ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

DEPARTMENT OF ELECTRICAL AND COMPUTER ENGINEERING

ASSESSMENT OF RESOURCE POTENTIAL AND MODELING OF STANDALONE PV/WIND HYBRID SYSTEM FOR RURAL ELECTRFICATION, CASE STUDY AXUM DISTRICT

A THESIS SUBMITTED TO THE ADDIS ABABA INSTITUTE OF TECHNOLOGY, SCHOOL OF GRADUATE STUDIES OF ADDIS ABABA UNIVERSITY

IN PARTIAL FULFILLMENT OF THE REQUIRMENT FOR THE DEGREE OF
MASTER OF SCIENCE IN ELECTRICAL AND COMPUTER ENGINEERING

BY

SOLOMON KIROS

ADVISOR

DR. GETACHEW BEKELE

JULY 2014

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Approved by Board of Examiners

Dr. Getachew Bekele Advisor	______________ Signature	______________ Date
Prof. Singh External Examiner	______________ Signature	______________ Date
Dr. Solomon Abebe Internal Examiner	______________ Signature	______________ Date
________________ Chairman	______________ Signature	______________ Date

DECLARATION

I hereby declare that the work which is being presented in this thesis entitles **"ASSESSMENT OF RESOURCE POTENTIAL AND MODELING OF STAND ALONE PV/WIND HYBRID SYSTEM FOR RURAL ELECTRFICATION, CASE STUDY IN AXUM DISTRICT"** is original work of my own, has not been presented for a degree in any other university and that all sources of material used for the thesis have been duly acknowledged.

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Solomon Kiros Date

(Candidate)

This is to certify that the above declaration made by the candidate is correct to the best of my knowledge.

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Dr. Getachew Bekele Date

(Thesis Advisor)

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Abstract

So far the Ethiopian Electric Power Corporation (EEPCo) has been electrifying the remote rural areas of the country by extending the national grid. Despite the tremendous efforts exhibited during the past few years, there are still exceedingly many people without access to electricity services. Some among them is rural populations living in the historically important district of Axum. However, the district has renewable energy resources, such as Wind and solar, with the capability of providing the needed service without requiring the extension of the national grid. But little studies investigating the value of such alternatives exist.

This thesis work focuses on comparing the economic performance of using various scenarios of stand-alone PV-Wind hybrid system,- with battery storage and diesel as a backup,- for electrifying Kutur village of Awlio kebele of the Axum district (which is 30 kms away from the closest national grid) to - the possibility of extending the grid. Axum district which is located at latitude of 14° 07' N and longitude of 38° 43' E is found to have 4.28 m/s wind speed at a height of 10m, and 6.19KWh/m^2/day solar radiation. Two electric load scenarios are estimated by considering set of incandescent and efficient lamps for lighting for the existing 120 households. The over mentioned solar radiation and wind speed are then used as an input to simulate the hybrid setup for the high and low load estimation using HOMER. Simulation result shows that the NPC corresponding to high and low load scenarios were $278,856and $194,174, respectively.

In addition, a simple load forecasting is done by considering 2013 G.C as a reference year to see the effect of the increase in electric demand of the community on the required investment to install stand alone hybrid setup. The NPC after load forecasting is found to be more than three folds of the NPC required for the reference simulation result. In both cases the results of the simulation indicates that using standalone PV/wind hybrid system with battery storage and diesel generator as a backup for electrifying Kutur village is cost effective and comparable against the cost required for electrifying the village by extending the grid.

Key words: national grid, hybrid PV-Wind, battery storage, diesel and HOMER.

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Acronyms

DPSP	Density of Power Supply Probability
GW	Giga Watt
HC	Health Center
HOMER	Hybrid Optimization Model for Energy Renewable
ICS	Interconnected system
Kms	kilometers
KVA	Kilovolt Ampere
kW	kilowatt
KWh	kilowatt hour
LCC	Life Cycle Cost
LF	Load Follow
LPSP	Loss of Power Supply Probability
MATLAB	Matrix Laboratory
MV	Medium voltage
MW	Megawatt
NASA	National Aeronautics and Space Administration
NMSA	National Metrological Service Agency
NPC	Net Present Cost
NPC	Net Present Cost
NREL	National Renewable Energy Laboratory
O and M	Operating and Maintenance Cost
PV	Photovoltaic
U.S	United States
UEAP	Universal Electric Access Program
W	watt

1. Introduction

1.1. Back ground of the study

At the current rates of consumption, the reserves of oil and gas would be adequate to meet demand for only another 41 and 67 years, respectively [1]. In addition to this, environmental problems are growing dramatically due to a combination of several factors. These factors include an increase in world population, energy consumption, and industrial activity. Solutions to such environmental challenges require a policy aimed at long-term sustainable and clean development. In this respect, renewable energy resources appear to be one of the most efficient and effective solutions.

Despite over a century of investment in electric power systems, there are roughly 1.6 billion people who lack access to electricity service, mainly in rural areas. While there are some open questions regarding the precise cause and effect relationships between rural electrification and human welfare, it is generally considered an important social, economic, and political priority to provide electricity to all. Unfortunately, the very complicated links between electricity and development are often obscured behind two idealized visions of rural electrification. Electricity is often limited to meeting the basic needs of households, and those basic needs tend to be in lighting, and entertainment. Electricity for productive activities or for welfare enhancing community structures (e.g. schools or clinics) tends to lag behind basic household electrification or sometimes is completely neglected in rural electrification objectives, making integration of electrification into larger development goals difficult [3].

An estimate of Ethiopia’s future electricity generation capacity includes more than 45000MW, 10000MW and 5000MW from hydropower, wind and geothermal resources, respectively [2]. Moreover, the country is a conducive geographic condition for solar power generation. Despite the abundance of potential resources suitable for the energy sector development, the level of electricity production has been poor. Currently, the national generation capacity stands at about 2000MW after the completion of Tekeze, Gilgel Gibe II and Tana-Beles with a capacity of 300MW, 420MW and 460MW, respectively. As a result, the overall access to electricity is increased to 35% [2].

The government has also a plan to exploit energy from wind and geothermal to improve the access to electricity to 50% in the coming five years [2]. The Ethiopian Electric Power Corporation (EEPCo), a sole electric power producer and supplier in the country is therefore endowed to fulfill the plan by increasing the production to 10,000MW in the near future including the other renewable energy resources especially wind [2]. Moreover, there is also a program to give electric access from solar to more than 150,000 households of remote rural areas of the country with sufficient solar radiation resource in the coming five years [2].

The electric supply system throughout the country is interconnected system (ICS). Hence, most of the remote rural areas which are located far off the grid do not have access to electricity. This could be attributed to a set of problems, such as, insufficient generation capacity, high cost of extending MV distribution line, lack of good planning and etcetra. Consequently, the rural areas have been dependent on local solutions for electricity supply. These areas have been using traditional biomass as source of energy for baking as well as cooking, and oil for lighting purpose. The limited availability of biomass resource is forcing them to relay on an efficient energy sources. These problems of the community and the current price increase in imported oil as well as the negative effects of fossil fuels on the local and global environment motivates the search for other alternatives.

The rural areas of Axum are among the villages of Ethiopia which are facing similar problems due to the difficulty of giving electric access by extending the grid. But this can be minimized by looking for alternative resources which can be used as a standalone to give electric access to the community. Solar and wind can be the first option.

Figure 1-1 shows the settlement of the people of Kutur village found in Axum district which is 30kms away from the closest national grid. It also shows their traditional use of firewood for baking. As it is shown on the figure, the area has a Tailor house. In addition to this, it has small shops which supply the daily goods needed by the community. It also shows the traditional "mitad" or stove used for baking bread and "Injera" (a flat pancake type bread). So far, the people of this area have been using firewood as a main source of energy as shown in the figure below. Hence, the greenery in the vicinity is highly exposed to deforestation. Therefore, this work is conducted to show the possibility of using PV-wind hybrid system for electrifying the village. It also shows its significance in improving the life of inhabitants and fertility of the land by reducing deforestation caused by the people of the area.

Figure 1-1 picture taken from Kutur village

1.2. Statement of the problem

Rural electrification is the basic issue of the government of Ethiopia for assuring the agricultural lead industrialization. As a result, the Ethiopian Electric Power Corporation is trying to electrify some rural areas which are even more than 120 kms away from a nearby substation or from existing MV distribution line by expending much money to extend the existing national grid even though most of the rural areas are potentially rich in renewable energy resources. These resources can be used as a stand-alone with minimum cost as compared against the cost required for extending the grid.

Most of the remote rural areas of the country are still without electricity access. Likewise the rural people of Axum district which are far away from the national grid are also facing the same problem; and they did not get electric access from the grid so far. As the consequence; the people of these areas are still confined to using traditional biomass as a source of energy for cooking their food, and imported oil for lighting. As a result, they are exposed to health problems caused by smokes while also contributing to deforestation. Therefore, it is important to investigate the potential role of various electrification options.

Moreover, supplying energy from hybrid system will help them improve their life style as well as reduce deforestation. In addition, it will contribute a lot to the achievement of agricultural lead industrialization by minimizing the expense of Universal Electric Access Program.

1.3. Objectives of the study

- General objective

In this thesis, assessment of resource potential and modeling of the Stand- alone PV/Wind Hybrid System for electrifying rural areas in the Axum region will be done.

- Specific objectives

The specific objectives of this thesis work are

- To select the best optimized hybrid model for providing electricity to the community by considering its overall installation cost, contribution of renewable energy sources and energy cost per kWh.
- To analyze the power and energy demand of the society of the selected areas by considering the basic needs of the people.
- To select appropriate solar modules, wind turbines and batteries depending on the energy demand for the individual sites.
- To compare the investment cost of the hybrid system against the cost required to electrify the areas by extending the national grid.
- To determine the demand of the community at the life span of the project through load forecasting.

1.4. Methodology

As mentioned above, this research is mainly concerned to looking in to better option of energy sources to electrify villages in remote areas of Ethiopia which are far-off from the existing national grid by comparing against the cost needed to extend the national grid. The main concern is the assessment of resource potential and modeling of the stand-alone hybrid system by analyzing the data taken from different data sources. These are done through reviewing literatures related to hybrid systems, and adopting different concepts and methodologies as required.

Primary data:

The primary work is field data collection, which includes data of the number of households and site observation to evaluate their living style. The field data supported by photographs to show equipments used by the community, as well as their daily life style and activity related to energy consumption. The power demand of each house hold has been estimated based on the need of the community and application of numerical data using Microsoft excel spread sheet. In addition, a simple exponential load forecasting method is used to consider the effect of change of electric load of the community with in the life span of the project which is 25 years.

Secondary Data:

The wind speed and solar radiation of the selected sites are collated from different sources such as: the national metrological service agency of Ethiopia (NMSA), National Aeronautics and Space Administration (NASA), previous works by other scholars and others. Then the data collected from NMSA are analyzed using theoretically proved formulas. Moreover, the data needed for calculating the cost of extending the grid is taken from EEPCO, and it is analyzed using Microsoft excel spread sheet.

Finally the hybrid system is modeled and simulated using HOMER software based on the primary and secondary analyzed data to get the best optimized solution for both load estimations which are estimated by considering incandescent and CFL for lighting.

2. Literature review and basic theory of system components

2.1. Renewable energy technologies

The sun generates its energy by nuclear fusion of hydrogen nuclei to helium. Sunlight is the main source of energy to the surface of the earth that can be harnessed via a variety of natural and synthetic processes. Basically all the forms of energy in the world as we know it are solar in origin. Oil, coal, natural gas, and wood were originally produced by photosynthetic processes, followed by complex chemical reactions in which decaying vegetation was subjected to very high temperatures and pressures over a long period of time. Even the energy of the wind has a solar origin, since it is caused by differences in temperature in various regions of the earth [5].

Renewable energy systems are important to decrease environmental pollution, and this can be achieved by the reduction of air emissions due to the substitution of conventional energy resources. The most important effects of air pollutants on the human and natural environment are their impact on the public health, agriculture, and ecosystems. The financial impact of these effects can be measured easily by relating to tradable goods. In addition to these factors, the consumption of renewable energy resources does not result in the depletion of resources [6]. And the instable energy provision which is the major problem of these energy resources can then be solved by using hybrid energy supply systems.

2.2. Wind energy

2.2.1. Basic theory of wind

Global wind is caused by pressure differences across the earth's surface due to the uneven heating of the earth by solar radiation. The uneven heating of the earth resulted in circulation of the atmosphere which is greatly influenced by the effects of the rotation of the earth. In addition, variations in the circulation can be caused due to seasonal variations in the distribution of solar energy.

This wind blows predominately in the horizontal plane, responding to horizontal pressure gradients since the pressure gradient force in the vertical direction is usually cancelled by the downward gravitational force. At the same time, there are forces that struggle to mix the different temperature and pressure air masses distributed across the earth‘s surface. Similarly, inertia of the air, the earth‘s rotation, and friction with the earth’s surface (resulting in turbulence), affect the atmospheric winds. Wind speed can also vary with height above the ground, geographical location and time.

These variations of wind speed with time can be categorized as inter-annual, annual, diurnal and short-term. The Inter-annual wind speed variation can have a large effect on long-term wind turbine production since it occurs over time scales greater than one year. Diurnal variation can be defined as an increase in wind speed during the day with the wind speeds lowest during the hours from midnight to sunrise. This is caused due to differential heating of the earth’s surface during the daily radiation cycle. Even though daily variations in solar radiation are responsible for diurnal wind variations in temperate latitudes over relatively flat land areas, it can also vary with location and altitude above sea level. The largest diurnal changes generally occur in spring and summer, and the smallest in winter. Similarly, the short term wind speed variation can be defined as the mean variations over time intervals of 10 minutes or less, and it includes turbulence and gusts [7].

2.2.2. Wind Data Analysis and Resource Estimation

Wind resource or power production potential of a particular site can be evaluated by direct and statistical techniques. Wind is produced due to temperature variation which results in pressure variation, and it blows from high pressure to low pressure area. The power from wind can be calculated using the formula

$$P = \tfrac{1}{2} \rho A U^3 \qquad \text{Eqn. 2-1}$$

Where: P is wind power

A is Rotor area

U is wind speed

And this can be described by its power curve (or characteristics curve) which is shown in figure 2-1 below. The characteristics curve illustrates the following terms:

Cut-in-velocity: is the wind speed at which the turbine starts to generate power.

Rated velocity: is the wind speed at which the turbine reaches rated turbine power.

Cut out velocity: the wind speed at which the wind turbine is shutdown to keep loads and generator power from reaching damaging levels.

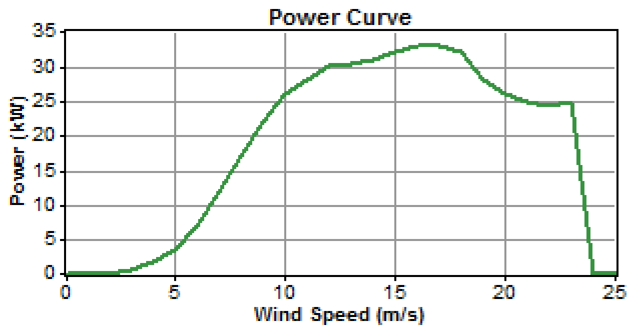


Figure 2-1 Power curve of the wind turbine [9]

The power density can be calculated as

$$P/A = \frac{1}{2}\rho \frac{1}{N}\sum_{i=1}^{N} U_i^3 \qquad \text{Eqn. 2-2}$$

This is the formula used to calculate the most approximate value for power density since the cubic of average speed is different from the sum of the cubic of individual speeds [8].

2.2.3. Analytical method for predicting long-term wind energy availability

After the wind speed data has been recorded for more than five years, the distribution probability can be used to predict a future wind speed availability and elucidate: (1) the period without wind, or when the wind is too weak to start up the wind turbines; (2) the range of most likely wind speeds; and (3) the nominal power output and the probabilities associated with various outputs [3]. The wind data can then be analyzed using two different analysis methods. These are the Rayleigh which uses the mean wind speed as a parameter, and Weibull which uses two parameters for statistical analysis.

The Weibull probability distribution (h (v)) is a mathematical expression which has been found to provide a good approximation to the measured wind speed distribution.

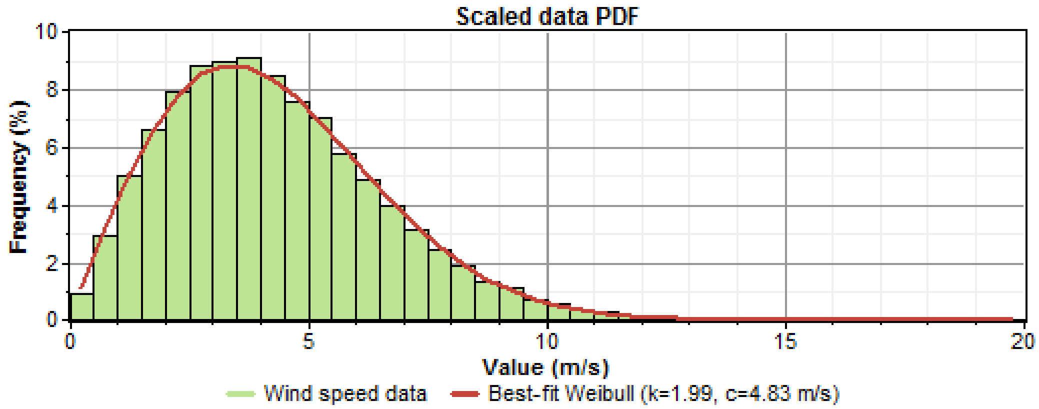


Figure 2-2 Wind speed probability density function for Axum [9]

A Weibull distribution graph is usually used to describe wind variation over a certain period of time at a particular site. Figure 2-2 shows a typical distribution plot for wind speed data based on wind speed measured five times every day for three years, 2007–2011, in Axum. As can be seen in the graph, the mean wind speed is about 4.83 m/s. 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.

The distribution of wind is expressed by Weibull distribution which is called a Raleigh distribution for K=2 [3, 10]. It is given by equations (2-3 to 2-5).

$$f(v) = \frac{\pi \cdot v}{2\bar{v}^2} \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \qquad \text{Eqn. 2-3}$$

$$prob(v \le V) = 1 - \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \qquad \text{Eqn. 2-4}$$

$$prob(v \ge V) = \exp\left[-\frac{\pi}{4}\left(\frac{v}{\bar{v}}\right)^2\right] \qquad \text{Eqn. 2-5}$$

Where, *f (v)*= Weibull probability density function of wind distribution

$\bar{v}$ = mean wind speed (m/s)

v=instantaneous wind speed (m/s)

prob(*v*<=V)=probability of instantaneous wind speed is less than V

prob(*v*<=V)=probability of instantaneous wind speed is greater than V

Wind speeds are always measured at 10 m height anemometer. But, wind turbines are installed at higher elevations at which the wind speed is completely different from the 10 m measurement. This variation of wind speed with height can be expressed with equation 2-6 [3, 10].

$$v(z)\cdot \ln\left(\frac{z_r}{z_0}\right) = v(z_r)\cdot \ln\left(\frac{z}{z_0}\right) \qquad \text{Eqn.2-6}$$

Where: $Z_r \rightarrow$ Reference height (m)

$Z \rightarrow$ Height where wind speed is to be determined (m)

$Z_0 \rightarrow$ Measure of surface roughness (0.1 to 0.25 for crop land)

$v(z) \rightarrow$ Wind speed at height of Z m (m/s)

$v(z_r) \rightarrow$ Wind speed at the reference height (m/s)

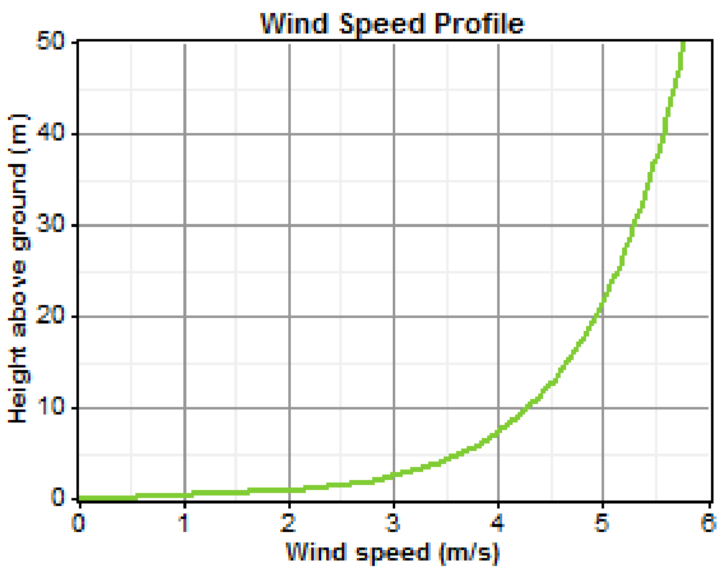


Figure 2-3 A typical wind speed profile of Axum for a surface roughness of 0.1[9]

From the relationship given in equation 2-6 it can be observed that the wind speed increases with height and therefore a higher tower captures more wind energy. If the wind speed $v(z_r)$ at a certain reference height z_r above a surface with a known roughness length (z_o); then, the wind speed $v(z)$ at a height of z can be determined using equation 2-6 above [6]. The figure shown above illustrates a typical wind speed profile for a surface roughness length of 0.1 of the selected site.

2.2.4. Assessment of Wind potential

To maintain the current economic growth of Ethiopia, it needs 38-fold increase [19] in its electric supply by 2030. Hence, new sources of energy are urgently needed. Subsequently, the answer to this may lie in wind energy since strong and reliable winds of the country can generate a substantial amount of electricity at a reasonable cost which can even be exported to neighboring countries. The areas which can provide the greatest potential for wind energy are the northern, central, eastern and southwestern part of the country. Axum is also one of the districts in the northern part of Ethiopia where there is good potential of wind and solar energy. Due to the absence of measured wind speed in the NMSA, wind speed extracted from NASA is simply taken to assess wind energy potential of the selected site. Therefore, the annual average wind speed of Axum which is located at latitude of 14° 07' N and longitude of 38° 43' E is 4.28 m/s at a height of 10m. This value is used as input to the wind resource in simulating the hybrid setup. The wind speed data shown at the third row of table 3-5 is at a blade height of the selected wind turbine which is converted using equation 2-6.

