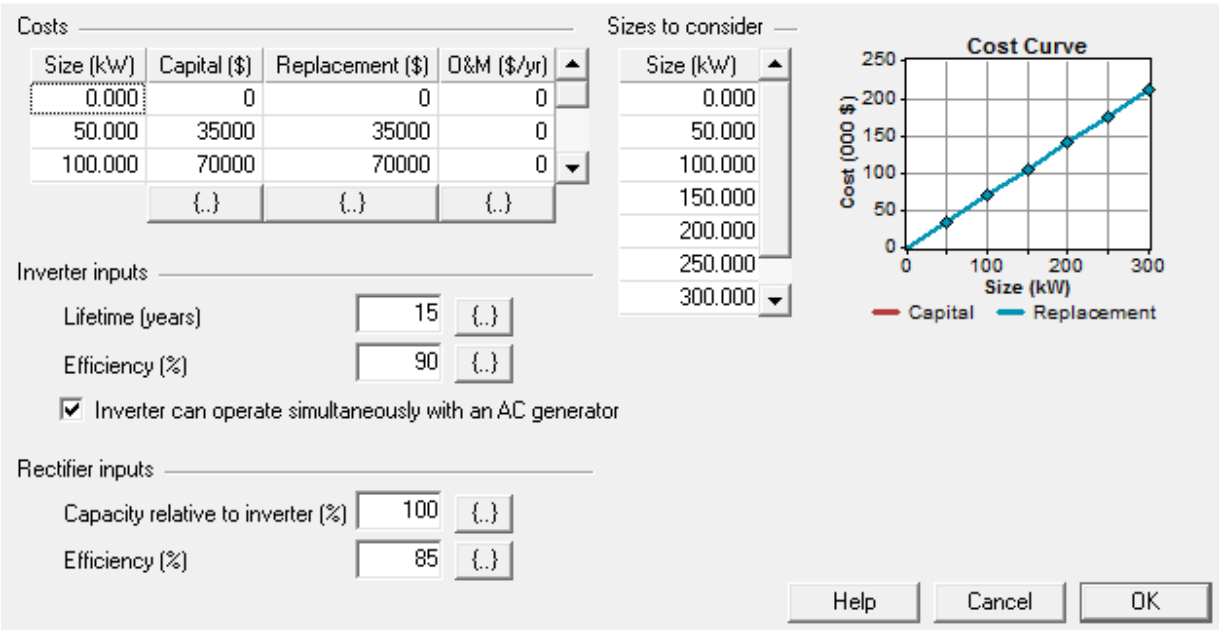
G) Battery Input Values in HOMER Window with FL250 Wind Turbine



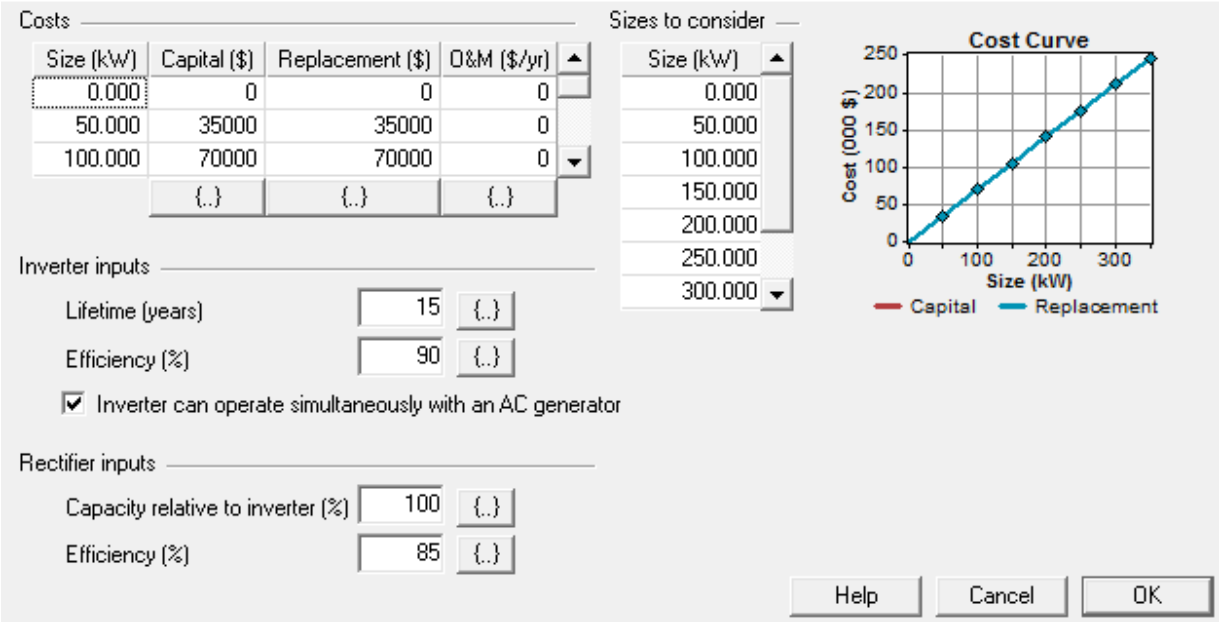
H) Battery Input Values in HOMER Window with FL100 Wind Turbine