Table 2-1 Monthly average wind speed

NASA	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
at 10m	4.45	4.48	4.46	4.26	3.64	4.92	5.42	5	4.08	3.13	3.56	4.01	4.28
at 26m	5.37	5.41	5.39	5.14	4.40	5.94	6.54	6.04	4.93	3.78	4.30	4.84	5.17

2.3. Solar energy

2.3.1. Basic theory of solar energy

The greatest advantage of solar energy as compared with conventional energy is that it is clean and can be supplied without environmental pollution. Due to little concern to environmental pollution, more convenient than energy from alternative energy sources and cheaper price, fossil fuels provide most of our energy over the past century. But now the conventional energy resources are being replaced by renewable energy resources. Solar energy technologies, which are among the renewable energy resources, have environmental and socioeconomic benefits. Reduction of greenhouse gas emission, retrieval of degraded land and reduction of grid extension are the environmental benefits of solar energy. In addition to these, accelerating rural electrification, creation of employment opportunities and improving diversification and stability of energy supply are its socioeconomic benefits [5].

2.3.2. Solar data analysis and resource estimation

Solar radiation data are available in several forms. There are two popularly used measuring instruments to know the amount of radiation incident on a horizontal surface of a specific (selected) area. Among these the one which measures the sun shine duration is used by the national metrological service agency of Ethiopia. Therefore, some mechanism has to be used to convert the values of the measured data to the required solar radiation if someone wants to know the possibility of using solar system as source of electricity. Hence, in this work theoretically proofed formulas which are written from equation 2-7 to 2-12 are used to determine the solar radiation of the selected site.

$$G_{on} = G_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right] \qquad \text{Eqn. 2-7}$$

Where: G_{on} is the extraterrestrial radiation measured on the plane normal to the radiation on the n^{th} day of the year (W/m^2) and G_{sc} is solar constant (i.e. 1366.1 W/m^2).

Based on the results of G_{on} obtained using equation 2-7, the total radiation incident on a horizontal surface can be calculated by

$$H_o = \frac{24\times 3600 G_{sc}}{\pi}\left[1 + 0.033\cos\left(\frac{360N}{365}\right)\right]\times\left[\cos(\phi)\cos(\delta)\sin(\omega_s) + \left(\frac{\pi\omega_s}{180}\right)\sin(\phi)\sin(\delta)\right] \quad \text{Eqn.2-8}$$

Where ϕ is latitude of the selected area

δ is declination angle

ω_s is the sunset hour in degrees

The daily solar radiation is measured in joules per square meter (J/m^2), however, Gsc is in watts per square meter (W/m^2).

The declination angle which shows the angular position of the sun at solar noon with respect to the plane of the equator can be found from the equation [11]

$$\delta = 23.45 \sin\left(360 \frac{284+n}{365}\right) \qquad \text{Eqn. 2-9}$$

The sunset hour in degrees is calculated by

$$\omega_s = \cos^{-1}(-\tan(\phi)\tan(\delta)) \qquad \text{Eqn. 2-10}$$

n is the day of the year which is a continuous function of time. It can be conventionally obtained from table 2-1 shown below.

$$N_s = \frac{2}{15} \times \omega_s \qquad \text{Eqn. 2-11}$$

Table 2-2 Recommended average days for months and values of n by months [11]

Month	n for i^{th} day of the month	For the average day of the month		
		date	n, day of year	δ declination
January	i	17	17	-20.9
February	31+i	16	47	-13.0
March	59+i	16	75	-2.4
April	90+i	15	105	9.4
May	120+i	15	135	18.8
June	151+i	11	162	23.1
July	181+i	17	198	21.2
August	212+i	16	228	13.15
September	243+i	15	258	2.2
October	273+i	15	288	-9.6
November	304+i	14	318	-18.9
December	334+i	10	344	-23.0

2.3.3. Measurement of sunshine duration and estimation of solar radiation

Two different instruments are commonly used for measuring hours of bright sunshine in countries which have no instrument for measuring the solar irradiance directly. These are the Campbell-

Stokes sunshine recorder which uses a solid glass sphere of approximately 10 cm as a lens that produces an image of the sun on the opposite surface of the sphere, and a photoelectric sunshine recorder.

In areas where the radiation data's are not available, empirical formula's can be used to estimate the average solar radiation from the hours of bright sunshine (sunshine duration). These data are available in many countries which are mainly measured by Campbell-Stokes instrument. The monthly average solar radiation then can be calculated using equation 2-12.

$$\frac{H}{H_0} = a + b\frac{\bar{n}}{N_s} \qquad \text{Eqn. 2-12}$$

Where ɑ and b are the regression coefficients (constants) which are dependent on the location, H is the monthly average of the daily global radiation on a horizontal surface, Ho is the average value of extraterrestrial solar radiation on a horizontal surface for each month which can be calculated from equation 2-8, $\bar{n}$ is the monthly average of bright sunshine hours per day, and N_s is the average of the maximum daily hours of sunshine which can be calculated from equation 2-11.

2.4. Hybrid system for rural electrification

A hybrid energy system produces power from more than one generating sources with different possible combinations. The generating sources can be renewable energy sources such as wind, solar, hydropower; and conventional energy sources like diesel which is commonly used as a back up in designing hybrid energy system. Additionally, battery storage units can be used to store excess power generated by any one of the generating sources. Nowadays, the basic problem for the economic development of developing countries is the energy demand. Hence, installing the hybrid energy systems in areas where the energy sources are available can meet the energy demand of the society [10].

Previous researches done on hybrid systems in different rural areas of the world shows as the hybrid set up is cost effective and reasonable to use for electrifying rural areas. This is proved using different approaches such as analytical models like LCC and LPSP. In addition, the researchers have used different software's like MATLAB, HOMER to obtain the best optimized result for the specific area where the research work has been conducted.

Salwan S. has proposed a hybrid system as a renewable resource of power generation for grid connected applications in three cities in Iraq. The proposed system was simulated using MATLAB solver.

The daily average solar radiation and wind data collected over eight years as a monthly average data from a metrological weather website are used as an input to the solver. Solar radiation and atmospheric temperature as well as the PV manufacturing data sheet information are used as major inputs to the solver for the PV modules. Similarly, wind speed and the wind turbine manufacturing data sheet information are used as an input for the wind turbine. Then, the proposed hybrid system is simulated using MATLAB to look for the possibility of using the system for electrifying rural areas of Iraq. Results showed that it is possible for Iraq to use the solar and wind energy to generate enough power for some villages in the desert or rural area. It is also possible to use such a system as a black start source of power during total shutdown time. In addition, Salwan has compared the potential of the selected three sites with each other. He obtained Basrah as an area which has the highest average daily solar radiation and wind speed among the sites; as a result, Basrah is selected as the preferred location for his system. Finally, he concluded that the plant location can strongly affect the plant performance i.e. installing the proposed system in Baghdad instead of Basrah will lead to decreased total gained power by 15% [4].

C. Dennis Barley, Debra J. Lew1, and Lawrence T [8] have used hourly values of wind speed and solar radiation for a period of one year for their models, so as to capture seasonal effects, diurnal cycles, storm cycles, and stochastic variations. The wind turbines modeled in this analysis include four Chinese turbines, three U.S. turbines and one German turbine. The Chinese 200W and 2kW turbines which have low hub heights and designed to accommodate the low wind speeds are then obtained to be the most cost effective in terms of total installed cost per annual output. In addition, photovoltaic modules of 50 watts rated power, with an installed cost of $321.50 and a service life of 20 years, and mounted at a slope of 44 degrees (equal to the latitude) as well as an inverter rated at 575 W, with an installed cost of $440 dollars and a service life of 10 years are used. They also use Chinese manufactured batteries which have a charge capacity of 1.26 kWh, a service life of 150 equivalent full cycles, and an installed cost of $142 each.

Assigning an arbitrary cost to unmet load in $/kWh, defining the augmented life cycle cost (LCC) as the sum of the equipments costs, O&M costs and unmet load cost, sizing the components to minimize LCC, and making a subjective judgment of the most appropriate design are used as a procedure for determining optimal designs. Then, quasi-steady-state time-series model to determine approximate least-cost designs and stochastic model Hybrid2 to more accurately determine the cost of energy (COE) and unmet of load for each of the designs indicated by the simple model are used to perform these computations. Finally, actual resource data from the region are processed to indicate that the combination of wind and PV are more cost effective than either one alone [8].

Frank Fieldler and etal have studied PV-Wind-Hybrid systems for 11 locations in Sweden. Their paper aims to the evaluation of system cost, cost of energy, the effect of load size, and comparing the cost of the hybrid system against the cost required to a PV system alone. The system is modeled to supply electricity for single family houses. HOMER developed by the National Renewable Energy Laboratory (NREL) is used for sizing of the hybrid systems based on the Net Present Costs (NPC). To reduce the annual electricity consumption, they assumed power efficient appliances and other energy saving measures. Based on these, three load profiles with 6000kWh, 3300kWh and 1800kWh are then generated. They limited their system size to 6kW PV power, 3.6kW wind turbine power and battery bank size of 120kWh. For the simulation a Bergey XL.1 wind turbine with a hub height of 20 m was used (max. 3 turbines each 1.2 kW).

The results of their simulation indicate that the hybrid system is feasible in all locations for loads of 3300kWh and 1800kWh, but no feasible systems are found for the two locations for the 6000kWh load. The NPC varies between $48,000 and $87,000 for the highest load and $17,000 and $33,000 for the lowest load. In addition, the comparison of PV-Wind Hybrid systems with PV alone systems is done by simulating the 1800kWh load profile, and they observed as the hybrid system is less expensive than the PV alone system even though the difference is greater in locations with higher wind speed than locations with lower wind speed [12].

M. Muralikrishna1used the methodology of life cycle cost for economic evaluation of stand-alone PV system, stand-alone wind system and PV-wind hybrid system. The results show as the hybrid system returns the lowest unit cost values to maintain the same level of DPSP as compare to stand-alone solar and wind systems, and they are techno-economically viable for rural electrification; in addition, the hybrid systems can be used to reduce energy storage requirements [13].

S.Diaf and etal presented a methodology to perform the optimal sizing of an autonomous hybrid PV/wind system. The methodology aims at finding the configuration, among a set of systems components, which meets the desired system reliability requirements, with the lowest value of levelised cost of energy. They used a mathematical model for estimating the power output of PV modules using solar radiation, ambient temperature and manufacturers' data of the PV modules as inputs to the model. However, a cubic spline interpolation of the values of the data provided by the manufacturer is used for estimating the wind generator output. Additionally, technical sizing model is developed for the hybrid PV/wind system using the concept of loss of power supply probability (LPSP) to evaluate its reliability. The developed methodology has been applied to design a standalone hybrid PV/wind system in order to power supply residential household located in the area. Then, one year hourly global solar radiation on a tilted plane, hourly mean values of wind speed as well as ambient temperature are used for simulation. Finally, several simulations have been done by considering different combinations of PV, wind and capacity storage. As a result, they obtained the configuration system comprising one wind generator (600 W), PV generator (using 125 W modules) and battery storage of 253 Ah to be the optimal one among the other options considering both the economical and technical point of view [14].

The combined utilization of these renewable energy sources are therefore becoming increasingly attractive and are being widely used as alternative of oil produced energy. Economic aspects of these renewable energy technologies are sufficiently promising to include them for rising power generation capability in developing countries. These hybrid energy systems are becoming popular in remote area power generation applications due to advancements in renewable energy technologies and substantial rise in prices of petroleum products [10].

The ecological dimension analysis of Timur Gul showed good potential for hybrid systems. Especially when compared against conventional electrification solutions, the hybrid systems have the potential to reduce emissions of air pollutants and greenhouse gases [6].

The main components of the hybrid system for this thesis work are: photovoltaic and wind. In addition to these, storage battery and diesel are used as a backup system to fill the gap resulted due to less production of energy from PV and wind.

3. Resource assessment and Load estimation

3.1. Assessment of solar radiation

The assessment of the potential for solar radiation of the selected area is done by taking data from different sources. These are NASA, SWERA and the National metrological service agency of Ethiopia. In the first approach, the data taken from the national metrological service agency is analyzed using formulas' in section 2.3.2 of chapter two (i.e. equation 2-7 through 2-12) based on the sunshine duration data collected over the past six consecutive years. The sunshine duration data taken from the National Metrological agency of Ethiopia is given in table 3-1. The measurements are taken for six consecutive years starting from 2006. As it can be seen in the table, the data's for years 2007, 2009 and 2010 are full, but for 2006, 2008 and 2011 measurements are incomplete. Hence, only the three year data is taken to convert in to MJ/m^2 using equation 2-12. This result is then compared with the data collected from NASA and is found to be nearly equal.

Table 3-1 Sunshine duration of Axum [15]

Region Tigray Long. Alt.

Station Axum Lat.

Element Daily S.S.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2006	x	x	x	x	x	x	x	x	x	x	9.2	9.21
2007	9.5	9.2	9.6	8.3	8.5	6.4	4.5	4.9	7.0	9.4	9.6	9.8
2008	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	xx	Xx
2009	9.9	8.5	9.0	9.1	9.5	6.0	3.1	4.7	7.9	8.9	9.3	9.0
2010	8.9	8.7	8.3	7.3	7.2	5.5	4.1	2.4	5.8	9.3	9.4	9.4
2011	8.6	10.8	7.4	9.3	7.6	xx	xx	xx	xx	xx	xx	Xx

The value for the coefficients ɑ and b which are used to calculate average solar radiation (H) varies with location, and hence the approximate values for the selected site are taken to be 0.30 and 0.50 for ɑ and b respectively [16, 17]. Therefore, the analysis for the monthly average solar radiation is then calculated using the values of the regression coefficients and H_o which can be calculated using equation 2.8. The result of the analysis shown in table 3-2 is the monthly average solar radiation in MJ/m^2 for the sunshine duration measured in 2010. In the same manner, the monthly average solar radiation for the hours of bright sunshine measured in 2007 and 2009 is converted in to MJ/m^2. Finally the monthly average solar radiation of the selected site based on the three year fully measured data is summarized and obtained to be as shown in table 3-3**.**

The symbols used in table 3-2 represent the measured and calculated values which are used to analyze the extraterrestrial radiation (i.e. H_o) and the solar radiation for the location. n and ϕ represents measured sunshine duration and the latitude angle of the area respectively. However, the symbols δ, ω_s and N_s indicates the calculated values for declination angle, sunset angle and day length which are obtained using equations 2-9, 2-10 and 2-11 respectively.

The monthly solar radiation data for each month of the years with full measured hours of bright sunshine are shown in table 3-3. This table also shows monthly and annual average solar radiation in MJ/m^2 of Axum.

Table 3-2 Analysis of the monthly average solar radiation in MJ/m^2 for year 2010

n	ω_s	ϕ	δ	**N**	**(360*N/365)**	**Cos (360*N/365)**	**Cos (ϕ)**	**Cos (δ)**	**(3.14*ω_s/180)**	**sin(ω)**	**sin(ϕ)**	**sin(δ)**	**H_o (MJ/m^2)**	**H (MJ/m^2)**	**month**
8.9	84.48	14	-20.9	11.3	11.11	0.981	0.97	0.93	1.47	0.995	0.244	-0.357	30	21	Jan
8.7	86.66	14	-13	11.6	11.40	0.980	0.97	0.97	1.51	0.998	0.244	-0.225	33	23	**Feb**
8.3	89.4	14	-2.4	11.9	11.76	0.979	0.97	0.99	1.56	1	0.244	-0.042	37	24	**Mar**
7.3	92.39	14	9.4	12.3	12.15	0.978	0.97	0.98	1.61	0.999	0.244	0.1633	40	24	**Apr**
7.2	94.92	14	18.8	12.7	12.48	0.976	0.97	0.94	1.65	0.996	0.244	0.3223	41	24	**May**
5.5	96.17	14	23.1	12.8	12.65	0.976	0.97	0.92	1.68	0.994	0.244	0.3923	41	21	**Jun**
4.1	95.61	14	21.2	12.7	12.57	0.976	0.97	0.93	1.67	0.995	0.244	0.3616	41	19	**Jul**
2.4	93.38	14	13.15	12.5	12.28	0.977	0.97	0.97	1.63	0.998	0.244	0.2275	40	16	**Aug**
5.8	90.56	14	2.2	12.1	11.91	0.978	0.97	0.99	1.58	1	0.244	0.0384	38	21	**Sept**
9.3	87.56	14	-9.6	11.7	11.52	0.979	0.97	0.98	1.53	0.999	0.244	-0.167	35	24	**Oct**
9.4	85.05	14	-18.9	11.3	11.19	0.981	0.97	0.94	1.48	0.996	0.244	-0.324	31	22	**Nov**
9.4	83.86	14	-23	11.2	11.03	0.982	0.97	0.92	1.46	0.994	0.244	-0.391	29	21	**Dec**

Table 3-3 Monthly and annual average solar radiation in MJ/m^2 of Axum

YEAR	Jan	Feb	Mar	April	May	June	July	Aug	Sept	Oct	Nov	Dec
2007	22	23	26	25	26	22	19	20	23	24	22	21
2009	22	22	25	27	27	22	17	20	24	24	21	21
2010	21	23	24	24	24	21	19	16	21	24	22	21
Monthly average	21.667	22.667	25	25.3333	25.667	21.667	18.333	18.667	22.667	24	21.667	21
Annual Average												22.361

Table 3-4 Monthly average solar radiation of Axum in KWh/m^2

year	January	February	March	April	May	June	July	August	September	November	October	December
2007	6.11	6.39	7.22	6.95	7.22	6.11	5.28	5.56	6.39	6.67	6.11	5.84
2009	6.11	6.11	6.95	7.50	7.50	6.11	4.72	5.56	6.67	6.67	5.84	5.84
2010	5.84	6.39	6.67	6.67	6.67	5.84	5.28	4.45	5.84	6.67	6.11	5.84
Monthly average	**6.02**	**6.30**	**6.95**	**7.04**	**7.13**	**6.02**	**5.09**	**5.19**	**6.30**	**6.67**	**6.02**	**5.84**

But the values specified in table 3-3 are not enough to use as an input to the software and to determine the potential of the area for implementing photovoltaic system. Consequently, these are then converted in to KWh/m^2 using the conversion relation 1MJ is equal to 277.78Wh [18]. Finally, the monthly and annual average solar irradiance in KWh/m^2 is obtained as shown in table 3-4.

As it can be seen in table 3.4 the monthly average solar irradiance of Axum district has maximum value on the month of May with a value of 7.13 KWh/m^2 and minimum on July and August with a value of 5.09 KWh/m^2 and 5.19 KWh/m^2. Since July and August are the months of the rainy season of Axum, the intensity of solar has reduced as compare with the other months of the year.

The annual average solar radiation of the area is found to be 6.19 KWh/m^2, and this value indicates that the area has good potential for the implementation of photovoltaic (PV) system to give electric access to the community.

3.2. Load estimation

The load estimation is mainly concerned with calculating the power and energy demand of the community. The primary and deferrable load estimation is performed for a village with 120 households by considering the basic needs of the community. The primary load contains lighting, radio receiver, TV and DVD player [3]. In addition to these, the community has school, clinic, farmers training center (FTC) and flour mill.

a. Primary load

The purpose of this work as already stated in the objective is to assess the resource potential and to model the stand-alone PV-Wind hybrid system to give electric access to the people living in Kutur village of Axum district, who are 30kms away from the existing national grid. At the same time it will also compare the investment cost required to electrify this area using this model against the cost required to extend a grid found nearby. For simulating the hybrid system using HOMER software the daily consumption in hours for the selected area is taken as an input to the software. The primary load is calculated by considering lower income and higher income (i.e. the model) farmers of the area. These model farmers use TV and DVD player in their daily activities in addition to the basic loads used by the lower income generating people. As per the information gathered from the district administrator of the selected area, around 10% of the total households have the potential to use TV and DVD player if electric access is available.

The estimation for the daily energy consumption of the society is done by considering two different cases. In the first case the primary load estimation is done by considering incandescent lamp of 60W with three lamps for each household, radio receiver of 20W, flour mill with rating of 15KW, TV and DVD with rating of 65 W and 20 W respectively. On the other hand, the load estimation for HC, FTC and kebele administration is taken from UEAP (i.e. 3KW each) [20].

Table 3-5 Primary load of Kutur using incandescent lamp

primary load	single household	No. of households	total no. of equipments	size in W for 1 equipment	Total power in KW	operating hrs per day	energy in KWh	remark
lighting lamps	3	120	360	60	21.6	6	129.6	
radio (tape recorder)	1	120	120	20	2.4	8	19.2	
TV	1	12	12	65	0.78	6	4.68	
DVD	1	12	12	20	0.24	4	0.96	
mill	1		1	15000	15	5	75	
health center					3	8	24	
FTC					3	8	24	
Kebele Adm.					3	8	24	
primary school	4	13	52	40	2.08	3	6.24	FL
Total					51.1		307.68	

The primary school of the area has 13 classes with 40 numbers of students for each. For the time being there are no students who can attend evening class due to lack of electricity, but if the school gets electric access there can be students who can be enrolled for the night classes.

Table 3-6 Equivalent energy efficient lamps for different conventional lamps [18]

Electrical power equivalents for differing lamps			
Minimum light output	Electrical power consumption		
Light Output Lumens (lm)	LEDs (Watts)	CFLs (Watts)	Incandescent (Watts)
450	4 - 5	8 - 12	40
300 - 900	6 - 8	13 - 18	60
1100 - 1300	9 - 13	18 - 22	75 - 100
1600 - 1800	16 - 20	23 - 30	100
2600 - 2800	25 - 28	30 - 55	150

The class will start at 05:30 PM and ends at 8:30 PM. Hence, the energy consumption of the school is calculated by considering three hours every day starting from Monday up to Friday.

The result of this estimation indicates that the total power of the community is 51.1KW where incandescent lamp is used for lighting, and its energy for the average operating hours per day is 307.68KWh as shown in table 3-5.

Similarly, the second primary load estimation is done by considering energy efficient lamps for the households. Compact Fluorescent Lamps (CFL) of 13-18 watts can substitute Incandescent lamps of 60 watts as shown in table 3-6. The estimation is done by replacing the incandescent lamp by CFL of 18W. As a result, the primary load of the community as shown in table 3-7 has decreased to a power and energy of 35.98KW and 216.96KWh respectively. The load profile of the primary load for both cases is as shown in figure 3-1 below.

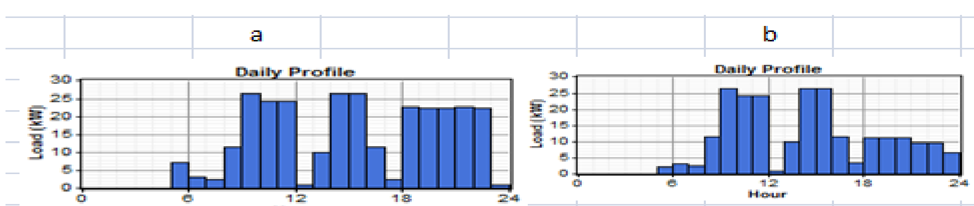


Figure 3-1 Primary load profile a, for Incandescent lamps b, for Efficeint lamps (CFL)

Table 3-7 Primary load of Kutur using energy efficient lamp (CFL)

primary load	single household	No. of households	total no. of equipments	size in W for 1 equipment	Total power in KW	operating hrs per day	energy in KWh	remark
lighting lamps	3	120	360	18	6.48	6	38.88	CFL
radio (tape recorder)	1	120	120	20	2.4	8	19.2	
TV	1	12	12	65	0.78	6	4.68	
DVD	1	12	12	20	0.24	4	0.96	
mill	1		1	15000	15	5	75	
health center					3	8	24	
FTC					3	8	24	
Kebele Adm.					3	8	24	
primary school	4	13	52	40	2.08	3	6.24	FL
Total					35.98		216.96	

b. Deferrable load

The deferrable load contains four water pumps for all households as well as the service centers which deliver public service to the community. The type of water pump is HR-14 which is taken from the Lorenz PS600 series with 300W power rating and pumping capacity of 40 l/m (i.e.2400 l/h) [21]. This can pump water at this rate from a depth of 15m. The average daily water consumption of the community per household is assumed to be 100 l [3]. The total daily water consumption of the community is then 12000 l. Additionally, all the service centers are assumed to use a summed average of 4000 l/day. This indicates that the overall water needed by the village in a day is 16000 l. Therefore, four water pumps of the over mentioned types with a peak load of 1.2KW are used to supply the water demand of the community. The water storage tank is assumed to have a capacity of storing water for four days (i.e.64000 l of water). To determine the number of hours required filling the daily consumption of the community, the daily water consumption is divided by the total pumping rate of the four water pumps which is 9600l/h. The number of hours needed to supply the daily water consumption of the community is then obtained to be approximately 1.7 hrs which is 16000/9600. Hence, the daily deferrable load will be 2.04KWh (i.e. 1.2kw*1.7hrs). Similarly, the total storage capacity of the water tank is divided by their total pumping rate to get the number of hours required by the four pumps to fill the tank.

And this is obtained to be 6.67hrs. This result is then multiplied with the total power demanded by the water pumps which is 1.2kW to get the corresponding energy equivalent of the reservoir capacity that is 8 kWh. The deferrable load is constant for all months except for June, July and August which are the months of the rainy season of the area, and their water consumption is assumed to reduce by 30% [3]. The load profile of the deferrable load is as shown in figure 3-2 below.

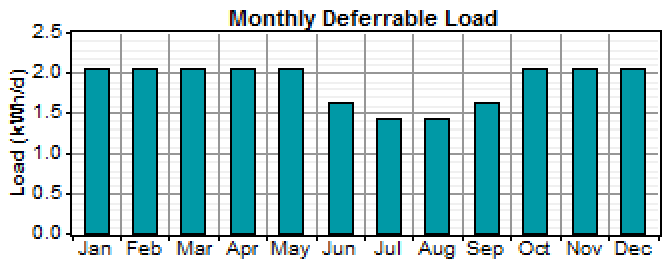


Figure 3-2 Deferrable load profile

3.3. Population growth and load forecasting

The population of Ethiopia accounts all residents regardless of legal status or citizenship except for refugees not permanently in the country of asylum, which are generally considered part of the population of the country of origin. The annual population growth rate for year t is the exponential rate of growth of midyear population from year t-1 to t, expressed as a percentage. Based on this formula different annual growth rate for different years are reported by the World Bank. The World Bank report released in 2009, 2010 and 2011 shows that the annual population growth of Ethiopia was 2.20, 2.17 and 2.15 for the years 2008, 2009 and 2010 respectively. The numbers show us the decrease in annual growth rate from year to year. Figure 3-3 shows the total population of Ethiopia. Figure 3-2 shows the annual population growth rate in rural areas of Ethiopia where the vertical axis (y-axis) indicates the annual growth rate of the population in percentage and horizontal axis (x-axis) indicates the year. But as it can be seen in figure 3-4 the growth rate has decreased sharply around 1980's. This is due to the drought that occurred in the country has become the cause for the death of many children. Moreover, the rural population as a percentage of the total population is also released in 2009, 2010 and 2011 in the report of the World Bank, and it is 83, 82.70 and 82.40 for the years 2008, 8009 and 2010 respectively. The average annual rural population growth rate of Ethiopia is reported to be 1.9% [22, 23].

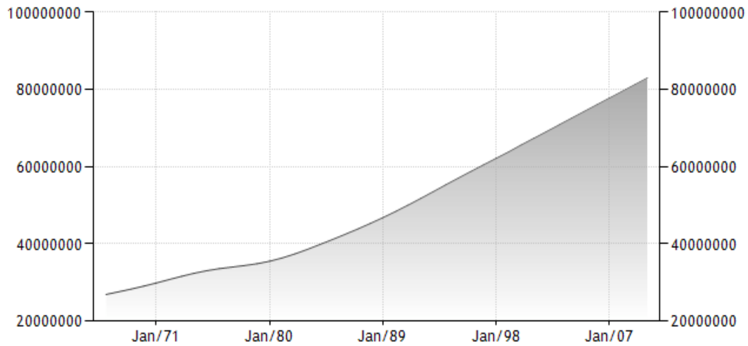


Figure 3-3 Total population of Ethiopia [22, 24]

The formula used for population forecasting is [24]:

$$P_n = P_0 \left(1 + \frac{r}{100}\right)^n \qquad \text{Eqn. 3-1}$$

Where: P_n is population at the n^{th} year

P_0 is the current population

r is annual population growth rate in %

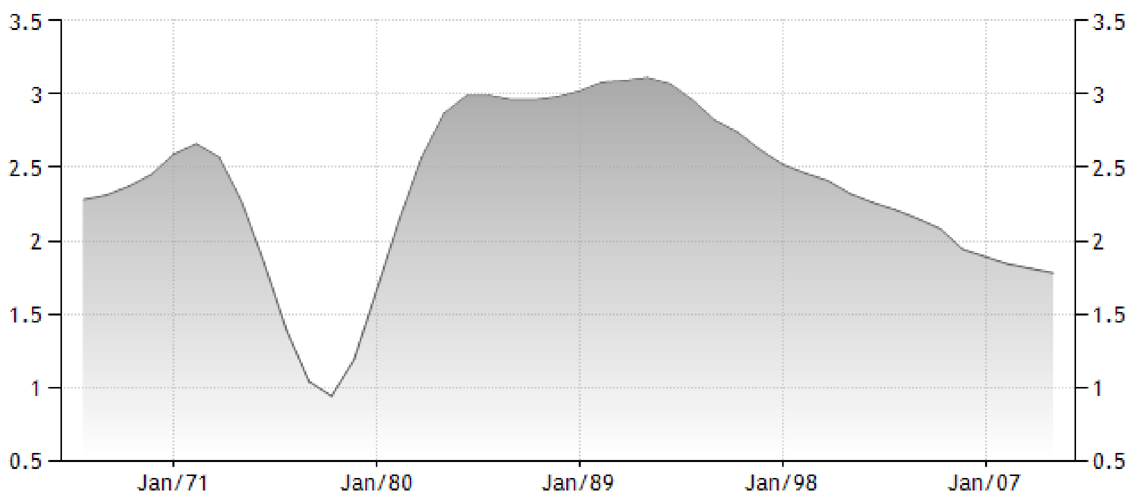


Figure 3-4 Annual population growth rates in rural areas of Ethiopia [22, 24]

a. Primary load forecasting

The load forecasting is done for the two load estimations separately. It is obvious that previously recorded data’s are required as an input to conduct load forecasting using different techniques.

But since the selected area is not electrified so far the previous data are extracted by using the load forecasting method which is in use by universal electric access program (UEAP). This is a governmentally owned company endowed in supplying electric access to rural areas by extending the national grid. The annual load growth rate is 5% which is calculated by considering the data taken from previously electrified areas. Hence, a primary load forecasting for the first five years is done using equation 3-2 given below. The current electric load is taken to be 35.98KW which is calculated by considering efficient lamps as shown in table 3-7.

$$E_n=E_0\left(1+\frac{r}{100}\right)^n \qquad \text{Eqn. 3-2}$$

Where: E_n is electric load at the n^{th} year

E_0 is the current electric load

r is the annual electric load growth (i.e. 5%) [20]

The result of this analysis is shown in table 3-8 below. These values are then used as input to forecast for the coming 20 years using the exponential method of forecasting.

Table 3-8 Results of primary load forecasting

0	1	2	3	4
35.98	37.779	39.66795	41.65135	43.73391

Thus, the principle of regression theory is used to forecast the load for the coming twenty years by using the results in table 3-8 as a previous data. Its principle is that any function y=f(x) can be fitted to a set of points (x_1,y_1), (x_2,y_2) so as to minimize the sum of errors squared at each point, i.e.

$$\sum_{i=1}^{n}\{y_i-f(x_i)\}^2=\text{minimum} \qquad \text{Eqn. 3-3}$$

Among the different typical regression curves used in power system forecasting the simple least square line is used for forecasting the load in this thesis. The line $y=a_0+ax$ is fitted to the sets of points (x_1,y_1), $(x_2,y_2)\ldots(x_n,y_n)$

$$\varepsilon^2=\sum_{i=1}^{n}[y_i-(a_0+a_1x_i)]^2=\text{minimum} \qquad \text{Eqn. 3-4}$$

Partial differentiation with respect to the regressions coefficients (a_0 and a_1) is made and the equations set to zero to obtain the minimum error criterion. This gives us a set of simultaneous equations in a_0 and a_1[25]:

For a_0: $2\sum[y_i-(a_0+a_0x_i)]=0$, we get,

$$\sum a_0 + a_1 \sum x_i = \sum y_i$$

$$Na_0 + a_1 \sum x_i = \sum y_i$$

For a_1: $2\sum[y_i-(a_0+a_1x_i)]x_i=0$

$$a_0 \sum x_i + a_1 \sum x_i^2 = \sum x_i y_i$$

Which yield

$$a_0=\frac{(\sum y)(\sum x^2)-[\sum (x)].\sum xy}{N\sum x^2-(\sum x)^2} \qquad \text{Eqn. 3-5 (a)}$$

$$a_1=\frac{\mathbf{N\sum xy-(\sum x).(\sum y)}}{\mathbf{N\sum x^2-(\sum x)^2}} \qquad \text{Eqn. 3-5 (b)}$$

Table 3-9 Results of the analysis

Year	Peak demand	x_i	$pDi=\frac{\text{peak Demand}}{10}$	$y_i=\ln^{pDi}$	x_iy_i	x_i^2
2011	35.98	-2	3.598	1.280378	-2.56076	4
2012	37.779	-1	3.7779	1.329168	-1.32917	1
2013	39.66795	0	3.966795	1.377958	0	0
2014	41.65135	1	4.16513475	1.426749	1.426749	1
2015	43.73391	2	4.373391488	1.475539	2.951078	4
		$\sum x_i=0$		$\sum y_i=6.889792$	$\sum x_iy_i=0.487902$	$\sum x_i^2=10$

a_0	a_1	x_i
1.377958464	0.04879	22

Finally, the values in table 3-9 are used to determine the load of the selected area in 2035 G.C. The forecasting is then done using equation 3-6 (a) and (b) shown below by considering 2013 as a reference year. Therefore, the load is obtained to be 116.04 kW.

$$Y=a_0+a_1.x_i \qquad \text{Eqn. 3-6 (a)}$$

$$P_n=10e^Y \qquad \text{Eqn. 3-6 (b)}$$

b. Deferrable load forecasting

Here the total population of the area after twenty five years is calculated using equation 3-1. The present value of the total population of the selected site is 4364 and the annual growth rate is 1.9%. Based on these data the total population and households of Awlio village after twenty five year is found to be 6986 and 1588 respectively. As per the data taken from the wereda administration only 120 of 992 households of the village are living in Kutur kebele. Therefore, the number of households of kutur after twenty five years will be 192. Thus, the total water consumption will be 23200 l/day, and the number of hours required to supply the daily water consumption will be around 2.4 hrs. As a result, the daily deferrable load and its energy equivalent of the reservoir capacity will be 2.88kWh/day and 8 kWh respectively. The energy equivalent of the reservoir is kept constant assuming that the size of the storage tank is not changed since it depends on the plan of the wereda administrator. This will then serve for only two days and 18 hours.

4. Modeling of the hybrid system and cost analysis of grid extension

4.1. Modeling the hybrid system

As it is shown in the assessment of solar radiation, Axum has a monthly average solar radiation varying between a minimum value of 5.09KWh/m^2 and a maximum value of 7.13KWh/m^2 with annual average of 6.19KWh/m^2. Similarly, the monthly average wind speed of Axum varies between 3.13m/s and 5.42m/s at a height of 10m with annual average of 4.28m/s. These numbers indicate that the area has a potential for implementing PV-wind hybrid system to give electric access to the community of Kutur kebele which is found in Axum district. However, the investment cost of PV and wind turbine have always been the main barrier to the use of the hybrid system for small scale as well as large scale applications. But this time the cost of PV system as well as wind turbine is decreasing, while the price of oil is increasing in addition to the depletion of oil resource. This can encourage developing countries like Ethiopia which have good resources in both systems to use stand-alone hybrid system for supplying electricity to the remote rural areas. The current total investment cost of PV has reduced to the range of 2508 to 2682 $/kWpeak, and for that of wind it has reduced to 1100$/kW [26]. Therefore, since current electricity grid coverage of Ethiopia is around 35% [1], the hybrid system can be competitive irrespective of its initial capital cost when considering the rapid increase in oil price and the shortage of electric supply. In addition to these, the hybrid setup has negligible impact on global and local environment.

On the other hand, solar as well as wind power are becoming a serious candidate in electricity market due to increasing oil prices and substantial increase in manufacturing capacity of wind turbine and solar modules [27]. According to the green energy report released in Denmark, an estimated 23.9 GW of cells and 20 GW of modules were produced in 2010 by the solar PV industry. Moreover, the total global capacity of wind power and solar photovoltaic power has reached 198 GW and 40 GW respectively [27]. These figures can encourage developing countries like Ethiopia which have good potential in wind as well as PV to look in to the possibility of using these resources for electrifying remote areas which are far away from the national grid. But the PV-wind hybrid system may not be sufficient to supply energy on 24 hours for the whole years, and therefore has to be supported by generator and batteries which can be used as a backup for supplying sustainable electricity using hybrid setup. In addition to this, it can minimize the investment cost of the setup since the cost of generators varies between 200 $/kW and 228 $/kW [21, 28].

The main objective of this work is to assess resource potential and to model PV-Wind hybrid system with generator and battery as a back up to electrify 120 households of Kutur kebele, and the model is also simulated for the load at the end of the life span of the project which is obtained using simple load forecasting. Additionally, it will compare the initial capital cost of the hybrid system against the cost required for extending a grid.

The components of the hybrid model are PV, Generator, Fuhrlander 30 wind turbine, S4KS25P battery, converter, primary load and deferrable load. The wind turbine and battery are taken from the types already loaded on the software.

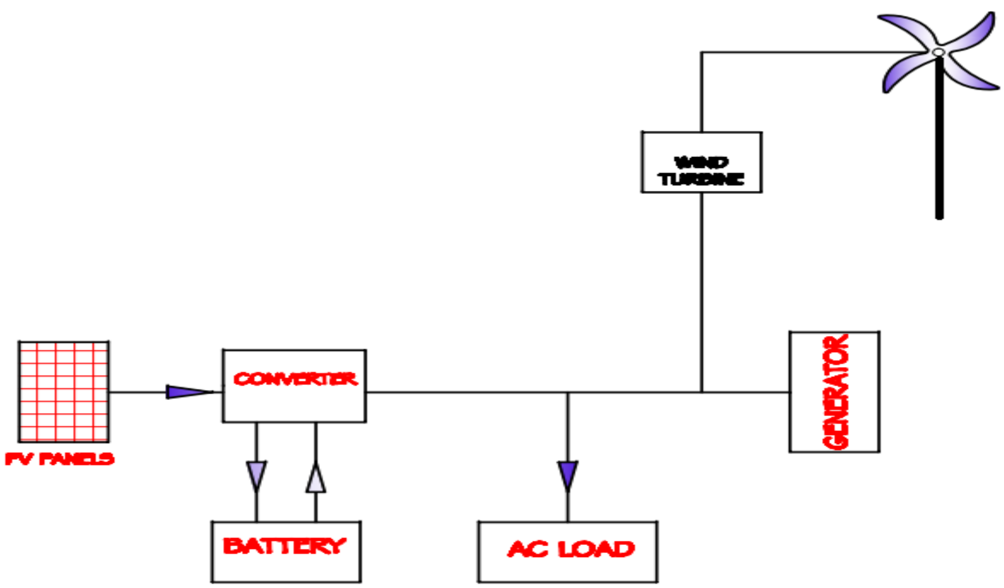


Figure 4-4 Model of the hybrid setup

4.2. Inputs to the software

One of the main purposes of this work is to simulate the PV-Wind hybrid setup using diesel and storage battery as a back up to get a best optimized system to give electric access to the people living in Kutur kebele. The best optimization will be selected by considering the total net present cost, contribution of renewable energy technologies and energy cost. The simulation of the hybrid model is done using Hybrid Optimization Model for Energy Renewable (HOMER) software, and this needs different input parameters for different energy sources and components of the model.

Table 5-1 Inputs to the software

Item	Size	Capital($)	Replacement ($)	O & M cost($)	Sizes(KW) considered	quantities considered	lifetime
AC wind turbine (Fuhrlander 30)	30KW	33000	24750	660		0-4	25 years
AC Generator	12KW	4000	2560	0.15	0,12,24,36, 48, 60		30000h
PV	1KW	2625	2625	0	0-100		25 years
Battery(S4KS2P)	1900Ah	1250	1100	25		0-100	
Converter	1KW	800	750	8	0-100		15 years

Photovoltaic as one components of the model it needs lifetime, capital cost, replacement cost and operating and maintenance cost per year as an input. Moreover, different PV sizes can then be added on the size to consider button to get different possible options for optimization.

The capital cost for PV module is taken to be 2625$/kWpeak [26]. Derating factor of 80% and ground reflectance of 20% without tracking is considered. Additionally, the PV modules are sloped at 14.0 degrees which is the latitude of the selected site. Sizes from 0 to 100kW with an interval of 5kW are used as input in the sizes to consider place for the purpose of optimization.

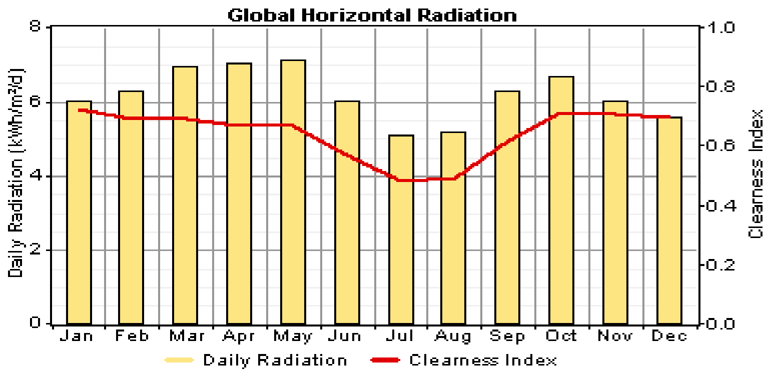


Figure 4-1 Monthly solar radiations in KW/m^2 of Kutur

The capital cost of wind turbine is taken to be 1.1$/W [26]. The Fuhrlander 30 wind turbine with rated power of 30kW AC and cut in speed of 3m/s is used for simulation from the turbine types available in the software since it has the lowest cut in speed. The cut in speed of this turbine is below the lowest monthly average wind speed of the selected village. Moreover, quantities from 0 to 4 are used as an input in the sizes to consider for the purpose of optimization.

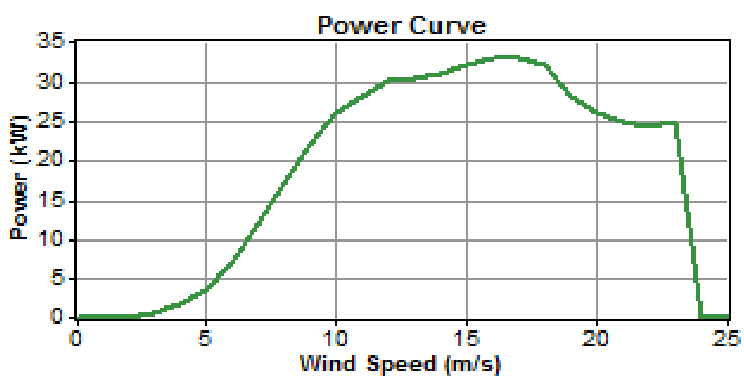


Figure 4-2 The power curve of Fuhrlander 30

Similarly, the capital cost for the converter, battery and generators are fed to the software. In addition to these, an operating reserve of 10% of hourly load, 25% of solar output power and 50 % of wind power output respectively is suggested for the hybrid setup. To account greenhouse effect, a $20/t of penalty for CO_2 emission is considered. Maximum annual energy shortage and minimum renewable fraction are set to 10% and 0% respectively. Interest rate of 14% and 25 years project life time is used for present cost analysis.