I) Convertor Input Values in HOMER Window with FL250 Wind Turbine



J) Convertor Input Values in HOMER Window with FL100 Wind Turbine



Appendix A6
Equipments

A) Specification of wind turbine (FL 100)

Rotor Diameter	**21m**
Surface area	346m^2
Power Control	Stall
Number of Blades	3
Rotor weight	2,300Kg
Nacelle Weight	4,400Kg
Tower Weight	18,000kg
Total Weight	24,700kg
Min rotation	32 RPM
Max rotation	47 RPM
Min Wind Speed	2.5 m/s
Nominal wind Speed	13 m/s
Max wind speed	25 m/s
Gear box stage number	2
Ratio	1:32
Generator type	asynchronous
Number of Generator	1
Maximum speed of generator	(1000-1500) RPM
Generator output voltage	400 V

Source: www.fuhrlaender.de

B) Specification of selected Generator

Engine Manufacturer	John Deere
Model Number	KD60U/KD66
Engine Model	4045TF120
Engine Type	4-Cycle, Turbocharged
Rated Power	53 KW
Operation Frequency	50Hz
Rated Voltage	200- 600 V
Rated rpm	1500
Recommended fuel	#2 Diesel
Fuel tank capacity, L (gal.)	180 (47.6)

Source: http://www.generatorpower.com.au/faq.php

C) Specification of Battery

DEEP CYCLE-SOLAR
SERIES 5000

BATTERY TYPE	**VOLTS**	**8**		**8 CS 25PS**	
DIMENSIONS					
LENGTH		718	MM	28 1/4	INCHES
WIDTH		286	MM	11 1/4	INCHES
HEIGHT		464	MM	18 1/4	INCHES
WEIGHT DRY		155	KG	342	LBS.
WEIGHT WET		193	KG	424	LBS.
CONTAINER CONSTRUCTION					
INNER CONTAINER	POLYPROPYLENE				
INNER COVER	POLYPROPYLENE - HEAT SEALED TO INNER CONTAINER				
OUTER CONTAINER	HIGH DENSITY POLYETHYLENE				
OUTER COVER	HIGH DENSITY POLYETHYLENE SNAP FIT TO OUTER CONTAINER				
HANDLES	MOLDED				
PLATES PER CELL		25			
ELECTROLYTE RESERVE	ABOVE PLATES	95	MM	3.75	INCHES
DESIGN CRITREA	10 YEAR WARRANTY	3300	CYCLES	15	YEAR LIFE
POSITIVE PLATE DIMENSION					
HEIGHT		273	MM	10.75	INCHES
WIDTH		143	MM	5.625	INCHES
THICKNESS		6.60	MM	0.260	INCHES
NEGATIVE PLATE DIMENSION					
HEIGHT		273	MM	10.75	INCHES
WIDTH		143	MM	5.625	INCHES
THICKNESS		4.57	MM	0.180	INCHES
SEPARATOR	SEPARATOR THICKNESS	0.105	INCH		
INSULATION	0.020" GLASS MAT				
TERMINALS	FLAG WITH STAINLESS STEEL NUTS AND BOLTS				