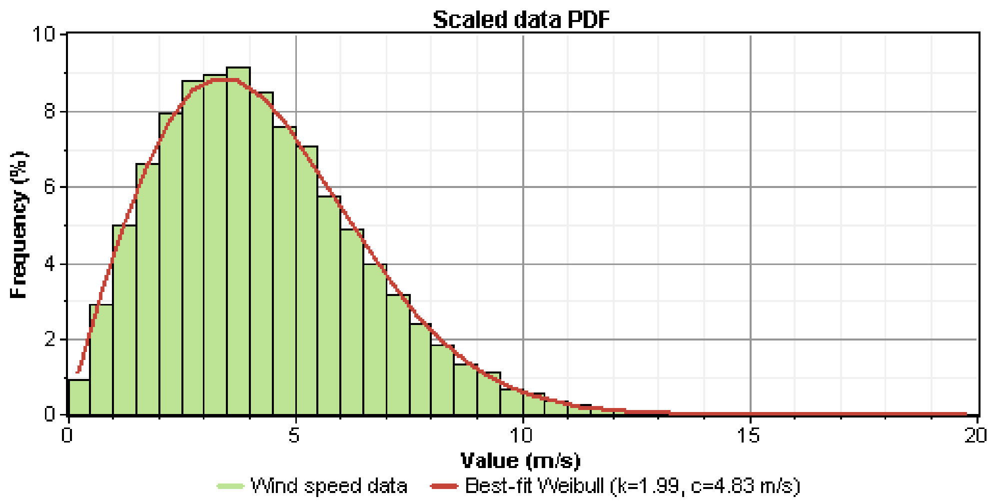


Figure 4-3 Probability density function of wind speed at 10m height

Both cyclic charge (CC) and load follow (LF) dispatch strategies are considered. The load following strategy is a dispatch strategy whereby whenever a generator operates; it produces only enough power to meet the primary load. Lower-priority objectives such as charging the battery bank or serving the deferrable load are left to the renewable power sources. The cyclic charging strategy is a dispatch strategy whereby whenever a generator needs to operate to serve the primary load, it operates at full output power. Surplus electrical production goes toward the lower-priority objectives. This surplus power will serve the deferrable load and charge the battery bank in order of decreasing priority [9].

4.3. Cost analysis of grid extension

Power is transmitted to the end users through distribution lines. The mission of Universal Electric Access Program (UEAP) is delivering power to the consumers found in the remote rural areas of the country. This is mainly done by extending the national grid from a near-by substation or from an over head medium voltage (MV) distribution line. The medium voltage levels that are most commonly used in MV line construction by the UEAP are 33KV, 19KV and 15KV. This time the UEAP is using the 33KV voltage level for electrifying the remote rural areas due to its advantage over the other options.

The main components of an overhead distribution line that can affect the cost of grid extension are: the line supports and their foundation, insulators, line accessories, conductors and overhead earth wires. The line supports can be wooden (like local wooden pole and South Africa pole), reinforced concrete pole and steel, but due to its strength and availability UEAP is using concrete poles for MV distribution line to give electric access for the people of rural areas.

The main tasks during line extension are surveying, excavation, pole erection, pole top configuration and stringing of conductors. For the MV distribution line construction All Aluminum Alloy Conductor with a size of 95mm^2 and 50mm^2 are used. However, the number of poles to be erected and the requirement of angle assemblies depend on the distance of the site from a nearby substation or MV distribution line, and geographical location of the selected site. Moreover, different accessories are used depending on type of assemblies. The assemblies that can be used in the construction are suspension, light angle 1, light angle 2, heavy angle, T-off, tension tower, and dead-end. These are classified based on the angle deviation from a straight line [20].

Based on the note mentioned earlier, the cost estimation for delivering electric access to Kutur village which is found in Axum is done. The distance of Kutur from an existing grid (i.e. Axum) is 30km, and based on this distance a rough survey is conducted to select the best route, and to identify the type of assemblies to be used for MV distribution line construction during the site visit. The power demand of the community and the rating of the transformers are estimated by the standard Excel sheet the UEAP is using now. As a result, the number of transformers needed for the community is obtained to be 1x50KVA and 1x100KVA.

Therefore, to give electric access to the 120 households, HC, FTC, flour mill, kebele administration and primary school of Kutur from the national grid found nearby, it needs extension of 30 km MV line and erection of two transformers with a rating of 1x50KVA and 1x100KVA. Hence, the cost is analyzed using an interlinked spread Microsoft excel sheet used by the UEAP; and the result obtained is as shown in table 4-1. The total cost includes material, transportation and labor cost. The investment cost is therefore obtained to be 5,007,181.05 Ethiopian birr which is equivalent with 285,309.5 US dollar.

Table 4-1 Cost estimation for grid extension

Description of Work: **Construction of 30km33KV with concrete pole, Erection of 1X50KVA , 1X100KVA , Transformers**

DESCRIPTION	SALARY AND WAGE	ALLOWANCE	TRANSPORT	MATERIAL	TOTAL
33KV LINE EXTENSION	555,518.52	678,967.08	339,100.20	2,809,915.63	4,383,501.43
1 X50KVA ERECTION	2,589.10	3,164.46	3,371.28	51,436.63	60,561.47
0 X200KVA ERECTION	0.00	0.00	0.00	0.00	0.00
1 X100KVA ERECTION	2,589.10	3,164.46	3,371.28	55,624.75	64,749.59
0 X25KVA ERECTION	0.00	0.00	0.00	0.00	0.00
2 X LOAD BREAK SWITCH	3,033.40	3,707.48	1,838.28	34,591.12	43,170.28
LV LINE EXTENSION	0.00	0.00	0.00	0.00	0.00
TOTAL	**563,730.12**	**689,003.48**	**347,681.04**	**2,951,568.13**	**4,551,982.77**
	INTEREST TO BE CAPITALIZED				
	OVER HEAD COST (10%)				455,198.28
	TOTAL COST				5,007,181.05
	RECHARGABLE/RECOVERABLE AMOUNT (**Contributions*)				
	NET TOTAL				5,007,181.05

5. Results, Discussion and Conclusion

5.1. Results of the simulation

The simulation result window of HOMER displays the components of the system and three outputs (i.e. the total net present cost, levelized cost of energy, and operating cost). In addition, the window has cost summary tab which displays the total cash flow, categorized either by component or by cost type, and electrical tab which displays details about the production and consumption of electricity by the system. The other tabs are PV, wind turbine, generator, grid, battery, converter and emissions.

HOMER simulates every system in the search space and ranks all feasible systems according to increasing net present cost, and displays the result in the optimization tab. The list of the optimization results which are capable of meeting the system load and constraints are then displayed in overall form and categorized form. In the overall form the top ranked system configuration (i.e. a combination of a particular numbers and size of components) according to the net present cost (NPC) are displayed. However, in the categorized form only the least-cost systems for each system configuration are displayed.

In the optimization result it can be observed, size of different components in each system configuration and their symbols, dispatch strategy, initial capital, operating and maintenance cost, total NPC, COE, renewable fraction and shortage capacity. Moreover, the consumption of diesel and operating hours of the generators can also be easily observed.

A sensitivity analysis is also done to get an answer for the effect of input variables having dynamic nature. It takes the most cost effective system configuration for each combination of sensitive variable values. The results of this analysis can be displayed either in a graphic or tabular form. In this work PV capital cost multiplier linked with PV replacement cost multiplier, wind speed and diesel price are used as sensitivity parameters for sensitivity analysis, even though, there are a lot of parameters to be considered.

Therefore, HOMER is used for simulating the hybrid system containing PV, wind, converter, diesel and storage battery. To get optimal combination of the hybrid components which could be implemented as a hybrid system for supplying electricity to the community of Kutur kebele, the setup was run repeatedly using different values for the most important variables. The diesel price is taken to be 1.1$/liter which is the current price within the country. The rate of interest is also taken to be 14% and project life time is 25 years.

The simulation is done for two different loads as already estimated in section 3-3. The first case is done by considering incandescent lamp of 60W for lighting system refer table 3-6.

Table 5-1 Results of the first case in categorized form

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
35	2		40	30	CC	231,875	4,783	278,856	0.284	1	0.09		
20	2	12	20	20	LF	163,500	11,959	280,965	0.281	0.89	0.09	7,480	2,821
	3	12	40	30	LF	177,000	11,983	294,702	0.299	0.92	0.1	5,643	1,871
70		12	40	30	LF	261,750	11,995	379,574	0.388	0.87	0.09	7,286	2,687
85			70	30	CC	334,625	5,475	388,403	0.397	1	0.09		
	3	24			LF	107,000	28,869	390,568	0.372	0.77	0.02	22,706	4,556
10	2	24		10	LF	108,250	29,795	400,911	0.381	0.71	0.01	23,767	4,894
30		24		20	LF	102,750	36,379	460,089	0.438	0.42	0.02	30,329	5,790
		24			LF	8,000	48,485	484,251	0.474	0	0.08	41,312	6,935
		24	10	10	LF	28,500	47,236	492,476	0.482	0	0.08	39,486	6,572

As a result, the outputs from the software are obtained as shown in table 5-1 and table 5-2 for the categorized and overall form respectively. But as the list for the overall result is long, part of it has been truncated keeping only those of greatest interest. As it can be seen in table 5-1, the optimum results displayed in the overall form have different possible combinations of PV, Wind, generator, battery and converter. The whole result of the overall form is then shown in appendix A.

The data tabulated in table 5-1 and 5-2 for the first load estimation indicates the optimization results which are candidate for implementation. They are ranked in their ascending order according to increasing total net present cost (NPC). The PV/wind/battery setup is ranked first in both cases since it has the least NPC as compared with the other possible optimal results. The total NPC of the optimized result ranked first is 278,856$, and its COE and renewable fraction are 0.284$/kWh and 100% respectively with a capacity shortage of 9%.

Table 5-2 Results of the first case in the overall form

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital $	Operating cost ($/yr)	Total NPC $	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
35	2		40	30	CC	231,875	4,783	278,856	0.284	1	0.09		
35	2		40	30	LF	231,875	4,783	278,856	0.284	1	0.09		
20	2	12	20	20	LF	163,500	11,959	280,965	0.281	0.89	0.09	7,480	2,821
15	2	12	30	30	LF	170,875	11,476	283,600	0.284	0.9	0.09	6,329	2,185
15	2	12	30	20	LF	162,875	12,309	283,779	0.283	0.89	0.08	7,200	2,766
20	2	12	20	30	LF	171,500	11,490	284,361	0.285	0.9	0.09	6,883	2,432
45	1		50	30	CC	237,625	4,794	284,711	0.292	1	0.1		
45	1		50	30	LF	237,625	4,794	284,711	0.292	1	0.1		
30	2		50	30	CC	231,250	5,454	284,819	0.289	1	0.09		
30	2		50	30	LF	231,250	5,454	284,819	0.289	1	0.09		
45	2		30	30	CC	245,625	4,112	286,019	0.291	1	0.09		
45	2		30	30	LF	245,625	4,112	286,019	0.291	1	0.09		
20	2	12	30	30	LF	184,000	10,412	286,276	0.284	0.92	0.07	5,415	1,919
25	2	12	20	20	LF	176,625	11,256	287,186	0.284	0.91	0.07	6,852	2,685
10	2	12	40	30	LF	170,250	11,995	288,069	0.29	0.89	0.1	6,210	2,085
25	2	12	20	30	LF	184,625	10,565	288,401	0.287	0.92	0.08	6,053	2,190
35	1	12	20	30	LF	177,875	11,286	288,735	0.293	0.87	0.1	7,278	2,609
10	3	12	20	20	LF	170,250	12,069	288,794	0.289	0.92	0.09	7,034	2,569
20	2	12	30	20	LF	176,000	11,508	289,038	0.285	0.91	0.06	6,503	2,622
35	2		40	40	CC	239,875	5,043	289,411	0.294	1	0.09		
35	2		40	40	LF	239,875	5,043	289,411	0.294	1	0.09		
25	2	12	30	30	LF	197,125	9,449	289,941	0.286	0.93	0.06	4,589	1,679
5	3	12	30	20	LF	169,625	12,272	290,167	0.291	0.92	0.09	6,629	2,480
10	2	12	40	20	LF	162,250	13,041	290,343	0.291	0.89	0.09	7,254	2,775
15	2	12	40	30	LF	183,375	10,896	290,401	0.289	0.92	0.08	5,264	1,824
25	2		60	30	CC	230,625	6,124	290,781	0.296	1	0.1		
25	2		60	30	LF	230,625	6,124	290,781	0.296	1	0.1		
5	3	12	30	30	LF	177,625	11,604	291,602	0.294	0.92	0.1	5,883	1,994
30	1	12	30	30	LF	177,250	11,651	291,691	0.295	0.87	0.1	7,016	2,535

Similarly, simulation is done for the second case where the load is estimated by considering CFL as efficient lamp for lighting (refer table 3-8). In the same manner, the results of the simulation are displayed in a tabular form as shown in table 5-3 and 5-4 for the overall and categorized form respectively. However, since the list of the optimization results displayed in the overall form is long, part of it has been truncated keeping only those of greatest interest. However, the full list of this result is shown in appendix B.

Table 5-3 Results of the second case in overall form

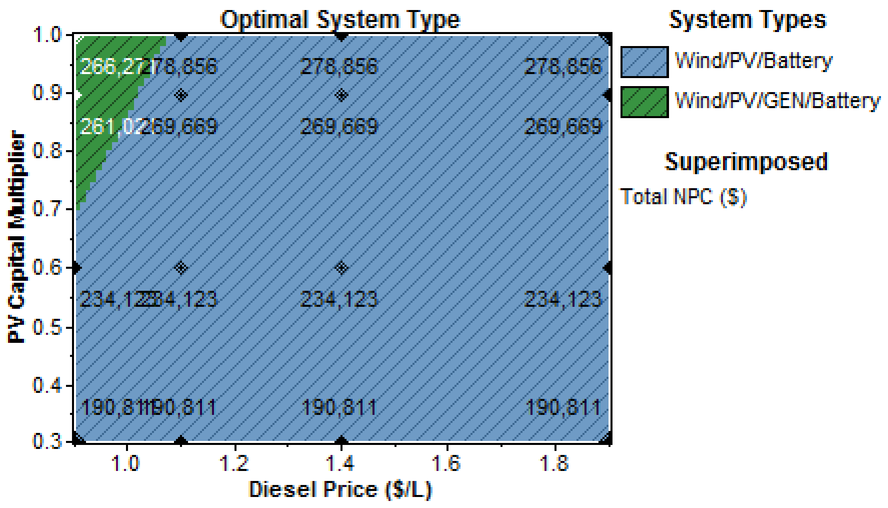
PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
5	2	12	10	10	LF	$103,625	13,175	$194,174	0.345	0.85	0.1	9,005	3,395
15	1	12	10	10	LF	$96,875	14,782	$198,470	0.346	0.77	0.08	10,818	4,151
10	1	12	20	10	LF	$96,250	15,085	$199,926	0.352	0.75	0.09	10,591	4,020
5	2	12	20	10	LF	$116,125	12,209	$200,037	0.35	0.87	0.07	7,736	2,962
5	2	12	10	20	LF	$111,625	12,882	$200,162	0.357	0.86	0.1	8,588	3,180
10	2	12	10	10	LF	$116,750	12,298	$201,271	0.35	0.87	0.07	8,283	3,195
5	2	12	20	20	LF	$124,125	11,281	$201,657	0.355	0.88	0.07	6,823	2,546
15	1	12	20	10	LF	$109,375	13,669	$203,322	0.352	0.79	0.07	9,437	3,658
20	1	12	10	10	LF	$110,000	13,613	$203,559	0.353	0.8	0.07	9,863	3,864
	2	12	30	10	LF	$115,500	12,889	$204,087	0.361	0.86	0.08	7,810	2,956
40	1		20	30	CC	$187,000	2,509	$204,243	0.368	1	0.1		
40	1		20	30	LF	$187,000	2,509	$204,243	0.368	1	0.1		
	2	12	30	20	LF	$123,500	11,768	$204,380	0.365	0.88	0.08	6,739	2,499
10	1	12	20	20	LF	$104,250	14,577	$204,436	0.361	0.76	0.09	10,017	3,745
15	1	12	10	20	LF	$104,875	14,660	$205,631	0.358	0.77	0.08	10,547	4,030
15	1	12	20	20	LF	$117,375	13,025	$206,894	0.358	0.8	0.06	8,746	3,367
10	2	12	10	20	LF	$124,750	11,973	$207,040	0.361	0.88	0.07	7,826	2,970
10	2	12	20	10	LF	$129,250	11,350	$207,257	0.358	0.89	0.05	7,032	2,755
10	2	12	20	20	LF	$137,250	10,226	$207,533	0.358	0.9	0.05	5,955	2,307
35	1		30	30	CC	$186,375	3,105	$207,712	0.371	1	0.09		
35	1		30	30	LF	$186,375	3,105	$207,712	0.371	1	0.09		
	3	12	10	10	LF	$123,500	12,277	$207,877	0.372	0.9	0.1	7,743	2,894
15	2	12	10	10	LF	$129,875	11,376	$208,064	0.358	0.89	0.05	7,529	2,969
20	1	12	20	10	LF	$122,500	12,565	$208,859	0.361	0.82	0.06	8,536	3,374
5	2	12	30	20	LF	$136,625	10,567	$209,250	0.365	0.9	0.06	5,753	2,200
20	1	12	10	20	LF	$118,000	13,282	$209,288	0.359	0.81	0.05	9,411	3,739

The data tabulated in table 5-3 and 5-4 for the second load estimation also indicates the optimization results which are candidate for implementation and this are also ranked in their ascending order according to increasing NPC. The PV/wind/Generator/battery setup is ranked first in both cases since it has the least NPC as compared with the other possible optimal results. In this case, the total NPC of the optimized result ranked first is 194,174$ which is 84,682$ less than the total NPC of the optimized result ranked first in the first case, and its COE and renewable fraction are 0.345$/kWh and 85% respectively with a dispatch strategy of LF.

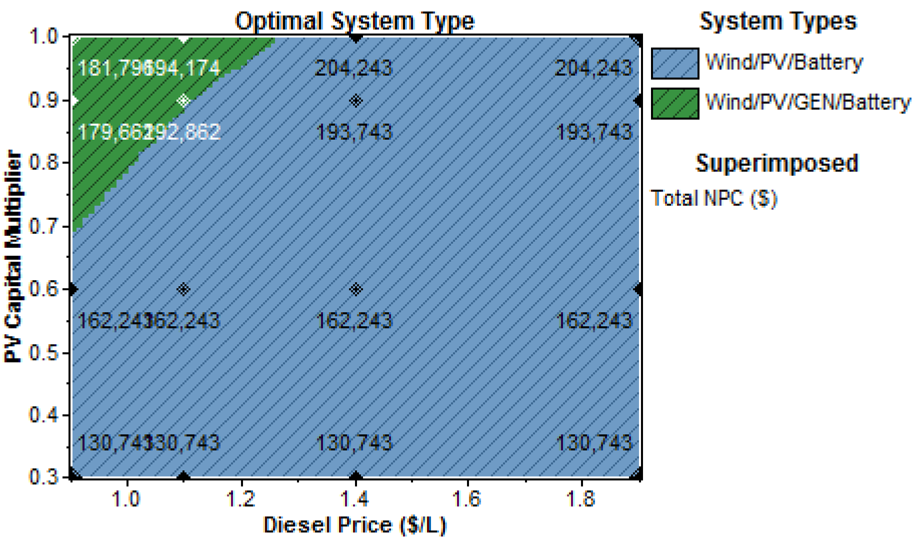
Table 5-4 Results of the second case in categorized form

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
5	2	12	10	10	LF	103,625	13,175	194,174	0.345	0.85	0.1	9,005	3,395
	2	12	30	10	LF	115,500	12,889	204,087	0.361	0.86	0.08	7,810	2,956
40	1		20	30	CC	187,000	2,509	204,243	0.368	1	0.1		
20	1	12		10	LF	97,500	17,872	220,336	0.384	0.74	0.1	13,777	5,320
35		12		20	LF	111,875	20,571	253,258	0.439	0.6	0.08	16,392	5,852
30		12	10	20	LF	111,250	20,810	254,278	0.442	0.57	0.07	16,096	5,786
	4		50	30	CC	218,500	6,276	261,634	0.475	1	0.1		
65			40	40	CC	252,625	3,259	275,026	0.505	1	0.1		
	2	24			LF	74,000	29,382	275,944	0.469	0.71	0.02	22,528	5,046
		24			LF	8,000	44,381	313,030	0.549	0	0.08	35,906	6,935
		24	20	10	CC	41,000	40,714	320,824	0.543	0	0	32,353	4,870

Finally, sensitivity analysis is carried out by varying the wind speed between 2.5 and 5 m/s. In the same manner, the price of diesel oil is varied between 0.9 and 1.9 $/l as well as the PV capital cost multiplier which is linked with PV replacement cost multiplier is varied between 0.3 and 1. Therefore, the results for these parameters in graph form are shown in figure 5-1 and figure 5-2 for the respective sensitivities of PV capital cost multiplier and wind speed to the price of diesel.

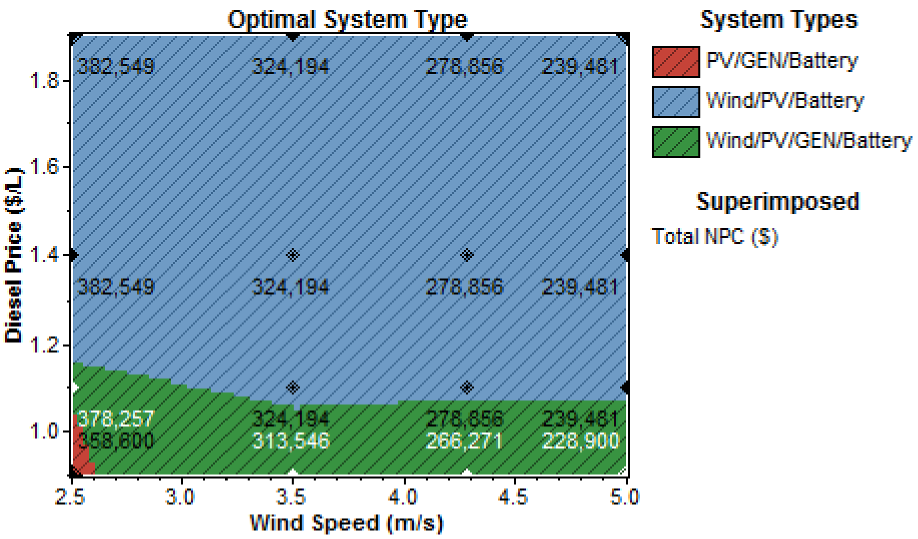


(a)

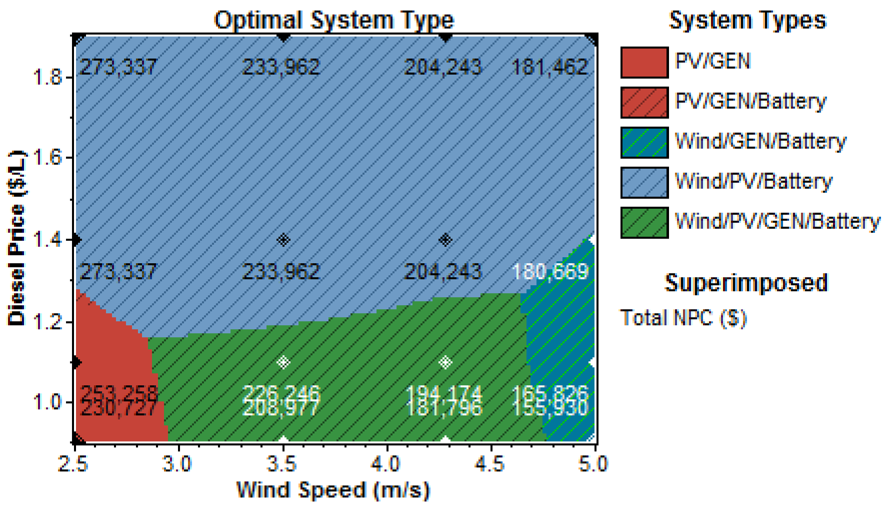


(b)

Figure 5-1 Sensitivity of PV capital multiplier to diesel price (12) (a) for incandescent lamps, (b) for efficient lamps



(a)



(b)

Figure 5-2 Sensitivity of wind speed to diesel price (12) (a) for incandescent lamps, (b) for efficient lamps

The results explained so far are based on the present load of the community of the selected site. But this is not sufficient to decide the overall investment cost required to implement the hybrid setup since the project is planned to supply power for the community for 25 years without any capacity shortage that occurs due to annual increase in demand of the community. Hence, load forecasting is done using simple load forecasting technique to fulfill the gap to some extent. The data's in table 5-5 show the optimized results of the hybrid setup after load forecasting.

Table 5-5 optimized result after load forecasting

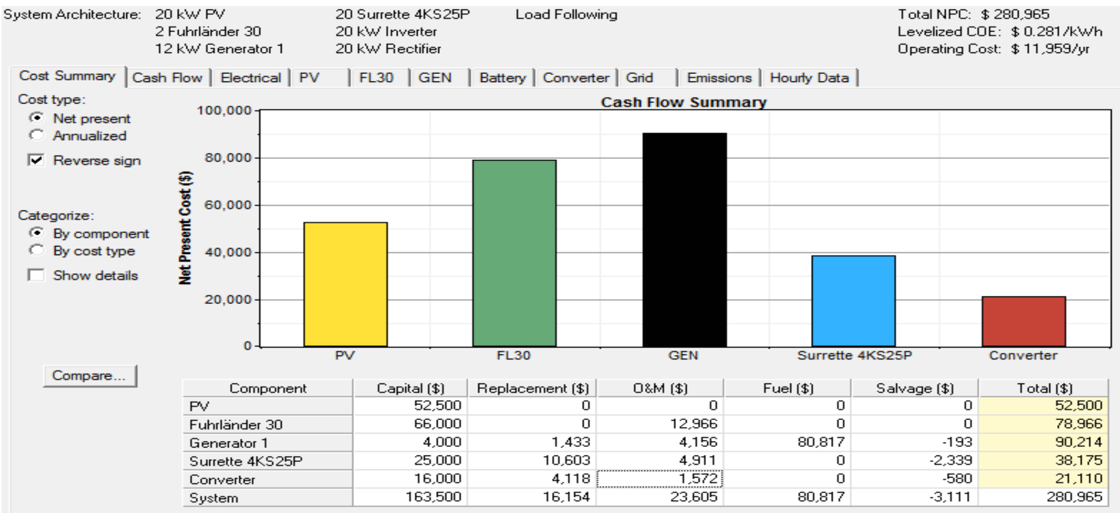
PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
105	4	12	60	70	LF	542,625	16,314	702,871	0.26	0.96	0.1	6,732	2,284
120	4		80	90	CC	619,000	10,346	720,627	0.27	1	0.1		
	8	36	80	40	LF	408,000	36,817	769,637	0.29	0.9	0.1	21,518	2,559
80	4	36		40	LF	386,000	50,106	878,167	0.32	0.8	0.1	39,326	4,977
115		36	30	60	LF	399,375	59,869	987,445	0.36	0.62	0.08	48,056	5,351
	7	60			LF	251,000	75,878	996,314	0.37	0.75	0.09	59,957	5,000
85		48		50	LF	279,125	81,861	1,083,213	0.4	0.47	0.1	68,439	6,090
		60	60	20	CC	111,000	125,416	1,342,905	0.5	0	0.09	103,887	5,839
		84			LF	28,000	147,427	1,476,116	0.54	0	0.07	124,346	6,935

5.2. Discussion

Looking at a few setup listed in the overall form (refer table 5-2 and 5-3) we find the following interesting results. The most cost effective system with the lowest net present cost is the PV-wind-battery setup for the first case, where the battery operates using a cycle charging (CC) strategy. Here the battery operates at full output power to serve the primary load, and any surplus electrical production goes toward the lower priority objectives. For this setup, the total net present cost (NPC) is $278,856, the cost of energy (COE) is 0.284 $/kWh and has 100% contribution from renewable energy resources with a capacity shortage of 9%. But for the second case the most cost effective setup which is ranked first is the PV/Wind/Generator and Battery setup, and the generator and battery operates using load following (LF) strategy which produces only enough power to meet the demand. However, serving the deferrable load is left to the renewable resources. This setup has a total net present cost of $194,174, COE of 0.345$/kWh and has 85% renewable fraction with a capacity shortage of 10%. In addition to these, it uses 9,005 l diesel for the generator. Similarly, the second cost effective option for the first case has 100% renewable resource contribution, but the battery operates using load following strategy. For this setup, the net present cost (NPC) and cost of energy (COE) are equal with the first option explained earlier. For the case of efficient lamps, the optimized result ranked second is again PV/Wind/Generator and Battery setup with generator and battery operating in LF strategy. The NPC of this setup is 4,296 US dollar higher than the first one and its renewable fraction is 77% which is 8% less than the first option.

On the other hand, the results from the categorized form listed in table 5-1and 5.4 are used to look at the other possible optimum combinations. The wind/Generator/battery and PV/wind/battery setups which have a renewable resource fraction of 86% and 100% respectively are the other possible optimized combinations for the second case which can be candidate for implementation. These setups have NPC of $204,087 and $204,243 as well as COE of 0.361$/kWh and 0.368$/kWh with a capacity shortage of 8% and 10% respectively. Similarly, some of the other optimized combinations for the first case where the primary load is estimated by considering incandescent lamp for lighting are PV/wind/generator/battery and wind/generator/battery setups which have a renewable fraction of 89% and 92% with a capacity shortage of 9% and 10% respectively. Their annual fuel consumption and hours of operation of the generators are 7,480lt and 2,821hrs and 5,643lt and 1,871hrs respectively.

Even though there are other optimal results which can be candidate for implementation only the system report of the selected simulation results are described. Among these the system report of the 89% utilization of renewable resources is described as follows. In figure 5-3 the cost breakdown for hybrid setup containing PV/wind/generator and battery which has 89% renewable fraction is illustrated by a bar-graph. The net present cost of each component is described by a different color, and generator has the maximum NPC among the components of the setup. The table at the bottom of the bar-graph shows the amount of the capital and salvage value for each component.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	52,500	0	0	0	0	52,500
Fuhrländer 30	66,000	0	12,966	0	0	78,966
Generator 1	4,000	1,433	4,156	80,817	-193	90,214
Surrette 4KS25P	25,000	10,603	4,911	0	-2,339	38,175
Converter	16,000	4,118	1,572	0	-580	21,110
System	163,500	16,154	23,605	80,817	-3,111	280,965

Figure 5-3 Cost summary by component to the 89% renewable fraction

The contribution of monthly average electric production of PV, wind and generator units for the 89% utilization of renewable resource is shown in figure 5-4. The yellow, dark blue and black colors represent the monthly average electric production of PV, wind and generator respectively. As it can be seen in the figure, generator has the least contribution throughout the year, and wind has the highest contribution dominating all the other sources including PV.

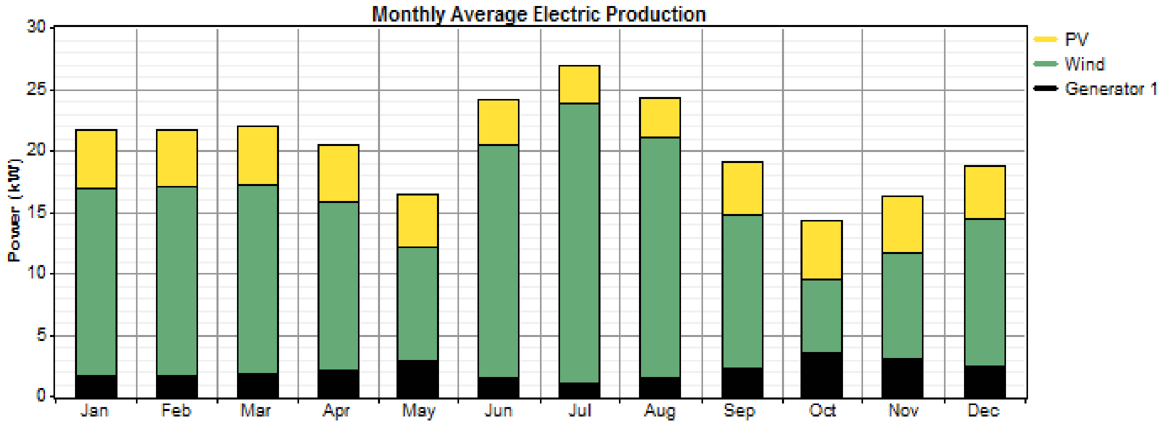
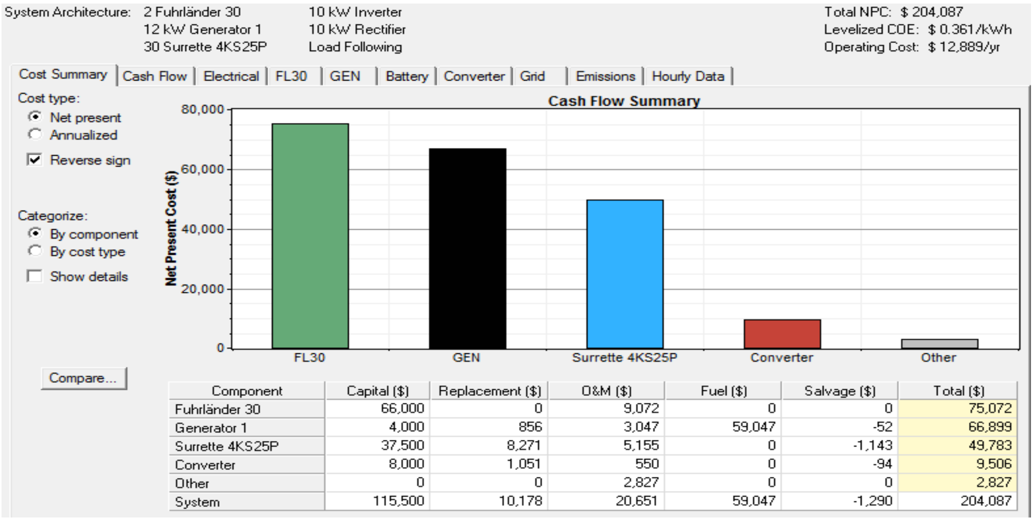


Figure 5-4 Contribution of power units for 89% utilization of renewable resources

Similarly, the system report of the 86% utilization of renewable resources from the second case where the primary load is estimated by considering CFL for lighting is described as follows. The cost breakdown for this hybrid setup which contains wind/generator and battery is illustrated by a bar-graph as shown in figure 5-5. The net present cost of each component is described by a different color, and for this case the wind has the maximum NPC among the components of the setup which has a value of $75,000. The table at the bottom of the bar-graph shows the amount of the capital and salvage value for each component.

The contribution of monthly average electric production of wind and generator units for the 86% utilization of renewable resource is shown in figure 5-6. The dark blue and black colors represent the monthly average electric production of wind and generator respectively. As it can be seen in the figure, generator has the least contribution as compared with the wind which has the highest contribution throughout the year.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
Fuhrländer 30	66,000	0	9,072	0	0	75,072
Generator 1	4,000	856	3,047	59,047	-52	66,899
Surrette 4KS25P	37,500	8,271	5,155	0	-1,143	49,783
Converter	8,000	1,051	550	0	-94	9,506
Other	0	0	2,827	0	0	2,827
System	115,500	10,178	20,651	59,047	-1,290	204,087

Figure 5-5 Cost summary by component to the 86% renewable fraction

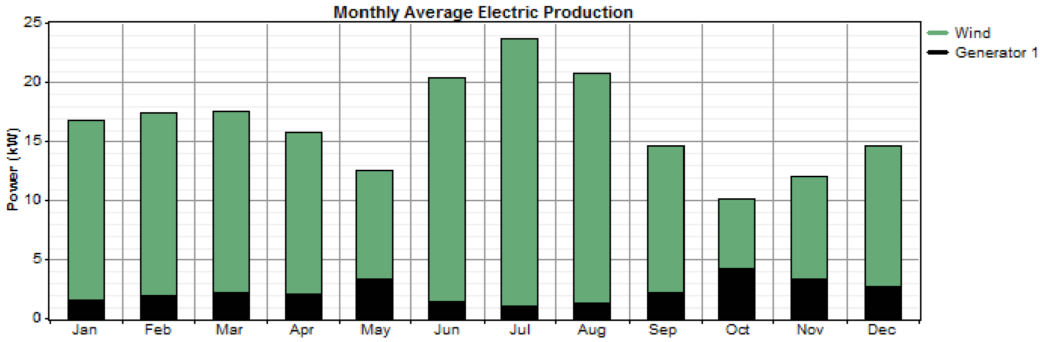
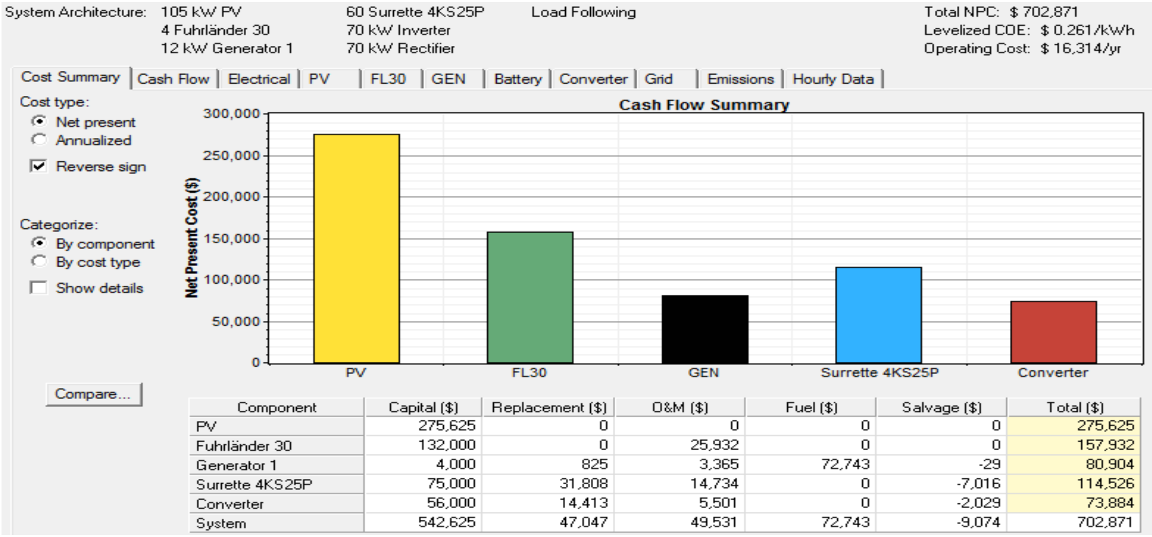


Figure 5-6 Contribution of power units for 86% utilization of renewable resources

In addition to the results described above, the simulation results after load forecasting are described below by referring to table 5-5. The most cost effective system with the lowest net present cost is the PV/wind/generator/battery setup, where the battery operates using a load following (LF) strategy. For this setup, the total net present cost (NPC) is $702,871, and the cost of energy (COE) is 0.261$/kWh with 96% contribution of renewable energy resources. Beside these, its annual oil consumption and working hours of the generator are 6,732 l and 2,284hrs. Similarly, the second cost effective option is PV/wind/battery which has 100% renewable resource contribution, but the battery operates using cycle charging strategy (CC). For this setup the NPC is $ 720,627 and COE is 0.269$/kWh. In both cases, the capacity shortage is 10%.

The system report of the setup which has 96% renewable fraction is described as follows. The cost breakdown for this hybrid setup which contains PV/wind/generator/battery is illustrated by a bar-graph as shown in figure 5-7. The net present cost of each component is described by a different color, and for this case PV has the maximum NPC among the components of the setup which has a value of $275,625. The table at the bottom of the bar-graph shows the amount of the capital and salvage value for each component.



Component	Capital ($)	Replacement ($)	O&M ($)	Fuel ($)	Salvage ($)	Total ($)
PV	275,625	0	0	0	0	275,625
Fuhrländer 30	132,000	0	25,932	0	0	157,932
Generator 1	4,000	825	3,365	72,743	-29	80,904
Surrette 4KS25P	75,000	31,808	14,734	0	-7,016	114,526
Converter	56,000	14,413	5,501	0	-2,029	73,884
System	542,625	47,047	49,531	72,743	-9,074	702,871

Figure 5-7 Cost summary of the set up with 96% renewable fraction

As it can be seen in figure 5-8 below yellow, dark blue and black refers to electric power contribution of PV, wind and generator for the setup with 96% renewable fraction respectively. Except for the months of May, October and November where PV has the highest monthly average electric production wind has the maximum power contribution than the other components of the setup.

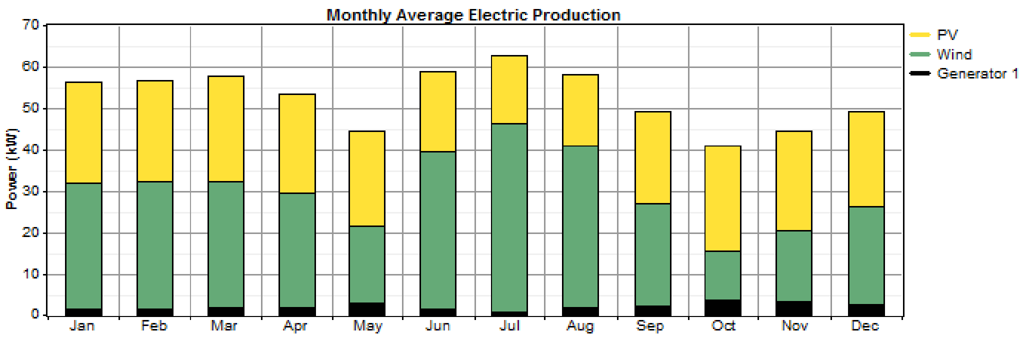


Figure 5-8 Contribution of power units for the setup with 96% renewable fraction

5.3. Conclusion

This thesis work is done firstly to assess solar and wind energy potentials of Kutur kebele. Then, based on these potentials, a feasibility study for a stand-alone hybrid setup electric power supply for the community is done. This is done first by considering the present number of households (i.e. 120), and then a simple load forecasting method is used to consider the change in the electric load of the community with in the life span of the project which is 25 years. In addition to these, its cost is compared against the cost required to electrify the area by extending MV distribution network from the closest national grid.

The solar energy potential of the site is determined based on the data taken from NMSA. Since only sunshine hour data are available, theoretically proved standard formulas are used to convert in to solar radiation to determine the potential of the area. The result is also cross checked against the satellite data obtained from NASA. However, the wind energy potential is taken from NASA since there is no measured data for the selected site in NMSA. From the results, it can be observed that the annual average wind speed of the selected site at ten meter height is 4.28m/s and its annual solar radiation is 6.19kWh/m^2/day. These results demonstrated the availability of extensive utilizable solar and wind energy at the selected location.

The hybrid setup is then simulated using HOMER software in order to select the best optimized result. For improving the viability of the supply the sources are integrated with other energy conversion systems i.e. diesel generator and battery. The results of this study indicate that they can be applicable to villages which have similar climatic conditions.

The feasibility study for the hybrid setup is based on the findings of the wind and solar energy potentials at the particular site. With the potentials determined, two different approaches are followed in the hybrid system design. In the first approach, the present load which is estimated based on the current number of households of the area is used as input for the load profile. In the second approach, the load attained at the end of the life span of the project which is obtained using a simple load forecasting method is used as an input to simulate the hybrid setup.

The results obtained in the second approach have shown that the net present cost is more than three folds of the first one. This has occurred due to the increase in the load of the community.

In the results, numerous alternative feasible hybrid setups, with different levels of contribution by the renewable resources were obtained. Despite the numerous alternatives, the choice is restricted by the varying net present cost, cost of energy and contribution of renewable energy resources of each setup. The cost of energy of the hybrid setup is compared against the current global electricity tariff and the tariff in the country, and it is found that the costs of the feasible setups obtained in the study are higher than the current tariff in the country since the main source of energy is hydropower. However, this will have a great role in alleviating deforestation, prevention of soil degradation and improvement of the quality of life of the many people residing in the area by minimizing the health problems caused by the smokes from fire-wood. Moreover, it will have a considerable effect in minimizing the shortage of power within the country as well as in the reduction of pollutant emissions in to the environment.