COLD CRANK	CCA	0°F / -17.8°C	2027	**RESERVE**	1624
	MCA	32°F / 0°C	2534	**MINUTES AT 25A**	

CAPACITY	20 HR RATE	820		
			CAP / AH	CURRENT / AMPS
CAPACITY AT THE 100 HOUR RATE		1.265 SP. GR.	1156	11.56
CAPACITY AT THE 72 HOUR RATE		1.265 SP. GR.	1091	15.15
CAPACITY AT THE 50 HOUR RATE		1.265 SP. GR.	1009	20.17
CAPACITY AT THE 24 HOUR RATE		1.265 SP. GR.	853	35.5
CAPACITY AT THE 20 HOUR RATE		**1.265 SP. GR.**	**820**	**41.0**
CAPACITY AT THE 15 HOUR RATE		1.265 SP. GR.	763	50.8
CAPACITY AT THE 12 HOUR RATE		1.265 SP. GR.	713	59.5
CAPACITY AT THE 10 HOUR RATE		1.265 SP. GR.	681	68.1
CAPACITY AT THE 8 HOUR RATE		1.265 SP. GR.	640	80.0
CAPACITY AT THE 6 HOUR RATE		1.265 SP. GR.	582	97.0
CAPACITY AT THE 5 HOUR RATE		1.265 SP. GR.	549	110
CAPACITY AT THE 4 HOUR RATE		1.265 SP. GR.	508	127
CAPACITY AT THE 3 HOUR RATE		1.265 SP. GR.	459	153
CAPACITY AT THE 2 HOUR RATE		1.265 SP. GR.	394	197
CAPACITY AT THE 1 HOUR RATE		1.265 SP. GR.	279	279

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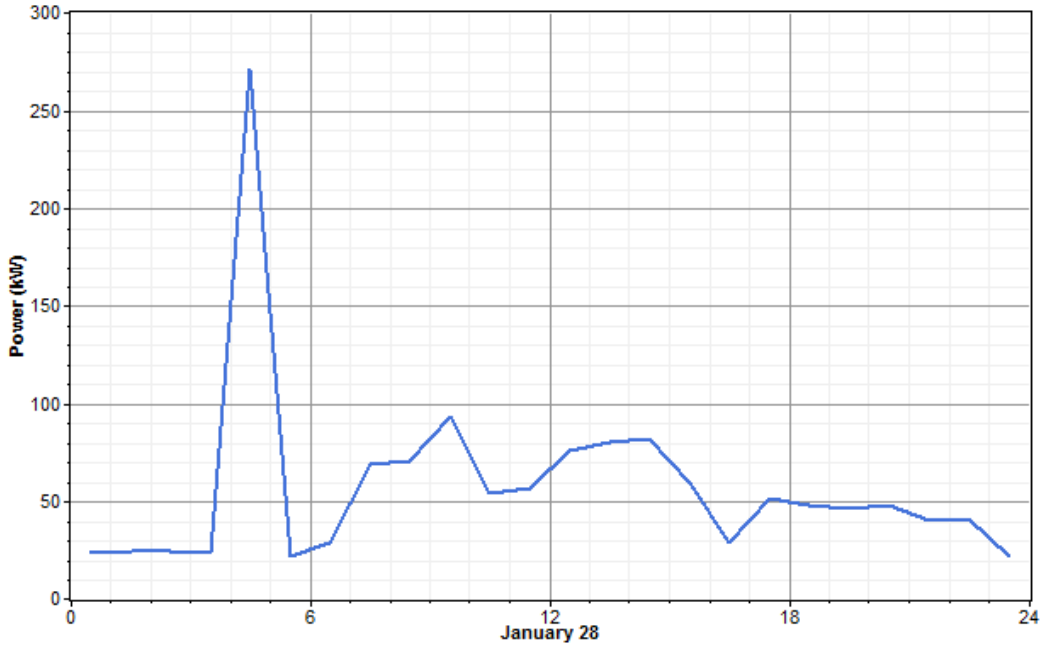
Source: www.rollsbattery.com

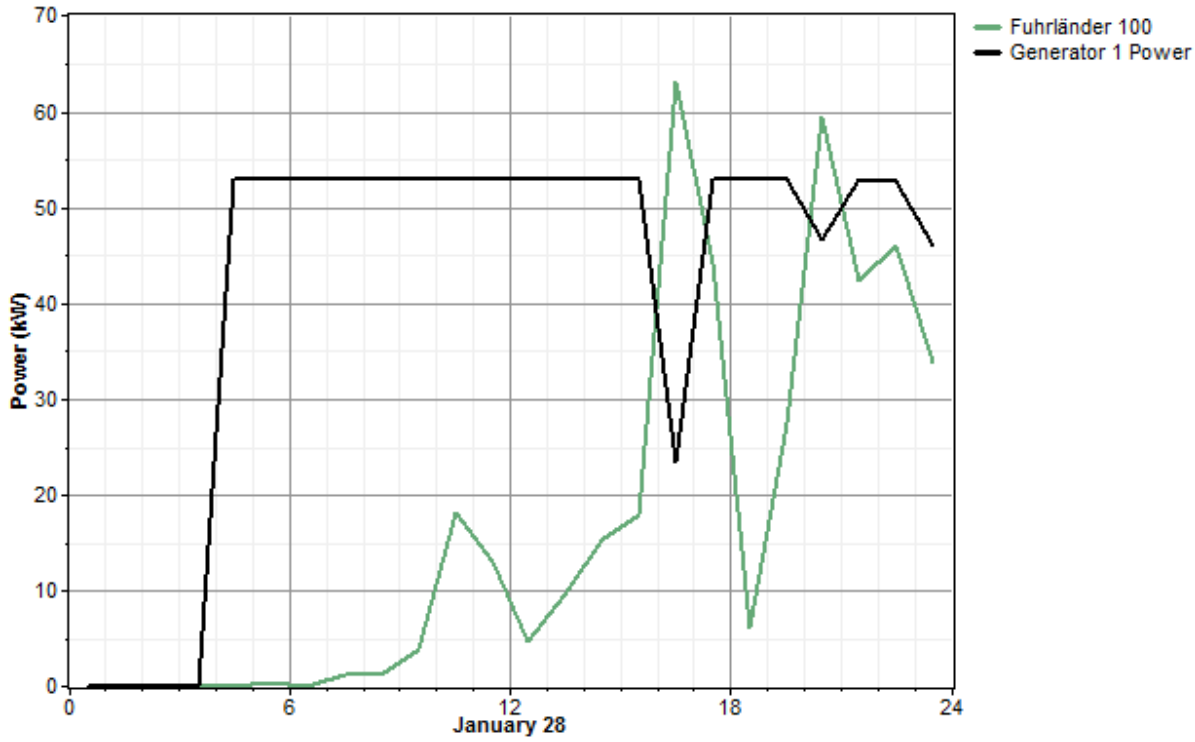
Appendix A7

Result page

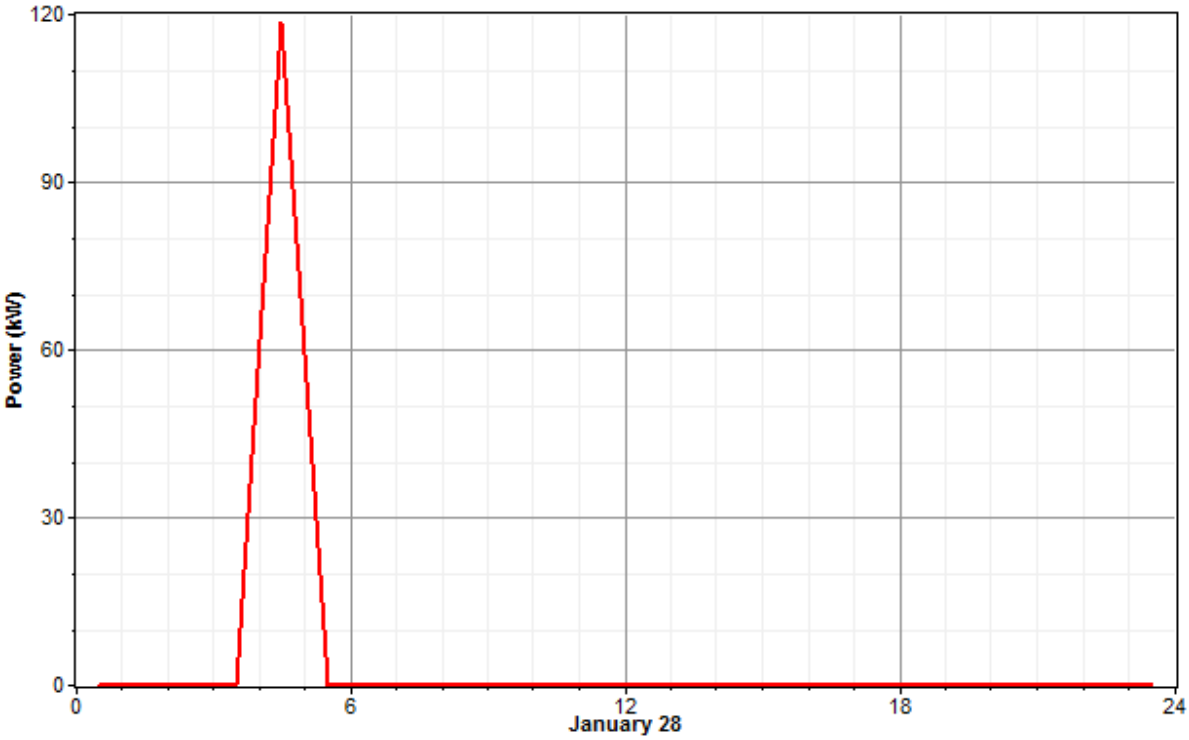
A) Hourly Profile of AC primary Load on January 28