Appendix A

Optimized results in overall form for the first case

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
35	2		40	30	CC	231,875	4,783	278,856	0.284	1	0.09		
35	2		40	30	LF	231,875	4,783	278,856	0.284	1	0.09		
20	2	12	20	20	LF	163,500	11,959	280,965	0.281	0.89	0.09	7,480	2,821
15	2	12	30	30	LF	170,875	11,476	283,600	0.284	0.9	0.09	6,329	2,185
15	2	12	30	20	LF	162,875	12,309	283,779	0.283	0.89	0.08	7,200	2,766
20	2	12	20	30	LF	171,500	11,490	284,361	0.285	0.9	0.09	6,883	2,432
45	1		50	30	CC	237,625	4,794	284,711	0.292	1	0.1		
45	1		50	30	LF	237,625	4,794	284,711	0.292	1	0.1		
30	2		50	30	CC	231,250	5,454	284,819	0.289	1	0.09		
30	2		50	30	LF	231,250	5,454	284,819	0.289	1	0.09		
45	2		30	30	CC	245,625	4,112	286,019	0.291	1	0.09		
45	2		30	30	LF	245,625	4,112	286,019	0.291	1	0.09		
20	2	12	30	30	LF	184,000	10,412	286,276	0.284	0.92	0.07	5,415	1,919
25	2	12	20	20	LF	176,625	11,256	287,186	0.284	0.91	0.07	6,852	2,685
10	2	12	40	30	LF	170,250	11,995	288,069	0.29	0.89	0.1	6,210	2,085
25	2	12	20	30	LF	184,625	10,565	288,401	0.287	0.92	0.08	6,053	2,190
35	1	12	20	30	LF	177,875	11,286	288,735	0.293	0.87	0.1	7,278	2,609
10	3	12	20	20	LF	170,250	12,069	288,794	0.289	0.92	0.09	7,034	2,569
20	2	12	30	20	LF	176,000	11,508	289,038	0.285	0.91	0.06	6,503	2,622
35	2		40	40	CC	239,875	5,043	289,411	0.294	1	0.09		
35	2		40	40	LF	239,875	5,043	289,411	0.294	1	0.09		
25	2	12	30	30	LF	197,125	9,449	289,941	0.286	0.93	0.06	4,589	1,679
5	3	12	30	20	LF	169,625	12,272	290,167	0.291	0.92	0.09	6,629	2,480
10	2	12	40	20	LF	162,250	13,041	290,343	0.291	0.89	0.09	7,254	2,775
15	2	12	40	30	LF	183,375	10,896	290,401	0.289	0.92	0.08	5,264	1,824
25	2		60	30	CC	230,625	6,124	290,781	0.296	1	0.1		
25	2		60	30	LF	230,625	6,124	290,781	0.296	1	0.1		
5	3	12	30	30	LF	177,625	11,604	291,602	0.294	0.92	0.1	5,883	1,994
30	1	12	30	30	LF	177,250	11,651	291,691	0.295	0.87	0.1	7,016	2,535
55	1		40	30	CC	251,375	4,123	291,873	0.297	1	0.09		
55	1		40	30	LF	251,375	4,123	291,873	0.297	1	0.09		
40	2		40	30	CC	245,000	4,783	291,981	0.292	1	0.07		
40	2		40	30	LF	245,000	4,783	291,981	0.292	1	0.07		

25	3		40	30	CC	238,625	5,443	292,089	0.296	1	0.09		
25	3		40	30	LF	238,625	5,443	292,089	0.296	1	0.09		
35	1	12	30	30	LF	190,375	10,391	292,440	0.294	0.89	0.08	5,946	2,164
20	2	12	40	30	LF	196,500	9,784	292,605	0.288	0.93	0.06	4,313	1,536
30	2	12	20	30	LF	197,750	9,677	292,802	0.29	0.93	0.07	5,264	1,912
40	1	12	20	30	LF	191,000	10,460	293,742	0.296	0.89	0.09	6,501	2,323
30	2	12	30	30	LF	210,250	8,510	293,838	0.288	0.95	0.05	3,792	1,403
15	2	12	30	40	LF	178,875	11,717	293,965	0.295	0.9	0.09	6,313	2,174
15	2	12	40	20	LF	175,375	12,120	294,430	0.291	0.91	0.06	6,456	2,596
15	3	12	20	20	LF	183,375	11,310	294,468	0.292	0.93	0.07	6,382	2,399
30	2	12	10	20	LF	177,250	11,947	294,601	0.295	0.9	0.09	7,853	2,966
	3	12	40	30	LF	177,000	11,983	294,702	0.299	0.92	0.1	5,643	1,871
30	2	12	20	20	LF	189,750	10,690	294,758	0.29	0.92	0.05	6,331	2,553
20	2	12	20	40	LF	179,500	11,744	294,858	0.296	0.9	0.09	6,878	2,429
10	3	12	20	30	LF	178,250	11,874	294,882	0.296	0.92	0.1	6,644	2,307
25	2	12	30	20	LF	189,125	10,795	295,158	0.289	0.92	0.05	5,882	2,498
35	1	12	20	20	LF	169,875	12,762	295,233	0.296	0.86	0.08	8,652	3,423
10	3	12	20	10	LF	162,250	13,539	295,235	0.292	0.9	0.08	8,502	3,059
45	1		50	40	CC	245,625	5,054	295,266	0.303	1	0.1		
45	1		50	40	LF	245,625	5,054	295,266	0.303	1	0.1		
40	1	12	30	30	LF	203,500	9,353	295,373	0.294	0.91	0.07	5,068	1,842
30	2		50	40	CC	239,250	5,714	295,374	0.299	1	0.09		
30	2		50	40	LF	239,250	5,714	295,374	0.299	1	0.09		
10	3	12	30	30	LF	190,750	10,691	295,760	0.294	0.94	0.08	5,102	1,751
	3	12	40	20	LF	169,000	12,910	295,805	0.298	0.92	0.09	6,601	2,471
25	2	12	40	30	LF	209,625	8,776	295,831	0.29	0.95	0.05	3,454	1,260
20	2	12	20	10	LF	155,500	14,293	295,899	0.289	0.86	0.07	9,696	3,498
10	3	12	30	20	LF	182,750	11,564	296,338	0.293	0.93	0.07	6,016	2,334
45	2		30	40	CC	253,625	4,372	296,573	0.302	1	0.09		
45	2		30	40	LF	253,625	4,372	296,573	0.302	1	0.09		
20	2	12	30	40	LF	192,000	10,656	296,667	0.295	0.92	0.07	5,402	1,910
30	1	12	30	20	LF	169,250	13,001	296,958	0.297	0.85	0.08	8,300	3,379
50	1		50	30	CC	250,750	4,794	297,836	0.299	1	0.07		
50	1		50	30	LF	250,750	4,794	297,836	0.299	1	0.07		
35	2		50	30	CC	244,375	5,454	297,944	0.296	1	0.06		
35	2		50	30	LF	244,375	5,454	297,944	0.296	1	0.06		
20	3		50	30	CC	238,000	6,114	298,052	0.302	1	0.09		
20	3		50	30	LF	238,000	6,114	298,052	0.302	1	0.09		
10	2	12	50	30	LF	182,750	11,751	298,177	0.299	0.91	0.09	5,432	1,822
10	2	12	40	40	LF	178,250	12,241	298,484	0.301	0.89	0.1	6,200	2,075
5	3	12	40	30	LF	190,125	11,033	298,498	0.298	0.94	0.08	4,830	1,624
25	2	12	20	40	LF	192,625	10,815	298,852	0.298	0.92	0.08	6,045	2,184
35	2	12	20	30	LF	210,875	8,968	298,969	0.294	0.94	0.06	4,621	1,677

15	3	12	20	30	LF	191,375	10,959	299,016	0.297	0.93	0.08	5,848	2,042
35	1	12	20	40	LF	185,875	11,520	299,034	0.304	0.87	0.1	7,257	2,594
50	2		30	30	CC	258,750	4,112	299,144	0.302	1	0.08		
50	2		30	30	LF	258,750	4,112	299,144	0.302	1	0.08		
35	1	12	40	30	LF	202,875	9,805	299,189	0.298	0.91	0.07	4,881	1,785
30	1	12	40	30	LF	189,750	11,143	299,204	0.3	0.88	0.08	6,017	2,181
35	3		30	30	CC	252,375	4,772	299,251	0.303	1	0.09		
35	3		30	30	LF	252,375	4,772	299,251	0.303	1	0.09		
35	2	12	30	30	LF	223,375	7,739	299,394	0.292	0.96	0.04	3,140	1,160
15	2	12	50	30	LF	195,875	10,562	299,619	0.296	0.93	0.07	4,413	1,523
30	2	12	10	30	LF	185,250	11,650	299,686	0.301	0.9	0.09	7,395	2,725
35	2		40	50	CC	247,875	5,303	299,966	0.305	1	0.09		
35	2		40	50	LF	247,875	5,303	299,966	0.305	1	0.09		
30	2	12	40	30	LF	222,750	7,866	300,012	0.292	0.96	0.04	2,673	985
20	2	12	40	20	LF	188,500	11,372	300,205	0.293	0.92	0.05	5,803	2,470
25	2	12	30	40	LF	205,125	9,691	300,311	0.296	0.93	0.06	4,574	1,668
15	3	12	30	30	LF	203,875	9,840	300,527	0.296	0.95	0.06	4,373	1,536
5	3	12	30	10	LF	161,625	14,146	300,575	0.297	0.9	0.08	8,451	3,029
45	1	12	30	30	LF	216,625	8,549	300,599	0.297	0.93	0.06	4,386	1,604
15	2	12	30	10	LF	154,875	14,841	300,654	0.294	0.86	0.07	9,594	3,453
15	2	12	40	40	LF	191,375	11,133	300,735	0.299	0.92	0.08	5,246	1,812
40	1	12	40	30	LF	216,000	8,663	301,093	0.297	0.93	0.05	3,915	1,434
25	2		60	40	CC	238,625	6,384	301,336	0.307	1	0.1		
25	2		60	40	LF	238,625	6,384	301,336	0.307	1	0.1		
5	3	12	40	20	LF	182,125	12,146	301,431	0.299	0.93	0.07	5,939	2,316
45	1	12	20	30	LF	204,125	9,916	301,528	0.301	0.9	0.08	5,956	2,117
20	2	12	50	30	LF	209,000	9,437	301,698	0.296	0.95	0.05	3,455	1,215
20	3	12	20	20	LF	196,500	10,726	301,854	0.296	0.94	0.06	5,872	2,291
5	3	12	30	40	LF	185,625	11,853	302,053	0.305	0.92	0.1	5,875	1,987
30	1	12	30	40	LF	185,250	11,893	302,074	0.306	0.87	0.1	7,002	2,524
20	3	12	10	20	LF	184,000	12,034	302,203	0.302	0.92	0.09	7,420	2,711
55	1		40	40	CC	259,375	4,383	302,428	0.307	1	0.08		
55	1		40	40	LF	259,375	4,383	302,428	0.307	1	0.08		
40	2		40	40	CC	253,000	5,043	302,536	0.302	1	0.07		
40	2		40	40	LF	253,000	5,043	302,536	0.302	1	0.07		
25	3		40	40	CC	246,625	5,703	302,644	0.307	1	0.09		
25	3		40	40	LF	246,625	5,703	302,644	0.307	1	0.09		
30	2	12	30	20	LF	202,250	10,221	302,647	0.294	0.94	0.03	5,385	2,383
35	1	12	30	40	LF	198,375	10,617	302,661	0.304	0.89	0.08	5,919	2,144
10	3	12	40	30	LF	203,250	10,131	302,765	0.299	0.95	0.06	4,059	1,387
15	3	12	30	20	LF	195,875	10,896	302,899	0.297	0.94	0.05	5,434	2,205
35	1	12	30	20	LF	182,375	12,271	302,912	0.3	0.87	0.06	7,665	3,241
20	2	12	40	40	LF	204,500	10,024	302,959	0.299	0.93	0.06	4,297	1,524

10	2	12	50	20	LF	174,750	13,055	302,985	0.301	0.9	0.07	6,688	2,635
30	2	12	20	40	LF	205,750	9,918	303,169	0.3	0.93	0.07	5,247	1,902
45	1		60	30	CC	250,125	5,464	303,799	0.305	1	0.07		
45	1		60	30	LF	250,125	5,464	303,799	0.305	1	0.07		
35	2	12	10	20	LF	190,375	11,556	303,881	0.303	0.91	0.08	7,502	2,863
30	2		60	30	CC	243,750	6,124	303,906	0.303	1	0.07		
30	2		60	30	LF	243,750	6,124	303,906	0.303	1	0.07		
40	1	12	20	40	LF	199,000	10,681	303,911	0.306	0.89	0.09	6,471	2,303
15	3		60	30	CC	237,375	6,784	304,014	0.31	1	0.1		
15	3		60	30	LF	237,375	6,784	304,014	0.31	1	0.1		
30	2	12	30	40	LF	218,250	8,743	304,125	0.298	0.95	0.05	3,770	1,387
15	3	12	20	10	LF	175,375	13,134	304,382	0.297	0.91	0.06	8,156	2,956
35	2	12	20	20	LF	202,875	10,337	304,409	0.297	0.93	0.04	5,979	2,464
20	3	12	20	30	LF	204,500	10,176	304,454	0.3	0.94	0.07	5,160	1,851
15	2	12	30	50	LF	186,875	11,977	304,520	0.305	0.9	0.09	6,313	2,174
	3	12	50	30	LF	189,500	11,713	304,552	0.307	0.93	0.09	4,845	1,593
20	3	12	10	10	LF	176,000	13,107	304,741	0.302	0.91	0.08	8,604	3,077
60	1		40	30	CC	264,500	4,123	304,998	0.306	1	0.07		
60	1		40	30	LF	264,500	4,123	304,998	0.306	1	0.07		
	3	12	40	40	LF	185,000	12,220	305,030	0.31	0.92	0.1	5,624	1,858
35	2	12	10	30	LF	198,375	10,859	305,042	0.305	0.92	0.08	6,714	2,459
45	2		40	30	CC	258,125	4,783	305,106	0.301	1	0.05		
45	2		40	30	LF	258,125	4,783	305,106	0.301	1	0.05		
30	3		40	30	CC	251,750	5,443	305,214	0.305	1	0.07		
30	3		40	30	LF	251,750	5,443	305,214	0.305	1	0.07		
20	2	12	20	50	LF	187,500	12,004	305,413	0.307	0.9	0.09	6,878	2,429
45	1	12	40	30	LF	229,125	7,768	305,426	0.299	0.95	0.04	3,156	1,164
10	3	12	20	40	LF	186,250	12,134	305,437	0.307	0.92	0.1	6,644	2,307
40	1	12	30	40	LF	211,500	9,568	305,478	0.304	0.91	0.07	5,032	1,816
25	2	12	50	30	LF	222,125	8,501	305,626	0.297	0.96	0.04	2,646	955
40	1	12	20	20	LF	183,000	12,487	305,658	0.304	0.87	0.07	8,299	3,352
45	1		50	50	CC	253,625	5,314	305,821	0.313	1	0.1		
45	1		50	50	LF	253,625	5,314	305,821	0.313	1	0.1		
30	2		50	50	CC	247,250	5,974	305,929	0.31	1	0.09		
30	2		50	50	LF	247,250	5,974	305,929	0.31	1	0.09		
25	2	12	40	40	LF	217,625	9,006	306,087	0.3	0.95	0.05	3,430	1,243
10	3	12	30	40	LF	198,750	10,932	306,132	0.304	0.94	0.08	5,087	1,741
20	3	12	30	30	LF	217,000	9,099	306,374	0.299	0.96	0.05	3,737	1,355
35	2	12	40	30	LF	235,875	7,197	306,571	0.297	0.97	0.03	2,098	780
40	2	12	30	30	LF	236,500	7,153	306,764	0.298	0.97	0.03	2,636	978
40	2	12	20	30	LF	224,000	8,435	306,854	0.3	0.95	0.05	4,140	1,488
45	2		30	50	CC	261,625	4,633	307,128	0.313	1	0.09		
45	2		30	50	LF	261,625	4,633	307,128	0.313	1	0.09		

20	2	12	30	50	LF	200,000	10,916	307,222	0.305	0.92	0.07	5,402	1,910
15	3	12	40	30	LF	216,375	9,252	307,250	0.3	0.96	0.05	3,305	1,159
25	2	12	20	10	LF	168,625	14,119	307,311	0.298	0.87	0.06	9,547	3,454
5	4	12	20	20	LF	190,125	11,931	307,320	0.308	0.94	0.09	6,364	2,308
25	2	12	40	20	LF	201,625	10,761	307,327	0.298	0.93	0.03	5,270	2,366
10	3	12	40	20	LF	195,250	11,445	307,673	0.302	0.94	0.05	5,330	2,173
35	3		40	20	CC	256,875	5,183	307,784	0.307	1	0.1		
35	3		40	20	LF	256,875	5,183	307,784	0.307	1	0.1		
10	2	12	40	10	LF	154,250	15,645	307,924	0.302	0.85	0.08	9,709	3,483
15	2	12	50	20	LF	187,875	12,228	307,990	0.302	0.91	0.05	5,968	2,490
30	1	12	40	20	LF	181,750	12,870	308,167	0.305	0.87	0.06	7,602	3,229
35	1	12	50	30	LF	215,375	9,468	308,371	0.304	0.92	0.06	4,029	1,469
50	1		50	40	CC	258,750	5,054	308,391	0.309	1	0.07		
50	1		50	40	LF	258,750	5,054	308,391	0.309	1	0.07		
35	2		50	40	CC	252,375	5,714	308,499	0.307	1	0.06		
35	2		50	40	LF	252,375	5,714	308,499	0.307	1	0.06		
10	2	12	50	40	LF	190,750	11,992	308,547	0.309	0.91	0.09	5,418	1,811
20	3		50	40	CC	246,000	6,374	308,607	0.313	1	0.09		
20	3		50	40	LF	246,000	6,374	308,607	0.313	1	0.09		
	3	12	40	10	LF	161,000	15,031	308,640	0.307	0.89	0.09	8,635	3,075
5	3	12	50	30	LF	202,625	10,796	308,674	0.306	0.95	0.07	4,061	1,353
5	3	12	40	40	LF	198,125	11,271	308,838	0.309	0.94	0.08	4,813	1,611
	4	12	30	20	LF	189,500	12,160	308,947	0.309	0.94	0.08	5,979	2,229
30	1	12	50	30	LF	202,250	10,871	309,034	0.308	0.9	0.07	5,217	1,897
10	2	12	40	50	LF	186,250	12,501	309,039	0.312	0.89	0.1	6,200	2,075
	3	12	50	20	LF	181,500	12,987	309,065	0.309	0.92	0.08	6,088	2,346
50	1	12	30	30	LF	229,750	8,084	309,155	0.303	0.94	0.05	3,921	1,449
35	2	12	20	40	LF	218,875	9,198	309,219	0.304	0.94	0.06	4,596	1,660
25	3	12	10	20	LF	197,125	11,418	309,282	0.307	0.93	0.08	6,879	2,577
35	1	12	40	40	LF	210,875	10,020	309,296	0.308	0.91	0.07	4,844	1,760
25	2	12	20	50	LF	200,625	11,075	309,407	0.308	0.92	0.08	6,045	2,184
15	3	12	20	40	LF	199,375	11,212	309,510	0.308	0.93	0.08	5,843	2,039
30	1	12	40	40	LF	197,750	11,378	309,513	0.311	0.88	0.08	5,997	2,167
25	3	12	20	20	LF	209,625	10,171	309,531	0.302	0.95	0.05	5,390	2,180
35	1	12	20	50	LF	193,875	11,780	309,589	0.314	0.87	0.1	7,257	2,594
35	2	12	30	40	LF	231,375	7,964	309,603	0.302	0.96	0.04	3,111	1,141
10	2	12	60	30	LF	195,250	11,642	309,608	0.308	0.92	0.08	4,772	1,589
50	2		30	40	CC	266,750	4,372	309,698	0.312	1	0.08		

Appendix B

Optimized result in overall form for efficient lamps

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital	Operating cost ($/yr)	Total NPC	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
5	2	12	10	10	LF	$103,625	13,175	$194,174	0.345	0.85	0.1	9,005	3,395
15	1	12	10	10	LF	$96,875	14,782	$198,470	0.346	0.77	0.08	10,818	4,151
10	1	12	20	10	LF	$96,250	15,085	$199,926	0.352	0.75	0.09	10,591	4,020
5	2	12	20	10	LF	$116,125	12,209	$200,037	0.35	0.87	0.07	7,736	2,962
5	2	12	10	20	LF	$111,625	12,882	$200,162	0.357	0.86	0.1	8,588	3,180
10	2	12	10	10	LF	$116,750	12,298	$201,271	0.35	0.87	0.07	8,283	3,195
5	2	12	20	20	LF	$124,125	11,281	$201,657	0.355	0.88	0.07	6,823	2,546
15	1	12	20	10	LF	$109,375	13,669	$203,322	0.352	0.79	0.07	9,437	3,658
20	1	12	10	10	LF	$110,000	13,613	$203,559	0.353	0.8	0.07	9,863	3,864
	2	12	30	10	LF	$115,500	12,889	$204,087	0.361	0.86	0.08	7,810	2,956
40	1		20	30	CC	$187,000	2,509	$204,243	0.368	1	0.1		
40	1		20	30	LF	$187,000	2,509	$204,243	0.368	1	0.1		
	2	12	30	20	LF	$123,500	11,768	$204,380	0.365	0.88	0.08	6,739	2,499
10	1	12	20	20	LF	$104,250	14,577	$204,436	0.361	0.76	0.09	10,017	3,745
15	1	12	10	20	LF	$104,875	14,660	$205,631	0.358	0.77	0.08	10,547	4,030
15	1	12	20	20	LF	$117,375	13,025	$206,894	0.358	0.8	0.06	8,746	3,367
10	2	12	10	20	LF	$124,750	11,973	$207,040	0.361	0.88	0.07	7,826	2,970
10	2	12	20	10	LF	$129,250	11,350	$207,257	0.358	0.89	0.05	7,032	2,755
10	2	12	20	20	LF	$137,250	10,226	$207,533	0.358	0.9	0.05	5,955	2,307
35	1		30	30	CC	$186,375	3,105	$207,712	0.371	1	0.09		
35	1		30	30	LF	$186,375	3,105	$207,712	0.371	1	0.09		
	3	12	10	10	LF	$123,500	12,277	$207,877	0.372	0.9	0.1	7,743	2,894
15	2	12	10	10	LF	$129,875	11,376	$208,064	0.358	0.89	0.05	7,529	2,969
20	1	12	20	10	LF	$122,500	12,565	$208,859	0.361	0.82	0.06	8,536	3,374
5	2	12	30	20	LF	$136,625	10,567	$209,250	0.365	0.9	0.06	5,753	2,200
20	1	12	10	20	LF	$118,000	13,282	$209,288	0.359	0.81	0.05	9,411	3,739
20	1	12	20	20	LF	$130,500	11,514	$209,633	0.358	0.84	0.04	7,501	3,030
5	2	12	10	30	LF	$119,625	13,098	$209,650	0.374	0.86	0.1	8,586	3,179
5	2	12	20	30	LF	$132,125	11,293	$209,739	0.37	0.88	0.08	6,665	2,438
10	1	12	30	10	LF	$108,750	14,762	$210,205	0.368	0.76	0.08	9,847	3,759
5	2	12	30	10	LF	$128,625	12,005	$211,136	0.367	0.88	0.06	7,085	2,749
30	1		40	30	CC	$185,750	3,700	$211,181	0.38	1	0.1		
30	1		40	30	LF	$185,750	3,700	$211,181	0.38	1	0.1		