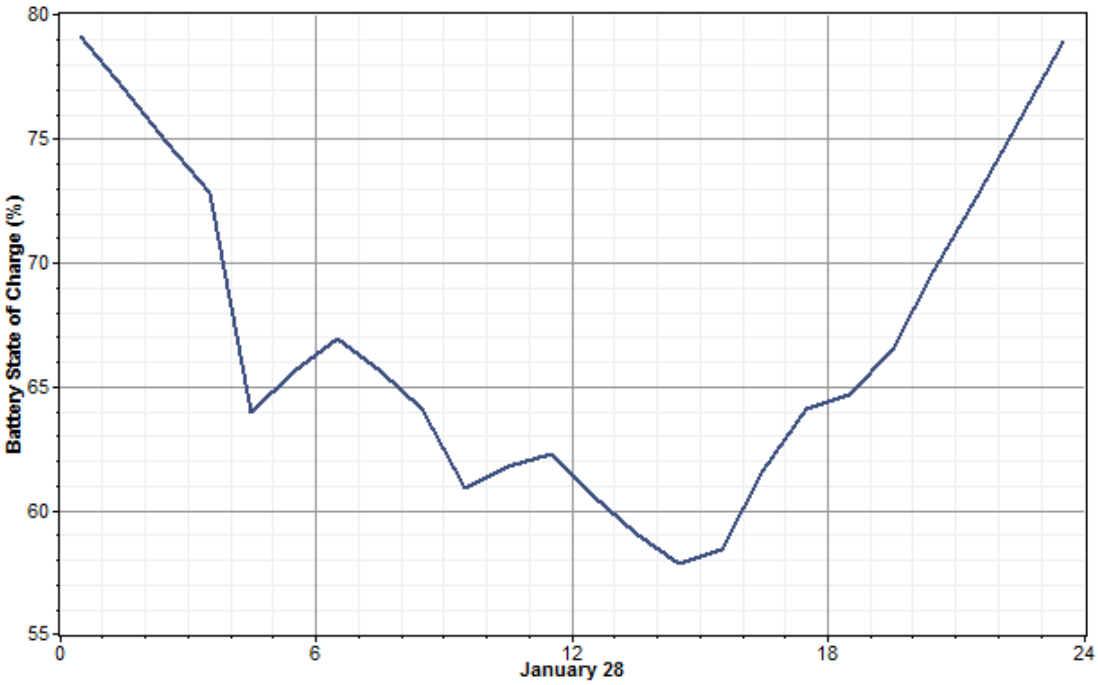
B) Hourly Profile of Wind and diesel power generation on January 28



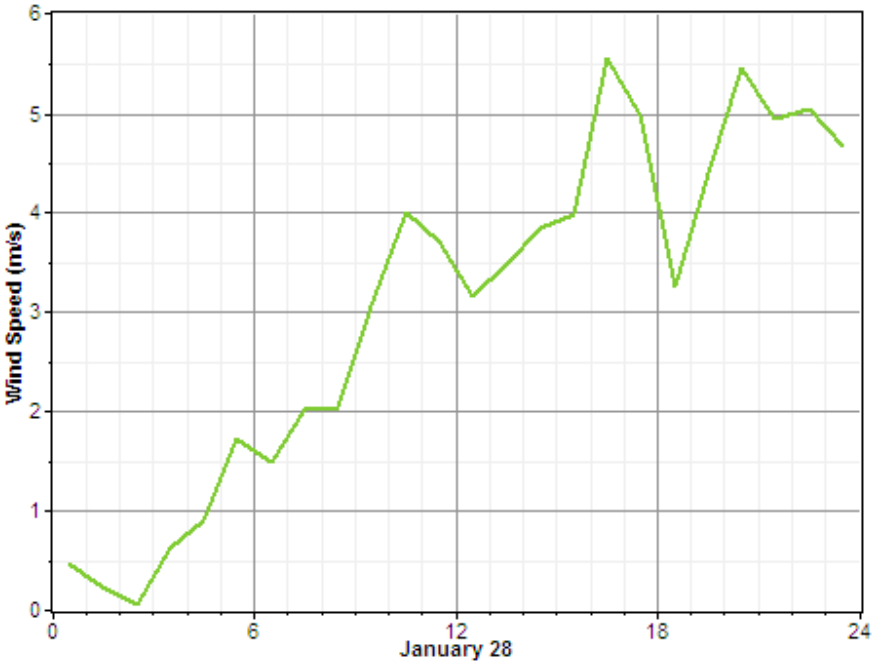
C) Hourly Profile of Unmet Load on January 28



D) Hourly Profile of Battery state of charge on January 28



E) Hourly Profile of Wind Speed variation on January 28



F) Total Electric Production

Cost Summary | Cash Flow | Electrical | FL100 | Label | Battery | Converter | Emissions | Hourly Data

Production	kWh/yr	%
Wind turbines	377,076	59
Generator 1	262,212	41
Total	639,288	100

Consumption	kWh/yr	%
AC primary load	479,250	100
Deferrable load	914	0
Total	480,164	100

Quantity	kWh/yr	%
Excess electricity	92,074	14.4
Unmet electric load	37,225	7.2
Capacity shortage	51,561	10.0

Quantity	Value
Renewable fraction	0.590

G) Wind Turbine Simulation Results

Cash Flow | Electrical | FL100 | Label | Battery | Converter | Emissions | Hourly Data

Quantity	Value	Units
Total rated capacity	200	kW
Mean output	43	kW
Capacity factor	21.5	%
Total production	377,076	kWh/yr

Quantity	Value	Units
Minimum output	0	kW
Maximum output	250	kW
Wind penetration	73.0	%
Hours of operation	7,927	hr/yr
Levelized cost	0.0912	$/kWh

H) Diesel Generator Simulation Result

Cost Summary | Cash Flow | Electrical | FL100 | Label | Battery | Converter | Emissions | Hourly Data

Quantity	Value	Units
Hours of operation	5,527	hr/yr
Number of starts	301	starts/yr
Operational life	2.71	yr
Capacity factor	56.5	%
Fixed generation cost	5.26	$/hr
Marginal generation cost	0.263	$/kWh

Quantity	Value	Units
Electrical production	262,212	kWh/yr
Mean electrical output	47.4	kW
Min. electrical output	15.9	kW
Max. electrical output	53.0	kW

Quantity	Value	Units
Fuel consumption	88,988	L/yr
Specific fuel consumption	0.339	L/kWh
Fuel energy input	875,639	kWh/yr
Mean electrical efficiency	29.9	%

I) Battery Simulation Result

Cost Summary | Cash Flow | Electrical | FL100 | Label | Battery | Converter | Emissions | Hourly Data

Quantity	Value
String size	1
Strings in parallel	200
Batteries	200
Bus voltage (V)	6

Quantity	Value	Units
Nominal capacity	1,387	kWh
Usable nominal capacity	832	kWh
Autonomy	14.1	hr
Lifetime throughput	1,929,040	kWh
Battery wear cost	0.064	$/kWh
Average energy cost	0.199	$/kWh