	2	12	30	30	LF	$131,500	11,610	$211,297	0.378	0.88	0.09	6,448	2,312
10	1	12	30	20	LF	$116,750	13,906	$212,326	0.373	0.78	0.08	8,990	3,386
25	1	12	20	20	LF	$143,625	10,057	$212,748	0.362	0.88	0.02	6,305	2,691
10	1	12	20	30	LF	$112,250	14,634	$212,830	0.376	0.76	0.1	9,895	3,654
15	2	12	10	20	LF	$137,875	10,957	$213,184	0.366	0.9	0.05	6,983	2,743
25	1	12	10	10	LF	$123,125	13,104	$213,187	0.369	0.82	0.06	9,409	3,740
25	1	12	10	20	LF	$131,125	11,966	$213,364	0.364	0.85	0.03	8,306	3,470
15	2	12	20	20	LF	$150,375	9,192	$213,548	0.365	0.92	0.03	5,102	2,063
40	1		20	40	CC	$195,000	2,728	$213,749	0.385	1	0.1		
40	1		20	40	LF	$195,000	2,728	$213,749	0.385	1	0.1		
15	1	12	30	20	LF	$129,875	12,219	$213,856	0.369	0.82	0.05	7,611	2,955
15	1	12	30	10	LF	$121,875	13,407	$214,017	0.37	0.8	0.07	8,740	3,419
	3	12	20	10	LF	$136,000	11,383	$214,233	0.376	0.92	0.07	6,542	2,482
	2	12	40	20	LF	$136,000	11,427	$214,538	0.38	0.89	0.07	5,973	2,250
15	1	12	10	30	LF	$112,875	14,821	$214,736	0.374	0.77	0.08	10,502	4,002
	3	12	10	20	LF	$131,500	12,119	$214,791	0.385	0.91	0.1	7,434	2,728
15	1	12	20	30	LF	$125,375	13,018	$214,844	0.372	0.8	0.06	8,577	3,229
10	2	12	20	30	LF	$145,250	10,166	$215,120	0.372	0.91	0.05	5,738	2,165
10	2	12	30	20	LF	$149,750	9,513	$215,132	0.369	0.92	0.03	4,885	1,950
15	2	12	20	10	LF	$142,375	10,591	$215,166	0.369	0.91	0.05	6,412	2,561
5	2	12	30	30	LF	$144,625	10,271	$215,218	0.376	0.9	0.06	5,354	1,945
15	1	12	10	10	CC	$96,875	17,244	$215,394	0.372	0.73	0.06	12,816	4,647
30	2		20	30	CC	$193,750	3,169	$215,529	0.385	1	0.09		
30	2		20	30	LF	$193,750	3,169	$215,529	0.385	1	0.09		
5	3	12	10	10	LF	$136,625	11,497	$215,640	0.378	0.92	0.07	7,101	2,715
10	2	12	10	30	LF	$132,750	12,171	$216,402	0.377	0.88	0.07	7,809	2,958
20	1	12	30	20	LF	$143,000	10,698	$216,529	0.369	0.87	0.03	6,359	2,621
20	2	12	10	10	LF	$143,000	10,706	$216,580	0.372	0.9	0.05	6,979	2,807
20	1	12	20	30	LF	$138,500	11,371	$216,655	0.371	0.85	0.04	7,228	2,830
30	1	12	20	20	LF	$156,750	8,727	$216,730	0.368	0.91	0.01	5,224	2,319
15	1	12	20	10	CC	$109,375	15,647	$216,915	0.374	0.75	0.06	11,111	3,862
20	1	12	10	10	CC	$110,000	15,560	$216,943	0.374	0.77	0.06	11,484	4,197
	3	12	20	20	LF	$144,000	10,616	$216,966	0.383	0.93	0.07	5,755	2,121
35	1		30	40	CC	$194,375	3,324	$217,218	0.388	1	0.09		
35	1		30	40	LF	$194,375	3,324	$217,218	0.388	1	0.09		
5	1	12	20	10	CC	$83,125	19,524	$217,315	0.375	0.63	0.06	14,396	4,249
45	1		20	30	CC	$200,125	2,509	$217,368	0.384	1	0.07		
45	1		20	30	LF	$200,125	2,509	$217,368	0.384	1	0.07		
	2	12	40	10	LF	$128,000	13,044	$217,648	0.383	0.87	0.07	7,448	2,854
20	1	12	10	30	LF	$126,000	13,378	$217,947	0.374	0.81	0.05	9,316	3,683
30	1	12	10	20	LF	$144,250	10,739	$218,060	0.371	0.87	0.02	7,277	3,164
25	1	12	20	30	LF	$151,625	9,672	$218,097	0.371	0.88	0.02	5,841	2,389
25	1	12	20	10	LF	$135,625	12,078	$218,633	0.377	0.84	0.06	8,138	3,245

10	1	12	20	10	CC	$96,250	17,811	$218,661	0.377	0.7	0.06	12,891	4,335
25	2		30	30	CC	$193,125	3,765	$218,998	0.388	1	0.08		
25	2		30	30	LF	$193,125	3,765	$218,998	0.388	1	0.08		
10	2	12	30	10	LF	$141,750	11,254	$219,100	0.377	0.9	0.05	6,469	2,568
35	2		20	20	CC	$198,875	2,950	$219,148	0.389	1	0.1		
35	2		20	20	LF	$198,875	2,950	$219,148	0.389	1	0.1		
5	2	12	10	40	LF	$127,625	13,318	$219,156	0.391	0.86	0.1	8,586	3,179
5	2	12	20	40	LF	$140,125	11,510	$219,236	0.386	0.88	0.08	6,664	2,437
20	2	12	10	20	LF	$151,000	9,937	$219,293	0.374	0.92	0.03	6,132	2,532
5	1	12	10	10	CC	$70,625	21,642	$219,368	0.383	0.62	0.07	16,327	5,474
25	1	12	30	20	LF	$156,125	9,218	$219,480	0.373	0.9	0.01	5,146	2,253
10	1	12	30	30	LF	$124,750	13,797	$219,575	0.387	0.78	0.09	8,744	3,189
5	2	12	40	20	LF	$149,125	10,260	$219,640	0.381	0.91	0.04	5,015	1,956
15	2	12	20	30	LF	$158,375	8,928	$219,734	0.376	0.93	0.03	4,727	1,824
30	1	12	20	30	LF	$164,750	8,001	$219,737	0.373	0.92	0.01	4,482	1,896
	2	12	40	30	LF	$144,000	11,038	$219,864	0.39	0.89	0.07	5,501	1,951
10	2	12	30	30	LF	$157,750	9,052	$219,961	0.378	0.93	0.04	4,355	1,621
20	2	12	20	20	LF	$163,500	8,230	$220,067	0.374	0.94	0.01	4,309	1,844
15	1	12	30	30	LF	$137,875	11,991	$220,288	0.38	0.83	0.06	7,273	2,708
20	1	12		10	LF	$97,500	17,872	$220,336	0.384	0.74	0.1	13,777	5,320
30	1		40	40	CC	$193,750	3,919	$220,687	0.397	1	0.1		
30	1		40	40	LF	$193,750	3,919	$220,687	0.397	1	0.1		
	2	12	30	40	LF	$139,500	11,816	$220,708	0.395	0.88	0.09	6,437	2,303
20	1	12	20	10	CC	$122,500	14,302	$220,793	0.381	0.79	0.06	10,002	3,578
40	1		30	30	CC	$199,500	3,105	$220,837	0.386	1	0.05		
40	1		30	30	LF	$199,500	3,105	$220,837	0.386	1	0.05		
25	1	12	10	30	LF	$139,125	11,912	$220,996	0.377	0.85	0.03	8,091	3,344
20	1	12		10	CC	$97,500	18,011	$221,286	0.386	0.74	0.1	13,897	5,320
15	2	12	30	20	LF	$162,875	8,522	$221,445	0.377	0.94	0.02	4,069	1,711
20	1	12	30	30	LF	$151,000	10,271	$221,594	0.378	0.87	0.03	5,863	2,286
20	1	12	30	10	LF	$135,000	12,608	$221,654	0.383	0.83	0.06	8,087	3,218
5	3	12	10	20	LF	$144,625	11,262	$222,029	0.39	0.92	0.08	6,719	2,524
15	2	12	10	30	LF	$145,875	11,114	$222,258	0.382	0.9	0.05	6,930	2,709
10	1	12	20	40	LF	$120,250	14,852	$222,325	0.393	0.76	0.1	9,894	3,653
5	3	12	20	10	LF	$149,125	10,666	$222,431	0.385	0.93	0.05	5,953	2,313
20	2		40	30	CC	$192,500	4,360	$222,467	0.396	1	0.08		
20	2		40	30	LF	$192,500	4,360	$222,467	0.396	1	0.08		
35	1	12	20	30	LF	$177,875	6,498	$222,533	0.378	0.94	0.01	3,270	1,393
30	2		30	20	CC	$198,250	3,545	$222,617	0.393	1	0.09		
30	2		30	20	LF	$198,250	3,545	$222,617	0.393	1	0.09		
25	1	12	30	30	LF	$164,125	8,518	$222,665	0.378	0.91	0.01	4,429	1,813
10	1	12	40	20	LF	$129,250	13,623	$222,882	0.391	0.79	0.07	8,278	3,130
10	1	12	40	10	LF	$121,250	14,801	$222,974	0.389	0.77	0.08	9,395	3,613

35	1	12	20	20	LF	$169,875	7,749	$223,135	0.378	0.93	0.01	4,429	2,032
40	1		20	50	CC	$203,000	2,947	$223,255	0.402	1	0.1		
40	1		20	50	LF	$203,000	2,947	$223,255	0.402	1	0.1		
10	2	12	20	10	CC	$129,250	13,692	$223,356	0.383	0.86	0.04	8,978	3,185
10	3	12	10	10	LF	$149,750	10,727	$223,473	0.386	0.93	0.05	6,478	2,540
5	2	12	40	30	LF	$157,125	9,692	$223,736	0.389	0.92	0.05	4,402	1,578
5	3	12	20	20	LF	$157,125	9,725	$223,961	0.389	0.94	0.05	5,017	1,926
15	2	12	10	10	CC	$129,875	13,702	$224,048	0.384	0.86	0.04	9,431	3,554
30	1	12	10	30	LF	$152,250	10,451	$224,079	0.381	0.88	0.02	6,874	2,944
15	1	12	10	40	LF	$120,875	15,040	$224,242	0.39	0.77	0.08	10,502	4,002
15	1	12	40	20	LF	$142,375	11,919	$224,291	0.385	0.84	0.04	6,881	2,718
30	1	12	30	30	LF	$177,250	6,845	$224,295	0.38	0.94	0.01	3,073	1,291
	3	12	10	30	LF	$139,500	12,338	$224,297	0.403	0.91	0.1	7,434	2,728
35	1		40	30	CC	$198,875	3,700	$224,306	0.393	1	0.05		
35	1		40	30	LF	$198,875	3,700	$224,306	0.393	1	0.05		
15	1	12	20	40	LF	$133,375	13,234	$224,331	0.388	0.8	0.06	8,574	3,227
5	2	12	40	10	LF	$141,125	12,110	$224,353	0.389	0.89	0.06	6,685	2,613
30	1	12	30	20	LF	$169,250	8,023	$224,392	0.38	0.93	0	4,172	1,914
45	1		30	20	CC	$204,625	2,885	$224,456	0.398	1	0.1		
45	1		30	20	LF	$204,625	2,885	$224,456	0.398	1	0.1		
5	2	12	30	40	LF	$152,625	10,470	$224,586	0.393	0.91	0.06	5,338	1,934
10	2	12	20	40	LF	$153,250	10,384	$224,617	0.388	0.91	0.05	5,737	2,164
35	1	12	10	20	LF	$157,375	9,798	$224,719	0.382	0.9	0.01	6,489	2,904
10	1	12	10	10	CC	$83,750	20,528	$224,835	0.39	0.67	0.07	15,309	5,628
30	1	12	10	10	LF	$136,250	12,894	$224,870	0.389	0.84	0.06	9,216	3,692
30	2		20	40	CC	$201,750	3,388	$225,035	0.402	1	0.09		
30	2		20	40	LF	$201,750	3,388	$225,035	0.402	1	0.09		
15	2	12	30	30	LF	$170,875	7,882	$225,045	0.384	0.95	0.02	3,397	1,306
20	2	12	20	30	LF	$171,500	7,801	$225,117	0.383	0.95	0.02	3,802	1,540
	3	12	30	20	LF	$156,500	9,984	$225,118	0.393	0.94	0.05	4,746	1,812
5	2	12	20	10	CC	$116,125	15,871	$225,202	0.386	0.82	0.04	10,749	3,782
	3	12	20	30	LF	$152,000	10,652	$225,209	0.398	0.93	0.07	5,612	2,030
25	1	12	10	10	CC	$123,125	14,878	$225,382	0.389	0.79	0.06	10,929	4,016
15	2	12		10	LF	$117,375	15,738	$225,543	0.393	0.84	0.09	11,508	4,564
25	2	12	10	20	LF	$164,125	8,950	$225,639	0.383	0.93	0.02	5,326	2,306
20	2	12	20	10	LF	$155,500	10,216	$225,710	0.387	0.91	0.04	6,105	2,467
	3	12	30	10	LF	$148,500	11,255	$225,857	0.393	0.93	0.06	5,950	2,297
10	2	12	10	40	LF	$140,750	12,390	$225,908	0.394	0.88	0.07	7,809	2,958
15	2		50	30	CC	$191,875	4,956	$225,937	0.407	1	0.09		
15	2		50	30	LF	$191,875	4,956	$225,937	0.407	1	0.09		
10	2	12	40	20	LF	$162,250	9,281	$226,036	0.387	0.93	0.03	4,209	1,722
25	2		40	20	CC	$197,625	4,141	$226,086	0.399	1	0.09		
25	2		40	20	LF	$197,625	4,141	$226,086	0.399	1	0.09		

20	1	12	20	40	LF	$146,500	11,589	$226,151	0.387	0.85	0.04	7,227	2,829
5	1	12	30	10	CC	$95,625	19,014	$226,306	0.39	0.64	0.06	13,532	3,779
15	2	12		10	CC	$117,375	15,850	$226,314	0.395	0.84	0.09	11,606	4,564
	2	12	50	20	LF	$148,500	11,355	$226,543	0.398	0.9	0.06	5,427	2,073
15	2	12	20	10	CC	$142,375	12,253	$226,592	0.388	0.88	0.04	7,801	2,826
15	1	12	30	10	CC	$121,875	15,237	$226,601	0.391	0.77	0.06	10,295	3,588
20	1	12	40	20	LF	$155,500	10,357	$226,685	0.385	0.88	0.02	5,598	2,356
35	1		30	50	CC	$202,375	3,543	$226,724	0.405	1	0.09		
35	1		30	50	LF	$202,375	3,543	$226,724	0.405	1	0.09		
45	1		20	40	CC	$208,125	2,728	$226,874	0.401	1	0.07		
45	1		20	40	LF	$208,125	2,728	$226,874	0.401	1	0.07		
25	2	12	20	20	LF	$176,625	7,327	$226,985	0.385	0.95	0.01	3,569	1,605
10	1	12	30	10	CC	$108,750	17,255	$227,345	0.392	0.71	0.06	11,966	3,976
20	1	12		20	LF	$105,500	17,740	$227,428	0.395	0.75	0.1	13,477	5,299
20	1	12	10	40	LF	$134,000	13,597	$227,453	0.39	0.81	0.05	9,316	3,683
35	1	12	10	30	LF	$165,375	9,035	$227,473	0.386	0.91	0.01	5,715	2,489
25	1	12	20	40	LF	$159,625	9,884	$227,555	0.387	0.88	0.02	5,836	2,384
15	1	12	40	10	LF	$134,375	13,566	$227,616	0.393	0.81	0.06	8,386	3,296
10	2	12	10	10	CC	$116,750	16,142	$227,696	0.391	0.83	0.05	11,316	4,318
30	1		50	30	CC	$198,250	4,296	$227,776	0.403	1	0.07		
30	1		50	30	LF	$198,250	4,296	$227,776	0.403	1	0.07		
20	2	12	10	30	LF	$159,000	10,018	$227,853	0.389	0.92	0.03	6,018	2,466
25	2	12	10	10	LF	$156,125	10,441	$227,888	0.391	0.91	0.04	6,761	2,751
40	1	12	20	30	LF	$191,000	5,372	$227,924	0.386	0.96	0	2,354	1,013
40	1		40	20	CC	$204,000	3,481	$227,925	0.403	1	0.1		
40	1		40	20	LF	$204,000	3,481	$227,925	0.403	1	0.1		
35	1	12	30	30	LF	$190,375	5,529	$228,378	0.387	0.96	0	1,996	853
20	1	12		20	CC	$105,500	17,885	$228,423	0.396	0.74	0.1	13,602	5,299
20	2	12	30	20	LF	$176,000	7,628	$228,429	0.387	0.95	0.01	3,336	1,480
	2	12	10	10	CC	$90,500	20,070	$228,442	0.405	0.77	0.09	14,336	5,448
	1	12	20	10	CC	$70,000	23,056	$228,462	0.394	0.56	0.06	17,273	5,164
25	2		30	40	CC	$201,125	3,984	$228,504	0.405	1	0.08		
25	2		30	40	LF	$201,125	3,984	$228,504	0.405	1	0.08		
35	2		20	30	CC	$206,875	3,169	$228,654	0.401	1	0.06		
35	2		20	30	LF	$206,875	3,169	$228,654	0.401	1	0.06		
5	2	12	10	50	LF	$135,625	13,537	$228,662	0.408	0.86	0.1	8,586	3,179
5	2	12	20	50	LF	$148,125	11,730	$228,742	0.403	0.88	0.08	6,664	2,437
10	2	12	40	30	LF	$170,250	8,515	$228,775	0.392	0.94	0.03	3,437	1,264

Appendix C

Optimized result in overall form after load forecasting

PV (kW)	FL30	GEN (kW)	S4KS25P	Converter (kW)	Dispatch strategy	Initial capital in $	Operating cost ($/yr)	Total NPC in $	COE ($/kWh)	Renewable fraction	Capacity shortage	Diesel (L)	GEN (hrs)
105	4	12	60	70	LF	542,625	16,314	702,871	0.26	0.96	0.1	6,732	2,284
100	4	12	70	70	LF	542,000	16,666	705,701	0.26	0.96	0.1	6,462	2,186
105	4	12	60	80	LF	550,625	16,113	708,896	0.26	0.96	0.1	6,328	2,207
95	4	12	80	70	LF	541,375	17,178	710,105	0.26	0.96	0.1	6,328	2,134
95	5	12	60	70	LF	549,375	16,393	710,396	0.26	0.97	0.1	6,239	2,108
115	3	12	70	70	LF	548,375	16,556	711,002	0.26	0.96	0.1	6,931	2,344
100	4	12	70	80	LF	550,000	16,454	711,621	0.26	0.96	0.09	6,049	2,106
115	4	12	50	70	LF	556,375	15,835	711,920	0.26	0.96	0.1	6,891	2,365
110	4	12	60	70	LF	555,750	15,918	712,104	0.26	0.96	0.09	6,392	2,186
100	5	12	60	60	LF	554,500	16,054	712,193	0.26	0.97	0.1	6,184	2,027
120	3	12	60	80	LF	557,000	15,908	713,261	0.27	0.96	0.1	6,711	2,367
90	5	12	70	70	LF	548,750	16,751	713,289	0.26	0.97	0.1	5,974	2,012
105	4	12	60	90	LF	558,625	15,827	714,084	0.27	0.97	0.1	5,872	2,005
95	5	12	70	60	LF	553,875	16,378	714,748	0.27	0.97	0.1	5,890	1,922
105	4	12	70	70	LF	555,125	16,257	714,811	0.26	0.96	0.09	6,112	2,077
75	4	24	60	50	LF	451,875	26,789	715,015	0.26	0.9	0.1	16,142	2,756
90	4	12	90	70	LF	540,750	17,747	715,076	0.27	0.96	0.1	6,242	2,104
110	3	12	80	70	LF	547,750	17,056	715,279	0.27	0.96	0.1	6,786	2,291
80	4	24	50	50	LF	452,500	26,778	715,529	0.26	0.9	0.1	16,689	2,880
95	4	12	80	80	LF	549,375	16,922	715,593	0.27	0.96	0.09	5,878	2,040
65	5	24	60	50	LF	458,625	26,186	715,836	0.26	0.91	0.1	15,073	2,572
115	3	12	70	80	LF	556,375	16,264	716,125	0.27	0.96	0.09	6,444	2,266
70	5	24	50	50	LF	459,250	26,163	716,238	0.26	0.91	0.1	15,611	2,690
60	5	24	60	60	LF	453,500	26,782	716,570	0.27	0.91	0.1	15,347	2,646
95	5	12	60	80	LF	557,375	16,232	716,817	0.27	0.97	0.1	5,873	2,024
115	4	12	50	80	LF	564,375	15,521	716,829	0.27	0.96	0.09	6,390	2,255
100	4	12	70	90	LF	558,000	16,177	716,902	0.27	0.97	0.09	5,601	1,904
85	5	12	80	70	LF	548,125	17,194	717,017	0.27	0.97	0.09	5,782	1,941
110	4	12	70	60	LF	560,250	15,980	717,213	0.27	0.96	0.1	6,112	1,999
60	5	24	70	50	LF	458,000	26,406	717,372	0.26	0.91	0.1	14,700	2,488
110	4	12	60	80	LF	563,750	15,642	717,391	0.27	0.97	0.09	5,923	2,089
120	3	12	60	90	LF	565,000	15,528	717,530	0.27	0.96	0.1	6,173	2,142