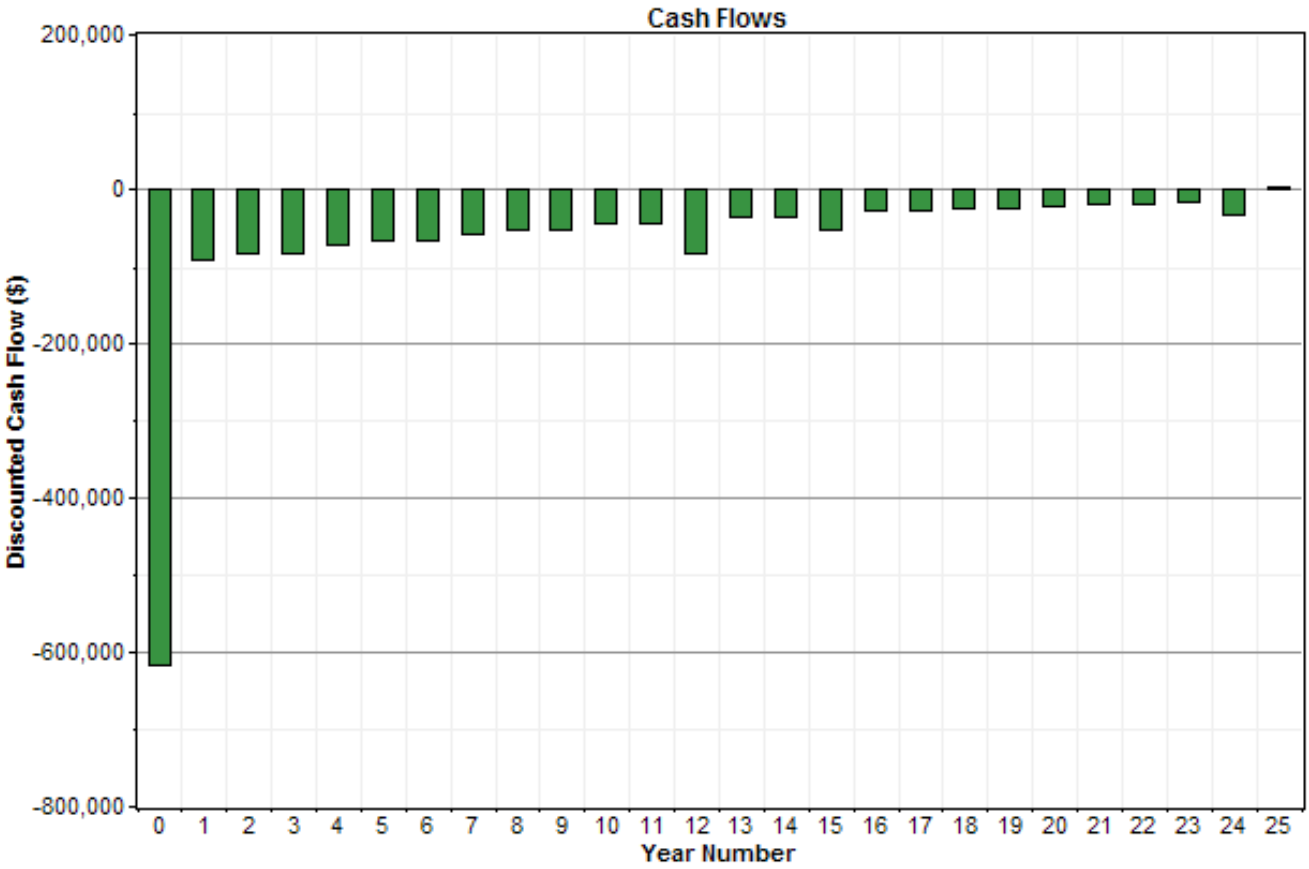
Quantity	Value	Units
Energy in	148,283	kWh/yr
Energy out	119,334	kWh/yr
Storage depletion	785	kWh/yr
Losses	28,164	kWh/yr
Annual throughput	133,419	kWh/yr
Expected life	12.0	yr

J) Convertor Simulation Result

Cost Summary | Cash Flow | Electrical | FL100 | Label | Battery | Converter | Emissions | Hourly Data

Quantity	Inverter	Rectifier	Units
Capacity	100	100	kW
Mean output	12	17	kW
Minimum output	0	0	kW
Maximum output	100	49	kW
Capacity factor	12.3	16.9	%

Quantity	Inverter	Rectifier	Units
Hours of operation	3,271	5,452	hrs/yr
Energy in	119,334	174,446	kWh/yr
Energy out	107,401	148,283	kWh/yr
Losses	11,933	26,164	kWh/yr

Appendix A8

Discounted Cash Flow Details