70	4	24	70	50	LF	451,250	27,149	717,919	0.26	0.9	0.1	15,885	2,696
75	5	12	90	80	LF	542,375	17,907	718,267	0.27	0.97	0.1	5,594	1,891
90	5	12	80	60	LF	553,250	16,831	718,573	0.27	0.97	0.1	5,704	1,860
100	4	12	80	70	LF	554,500	16,767	719,191	0.27	0.96	0.09	5,974	2,036
105	5	12	50	70	LF	563,125	15,890	719,209	0.27	0.97	0.09	6,377	2,182
90	5	12	70	80	LF	556,750	16,580	719,609	0.27	0.97	0.09	5,600	1,924
55	6	24	60	50	LF	465,375	25,889	719,668	0.27	0.92	0.1	14,269	2,422
75	5	24	40	50	LF	459,875	26,460	719,779	0.27	0.91	0.1	16,420	2,854
85	4	24	40	50	LF	453,125	27,156	719,866	0.27	0.9	0.1	17,566	3,058
105	4	12	70	80	LF	563,125	15,962	719,911	0.27	0.97	0.08	5,627	1,978
100	5	12	60	70	LF	562,500	16,031	719,969	0.27	0.97	0.09	5,928	2,018
120	3	12	70	70	LF	561,500	16,142	720,053	0.27	0.96	0.09	6,575	2,240
115	3	12	70	90	LF	564,375	15,862	720,181	0.27	0.96	0.09	5,890	2,028
80	4	24	60	50	LF	465,000	25,985	720,241	0.26	0.91	0.09	15,458	2,649
85	4	12	100	70	LF	540,125	18,358	720,448	0.27	0.96	0.1	6,193	2,076
60	6	24	50	50	LF	466,000	25,908	720,488	0.27	0.92	0.1	14,843	2,545
90	4	12	90	80	LF	548,750	17,487	720,516	0.27	0.96	0.09	5,788	2,008
95	4	12	80	90	LF	557,375	16,610	720,532	0.27	0.97	0.09	5,402	1,824
55	5	24	80	50	LF	457,375	26,792	720,538	0.27	0.91	0.1	14,465	2,434
110	3	12	80	80	LF	555,750	16,777	720,541	0.27	0.96	0.09	6,310	2,221
85	6	12	60	70	LF	556,125	16,739	720,543	0.27	0.97	0.1	5,973	2,012
120	4		80	90	CC	619,000	10,346	720,627	0.27	1	0.1		
120	4		80	90	LF	619,000	10,346	720,627	0.27	1	0.1		
105	4	12	80	60	LF	559,625	16,408	720,792	0.27	0.96	0.1	5,906	1,928
85	4	24	50	50	LF	465,625	25,990	720,910	0.27	0.9	0.09	16,019	2,771
105	3	12	90	70	LF	547,125	17,698	720,961	0.27	0.95	0.1	6,763	2,275
50	6	24	70	50	LF	464,750	26,116	721,279	0.27	0.92	0.1	13,899	2,341
80	5	12	90	70	LF	547,500	17,701	721,372	0.27	0.97	0.09	5,644	1,887
70	5	24	60	50	LF	471,750	25,423	721,472	0.26	0.92	0.09	14,426	2,468
115	4	12	60	70	LF	568,875	15,570	721,811	0.27	0.97	0.08	6,092	2,102
90	6	12	60	60	LF	561,250	16,364	721,991	0.27	0.97	0.1	5,886	1,926
120	4	12	50	70	LF	569,500	15,536	722,101	0.27	0.96	0.09	6,634	2,289
115	4	12	50	90	LF	572,375	15,244	722,114	0.27	0.97	0.09	5,941	2,059
105	4	12	60	100	LF	566,625	15,832	722,135	0.27	0.97	0.1	5,665	1,883
105	5	12	60	60	LF	567,625	15,754	722,370	0.27	0.97	0.09	5,928	1,942
75	5	24	50	50	LF	472,375	25,458	722,435	0.27	0.92	0.09	15,012	2,594
110	4	12	60	90	LF	571,750	15,345	722,479	0.27	0.97	0.09	5,459	1,881
110	5	12	50	60	LF	568,250	15,710	722,564	0.27	0.97	0.1	6,461	2,127
75	4	24	70	50	LF	464,375	26,294	722,653	0.27	0.9	0.09	15,158	2,582
95	5	12	70	70	LF	561,875	16,369	722,660	0.27	0.97	0.09	5,646	1,915
65	4	24	80	50	LF	450,625	27,708	722,790	0.27	0.9	0.1	15,795	2,671
60	5	24	60	70	LF	461,500	26,601	722,793	0.27	0.91	0.1	14,964	2,604
85	5	12	80	80	LF	556,125	16,978	722,898	0.27	0.97	0.09	5,369	1,844

80	6	12	70	70	LF	555,500	17,043	722,905	0.27	0.97	0.1	5,662	1,898
95	5	12	60	90	LF	565,375	16,044	722,965	0.27	0.97	0.1	5,499	1,860
70	5	12	100	80	LF	541,750	18,451	722,987	0.27	0.97	0.1	5,489	1,838
65	5	24	70	50	LF	471,125	25,670	723,274	0.27	0.92	0.09	14,073	2,393
110	5		80	80	CC	617,750	10,746	723,305	0.27	1	0.1		
110	5		80	80	LF	617,750	10,746	723,305	0.27	1	0.1		
65	5	24	60	60	LF	466,625	26,135	723,339	0.27	0.92	0.09	14,789	2,577
85	5	12	90	60	LF	552,625	17,391	723,447	0.27	0.97	0.1	5,611	1,825
75	5	12	90	90	LF	550,375	17,666	723,898	0.27	0.97	0.1	5,178	1,692
110	4		90	100	CC	613,250	11,277	724,020	0.27	1	0.1		
110	4		90	100	LF	613,250	11,277	724,020	0.27	1	0.1		
95	4	12	90	70	LF	553,875	17,322	724,026	0.27	0.96	0.09	5,876	2,001
45	6	24	80	50	LF	464,125	26,463	724,058	0.27	0.92	0.1	13,628	2,280
115	3	12	80	70	LF	560,875	16,625	724,178	0.27	0.96	0.09	6,416	2,183
120	3	12	70	80	LF	569,500	15,748	724,182	0.27	0.96	0.08	5,997	2,152
100	4	12	80	80	LF	562,500	16,467	724,249	0.27	0.97	0.08	5,486	1,932
65	6	24	40	50	LF	466,625	26,230	724,274	0.27	0.92	0.1	15,674	2,708
70	5	24	50	60	LF	467,250	26,175	724,357	0.27	0.92	0.09	15,383	2,697
110	4	12	70	70	LF	568,250	15,899	724,421	0.27	0.97	0.08	5,802	1,998
110	3	12	80	90	LF	563,750	16,367	724,512	0.27	0.96	0.09	5,749	1,975
120	3	12	60	100	LF	573,000	15,435	724,612	0.27	0.96	0.1	5,886	1,974
65	6	24	60	40	LF	483,625	24,535	724,623	0.27	0.93	0.1	13,319	2,313
85	6	12	70	60	LF	560,625	16,703	724,695	0.27	0.97	0.1	5,603	1,834
100	4	12	70	100	LF	566,000	16,158	724,715	0.27	0.97	0.1	5,375	1,771
75	4	24	60	60	LF	459,875	26,973	724,815	0.27	0.9	0.09	16,047	2,815
60	5	24	70	60	LF	466,000	26,352	724,848	0.27	0.92	0.09	14,411	2,499
100	5	12	70	60	LF	567,000	16,071	724,861	0.27	0.97	0.09	5,627	1,843
105	4	12	70	90	LF	571,125	15,656	724,907	0.27	0.97	0.08	5,154	1,773
90	5	12	70	90	LF	564,750	16,342	725,273	0.27	0.97	0.09	5,186	1,734
90	4	12	90	90	LF	556,750	17,164	725,347	0.27	0.97	0.09	5,303	1,786
50	5	24	90	50	LF	456,750	27,348	725,373	0.27	0.91	0.1	14,372	2,409
100	4	12	90	60	LF	559,000	16,957	725,565	0.27	0.96	0.1	5,804	1,889
70	6	24	50	40	LF	484,250	24,569	725,580	0.27	0.93	0.1	13,912	2,429
80	4	24	50	60	LF	460,500	26,989	725,599	0.27	0.9	0.09	16,618	2,941
105	5	12	50	80	LF	571,125	15,741	725,745	0.27	0.97	0.09	6,018	2,115
85	4	24	60	50	LF	478,125	25,220	725,854	0.27	0.91	0.08	14,809	2,541
85	4	12	100	80	LF	548,125	18,102	725,935	0.27	0.96	0.09	5,745	1,971
105	3	12	90	80	LF	555,125	17,396	725,995	0.27	0.96	0.09	6,269	2,190
100	5	12	60	80	LF	570,500	15,840	726,092	0.27	0.97	0.09	5,535	1,935
80	5	24	40	50	LF	473,000	25,770	726,129	0.27	0.92	0.09	15,834	2,760
55	6	24	60	60	LF	473,375	25,745	726,254	0.27	0.93	0.09	13,911	2,401
115	4	12	60	80	LF	576,875	15,209	726,271	0.27	0.97	0.08	5,551	1,987
120	4	12	50	80	LF	577,500	15,153	726,341	0.27	0.97	0.08	6,071	2,176

120	4	12	60	60	LF	574,000	15,519	726,432	0.27	0.96	0.1	6,289	2,067
90	5	12	80	70	LF	561,250	16,819	726,455	0.27	0.97	0.08	5,459	1,848
80	4	12	110	70	LF	539,500	19,035	726,475	0.27	0.96	0.1	6,200	2,070
90	4	24	40	50	LF	466,250	26,503	726,578	0.27	0.9	0.09	16,971	2,958
115	4		90	90	CC	618,375	11,017	726,590	0.27	1	0.09		
115	4		90	90	LF	618,375	11,017	726,590	0.27	1	0.09		
75	5	12	100	70	LF	546,875	18,297	726,598	0.27	0.97	0.09	5,582	1,858
75	6	12	80	70	LF	554,875	17,487	726,646	0.27	0.97	0.09	5,471	1,826
60	5	24	80	50	LF	470,500	26,079	726,663	0.27	0.92	0.09	13,854	2,344
60	6	24	60	50	LF	478,500	25,267	726,683	0.27	0.93	0.09	13,736	2,342
100	5		90	90	CC	612,000	11,677	726,698	0.27	1	0.1		
100	5		90	90	LF	612,000	11,677	726,698	0.27	1	0.1		
90	3	24	60	50	LF	458,250	27,335	726,753	0.27	0.88	0.1	17,167	2,924
70	4	24	80	50	LF	463,750	26,806	727,052	0.27	0.9	0.09	15,025	2,556
85	6	12	60	80	LF	564,125	16,588	727,065	0.27	0.97	0.1	5,620	1,908
45	7	24	60	50	LF	472,125	25,955	727,069	0.27	0.93	0.1	13,767	2,329
70	4	24	70	60	LF	459,250	27,280	727,207	0.27	0.9	0.09	15,749	2,739
115	3	12	70	100	LF	572,375	15,767	727,247	0.27	0.96	0.09	5,601	1,857
60	6	24	70	40	LF	483,000	24,866	727,248	0.27	0.93	0.1	13,035	2,250
80	5	12	90	80	LF	555,500	17,493	727,326	0.27	0.97	0.09	5,237	1,794
90	4	24	50	50	LF	478,750	25,320	727,462	0.27	0.91	0.09	15,449	2,682
115	4	12	70	60	LF	573,375	15,688	727,469	0.27	0.97	0.09	5,862	1,923
100	3	12	100	70	LF	546,500	18,426	727,495	0.27	0.95	0.1	6,812	2,296
75	5	24	60	50	LF	484,875	24,702	727,511	0.27	0.92	0.08	13,811	2,372
50	6	24	70	60	LF	472,750	25,937	727,520	0.27	0.93	0.09	13,510	2,315
55	5	24	80	60	LF	465,375	26,689	727,533	0.27	0.92	0.09	14,137	2,431
120	3	12	70	90	LF	577,500	15,288	727,668	0.27	0.97	0.08	5,396	1,889
65	6	12	90	80	LF	549,125	18,179	727,693	0.27	0.97	0.1	5,271	1,747
80	5	24	60	40	LF	490,000	24,200	727,707	0.27	0.93	0.1	13,589	2,378
65	6	24	50	50	LF	479,125	25,320	727,835	0.27	0.93	0.09	14,340	2,473
115	5		70	90	CC	626,375	10,336	727,897	0.27	1	0.1		
115	5		70	90	LF	626,375	10,336	727,897	0.27	1	0.1		
55	6	24	70	50	LF	477,875	25,463	727,990	0.27	0.93	0.09	13,339	2,256
80	4	24	70	50	LF	477,500	25,508	728,051	0.27	0.91	0.08	14,490	2,475
60	6	24	50	60	LF	474,000	25,875	728,160	0.27	0.93	0.09	14,581	2,534
95	4	12	80	100	LF	565,375	16,578	728,213	0.27	0.97	0.09	5,165	1,683
115	3	12	80	80	LF	568,875	16,223	728,228	0.27	0.96	0.08	5,834	2,080
40	6	24	90	50	LF	463,500	26,965	728,369	0.27	0.92	0.1	13,487	2,251
105	4	12	80	70	LF	567,625	16,366	728,379	0.27	0.97	0.08	5,630	1,935
70	5	12	100	90	LF	549,750	18,194	728,460	0.27	0.97	0.1	5,060	1,637
110	5	12	40	80	LF	571,750	15,956	728,478	0.27	0.97	0.1	6,628	2,301
80	6	12	80	60	LF	560,000	17,159	728,541	0.27	0.97	0.1	5,422	1,760
95	5	12	70	80	LF	569,875	16,163	728,637	0.27	0.97	0.08	5,240	1,829

40	7	24	70	50	LF	471,500	26,180	728,654	0.27	0.93	0.1	13,393	2,250
80	5	24	50	50	LF	485,500	24,757	728,673	0.27	0.92	0.08	14,414	2,502
65	5	24	60	70	LF	474,625	25,866	728,691	0.27	0.92	0.09	14,330	2,524
95	5	12	80	60	LF	566,375	16,529	728,732	0.27	0.97	0.09	5,446	1,779
85	5	12	80	90	LF	564,125	16,759	728,737	0.27	0.97	0.09	4,970	1,658
110	4	12	70	80	LF	576,250	15,526	728,757	0.27	0.97	0.07	5,252	1,876
100	4	12	80	90	LF	570,500	16,112	728,758	0.27	0.97	0.08	4,973	1,705
75	5	24	70	40	LF	489,375	24,374	728,790	0.27	0.93	0.1	13,173	2,286
95	3	24	50	50	LF	458,875	27,488	728,877	0.27	0.88	0.1	17,852	3,072
70	5	24	70	50	LF	484,250	24,905	728,879	0.27	0.92	0.08	13,417	2,292
80	5	12	100	60	LF	552,000	18,027	729,072	0.27	0.97	0.1	5,583	1,808
95	4	12	90	80	LF	561,875	17,024	729,090	0.27	0.97	0.08	5,390	1,893
120	4		90	80	CC	623,500	10,757	729,160	0.27	1	0.09		
120	4		90	80	LF	623,500	10,757	729,160	0.27	1	0.09		
95	6	12	50	70	LF	569,875	16,224	729,232	0.27	0.97	0.09	6,100	2,080
105	5		90	80	CC	617,125	11,417	729,268	0.27	1	0.1		
105	5		90	80	LF	617,125	11,417	729,268	0.27	1	0.1		
110	5	12	50	70	LF	576,250	15,581	729,293	0.27	0.97	0.09	6,109	2,116
105	5	12	60	70	LF	575,625	15,657	729,418	0.27	0.97	0.08	5,607	1,924
110	3	12	90	70	LF	560,250	17,232	729,510	0.27	0.96	0.09	6,362	2,162
75	5	24	40	60	LF	467,875	26,640	729,550	0.27	0.91	0.09	16,295	2,887
90	4	12	100	70	LF	553,250	17,954	729,608	0.27	0.96	0.09	5,845	1,984
80	5	24	30	50	LF	460,500	27,398	729,622	0.27	0.91	0.1	17,590	3,076
85	4	24	40	60	LF	461,125	27,338	729,658	0.27	0.9	0.09	17,473	3,112
80	6	12	70	80	LF	563,500	16,918	729,680	0.27	0.97	0.09	5,330	1,814
60	5	24	70	70	LF	474,000	26,030	729,681	0.27	0.92	0.09	13,908	2,437
75	4	24	60	70	LF	467,875	26,660	729,743	0.27	0.9	0.09	15,549	2,763
80	4	24	60	60	LF	473,000	26,143	729,787	0.27	0.91	0.08	15,339	2,707
120	3		100	100	CC	619,000	11,288	729,874	0.28	1	0.1		
120	3		100	100	LF	619,000	11,288	729,874	0.28	1	0.1		
85	3	24	70	50	LF	457,625	27,724	729,950	0.27	0.88	0.1	16,934	2,869
115	4	12	50	100	LF	580,375	15,229	729,966	0.27	0.97	0.09	5,718	1,927
105	4		100	100	CC	612,625	11,948	729,982	0.27	1	0.1		
105	4		100	100	LF	612,625	11,948	729,982	0.27	1	0.1		
105	3	12	90	90	LF	563,125	16,988	729,992	0.27	0.96	0.09	5,709	1,952
60	5	24	60	80	LF	469,500	26,521	730,004	0.27	0.91	0.1	14,682	2,541
45	6	24	80	60	LF	472,125	26,263	730,097	0.27	0.93	0.09	13,221	2,253
90	6	12	60	70	LF	569,250	16,376	730,108	0.27	0.97	0.09	5,662	1,920
75	6	24	40	40	LF	484,875	24,976	730,203	0.27	0.93	0.1	14,819	2,597

References

[1].Invest in Ethiopia, Ethiopia trade and investment. *www.ethioembassy.org.uk/**trade_and_investment***. January 2012

[2].Ethiopian Television (ETV) news. http://www.erta.gov.et January 2012

[3].Bekele G. (2009) "The Study into the Potential and Feasibility of Standalone Solar-Wind Hybrid Electric Energy Supply System for Application in Ethiopia", KTH-Royal Institute of Technology Doctoral Thesis.

[4].Salwan S. Dihrab*, K. Sopian. (2010). Electricity generation of hybrid PV/wind systems in Iraq. Malaysia: University Kebangsaan Malaysia

[5].Soteris Kalogirou. Solar energy engineering: processes and systems, 1st edn.

[6].Timur Gül (2004).Integrated Analysis of Hybrid Systems for Rural Electrification in Developing Countries, Stockholm.

[7].J.F. Manwell, J.G. McGowan and A.L. Rogers (2002). Wind energy explained theory, design and application. University of Massachusetts, Amherst, USA.

[8].C. Dennis Barley, Debra J. Lew1, and Lawrence T. (1997). Sizing wind/ PV hybrids for households in Inner Mongolia. Austin: Texas Ethiopian Television (ETV) news. http://www.erta.gov.et January 2012

[9]. HOMER, The Optimization Model for Distributed Power: http://www.nrel.gov/homer

[10].Prof. Antonio Ficarella. A current and future state of art development of hybrid energy system using wind and PV- solar. Rollo Dario

[11].Duffie J.A., Beckman W.A. (1991) "Solar Engineering of Thermal Processes", 3rd Edn. Wiley, New York,

[12].Frank Fiedler, Victor Pazmino, Irati Berruezo, Victor Maison. PV-wind hybrid systems for Swedish locations. Högskolan Dalarna: Borlänge

[13].M. Muralikrishna1 and V. Lakshminarayana, (2008). Hybrid (solar and wind) energy systems for rural electrification. Kilakarai, Tamil Nadu, India, vol. 3, no. 5

[14].S. Diaf 1*, D. Diaf, M. Belhamel, M. Haddadi, A. Louche. A methodology for optimal sizing of autonomous hybrid PV/wind system. France: Ajaccio

[15].Ethiopian National Metreological Agency

[16].Drake F. and, Mulugetta Y. (1996) "Assessment of solar and wind energy in Ethiopia. I. Solar energy", Solar Energy, Vol. 57, No. 3, pp. 205-217

[17].Mulugetta Y. and Drake F. (1996) "Assessment of solar and wind energy resources in Ethiopia: II. Wind energy", *Solar Energy*, Vol. 57, No. 4, pp. 323-334

[18].http://en.wikipedia.org

[19].Ethiopia news / GTZ Staff Magazine/August2010. www.enervest.de/fileadmin/downloads/gtz060810. January 2012

[20].Getachew Asaye. EEPCo Human Power Training and Development. Over Head Distribution Training 2011/12

[21].http://www.alibaba.com/products/denyo_generator_with_ATS/--410402.html. January 2012

[22].http://www.tradingeconomics.com/ethiopia/population-growth-annual-percent-wb-data.html

[23].http://www.tradingeconomics.com/ethiopia/rural-population-percent-of-total-population-wb-data.html

[24].http://www.lorentz.de/info@lorentz.de 18 Jan 2012

[25].A. S. Pabla "Electric power distribution", 6th edition, Tata McGraw Hill Edition Private Limited, New Delhi

[26].Wind Power to be Competitive with Natural Gas by 2016 Monday 14 November 2011. http://oilprice.com/Alternative-Energy/Wind-Power/Wind-Power-To-Be-Competitive-With-Natural-Gas-By-2016.html. January 2012

[27].Renewable 2011 global report, version2.0/07/2011. http://www.ren21.net

[28].Hardy diesel generators. http://www.hardydiesel.com/diesel-generators-7-33-kw.html. January 2012