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Addis Ababa Institute of Technology

School of Graduate

Energy Center

Techno – Economic Feasibility Study of Solar and Wind Energy Potential for Kombolcha Industrial Park

A thesis submitted to the School of Graduate Studies of Addis Ababa University Institute of Technology in partial fulfillment for the degree of Masters of Science in Energy of Technology.

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Certification

I, the undersigned, certify that I read and here by recommend for the acceptance by Addis Ababa University, Addis Ababa Institute of Technology, Energy Center a thesis entitled " Assessment of Solar and Wind Energy Potential for Electrification of Kombolcha Industrial Park". This certificate used as a partial fulfilment of the requirement for the degree of Master of Science in Energy Technology.

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Declaration

I, the undersigned, declare that this thesis is my original work, and has not been presented for a degree in this or other universities, and all sources of materials used for this thesis work have been fully acknowledged. This thesis is submitted in partial fulfilment of the requirement for Master's Degree in Energy Technology at Addis Ababa University and to be made available at the university's Library under the role of the Library.

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ADDIS ABABA UNIVERSITY

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ENERGY CENTER

Assessment of Solar and Wind Energy Potential for Electrification of Kombolcha Industrial Park

By Mekdes Paulos Mulat

Approved by Board of Examiners

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Abstract

Ethiopia being one of the developing countries, industrial park is one of the options it has chosen to improve its economy. While the country is involved in works of different sectors, nationwide electricity access is still a major challenge. With the problem of lack of sufficient electricity, industrial parks also face challenges in blackout and interruption of electricity. This thesis is basically a case study addressing the techno-economic feasibility study of solar and wind energy potential for Kombolcha Industrial Park (KIP) as an off-grid system. With different methods starting from data collection incorporating site visit, qualitative data of interview, questionnaire, data collection from different governmental office the analysis was begun. Further analysis was done using Matlab and HOMER to model, simulate, and state the most optimized system. The viability of solar and wind energy system was analyzed using data collected from National Metrology Agency as a primary input. With the utilization of Matlab, a specific solar PV was chosen along with the site data of solar irradiation, it was simulated to give a viable outcome. The wind energy viability was also assessed to give a positive output. This being said the current energy demand of KIP is 2.8 MW. At present, to withstand the challenge, the industrial park uses diesel generators to cover their energy demand. The solar and wind potential was predicted using HOMER software taking the collected data as an input. The economical and emission reduction aspect was also estimated using HOMER. One of the best options of the technology mix was to generate the required 2.8 MW of electrical power by combing 69% (1.8 MW) of PV modules with 31% (1.0 MW) of wind turbine with cost of energy of USD 0.198/ kWh. However, this costs around USD 19 million. It has been with much cheaper cost of USD 6.65 million is required the 2.8 MW using only PV modules with battery and cost of energy of USD 0.07/kWh. The total free rooftop area of the park is around 43.3 thousand square meters. All the seven park's sheds have V-shaped ceilings. One side of the ceiling is facing towards the south and the other half is facing toward the north. Totally 14,250 - PV modules have to be mounted to generate the designed power on the south facing rooftop occupant 20 thousand square meter. The park uses a total amount of 1,080 liters of diesel per month to run a generator when interruption of power occurs. Emitting a total estimated emission of 24 tCO2 e per annum.

Keywords: Solar Photovoltaic, Wind Energy, Industrial Park

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Nomenclature

Symbols

W	Watt
h	Hour
l	Liter
m	Meter
V	Voltage
I	Current
P	Power
R_{sh}	Shunt Resister
Rs	Series Resistance
R_P	Parallel Resistance
V_{mpp}	Voltage at maximum power point
I_{mpp}	Current at maximum power point
I_D	Diode current
I_{sh}	Shunt Current
$V_{oc,n}$	Nominal open-circuit voltage
$I_{sc,n}$	Nominal short-circuit current
Vt	Thermal voltage
G	Radiation Intensity
G_{GLOB}	Global Solar Radiance
G_{REF}	Incidence Solar Radiance
Gn	Nominal Irradiance
G_B	Beam Radiation
G_D	Diffuse Radiation
T	Temperature

Ta	Ambient Temperature
^{o}C	Degree Centigrade
N	Any day of the year
K_v	Open circuit voltage/temperature coefficient
K_I	Short circuit current/temperature coefficient
kW	Kilowatt
kWh	Kilowatt hour
MW	Megawatt
kJ	Kilojoule
c	Weibull scale factor
k	Weibull shape factor

Abbreviation

EIPs	Eco Industrial Parks
IP	Industrial Park
IPD	Industrial park development
GoE	Government of Ethiopia
CRGE	Climate-Resilient Green Economy
IPDC	Industrial Park Development Cooperation
GTP	Growth and Transformational Plan
KIP	Kombolcha Industrial Park
LCOE	Levelized cost of energy (LCOE)
UTC	Coordinated Universal Time
EAT	East African Time
PV	Photovoltaic
MPPT	Maximum Power Point Tracing
MW	megawatt
STC	Standard Test Condition

NOCT	Nominal Operating Cell Temperature
AST	Apparent Solar Time
LST	Local Solar Time
LSN	Local Solar Noon
SL	Standard Longitude
LL	Local Longitude
ET	Equation of Time
NPC	Net Present Cost
WT	Wind Turbine
SWT	Siemens Wind Turbine (Wind Turbine Brand)
KC	KYOCERA (PV panel Brand)
CO_2	Carbon dioxide
COE	Cost of Energy
AM	Ante Meridiem (Before Noon)
PM	Post Meridiem (After Noon)

Greek Symbols

ρ	Density
η	Efficiency
β	Tilt angle of solar panel (slope)
Ķ	Boltzmann constant
δ	Declination angle
θ	Incident angle of Solar radiation
θz	Zenith angle
γ	Azimuth angle
L′	Latitude angle
H′	Hour angle

Chapter One

1. Introduction

This chapter deals with the introduction part of this thesis. It comprises of background of the study dealing with the major background information of the thesis topic, statement of the problem, objective of the study, research questions, significance of the study, scope of the study, and outline of the study.

Ethiopia is one of the developing countries in the world which tries to improve its economy in works involved with different sectors. Industrial park is one of the options the country is using nationwide to tackle economic problems. Though these parks are energy intensive, the country's energy demand is still not sufficient to reach them adequately in the near future. Additionally, power interruption and blackout happen not only in household and commercial buildings but also in the industrial sectors. This research studies the solar photovoltaic and wind energy potential of one of these parks named as Kombolcha Industrial Park. In general, the 20's century has concern about global climate change. It is vital to search for reliable, environmentally friendly and renewable source of energy to meet the rising demand of electricity.

An energy that is found naturally and replenished constantly are termed to be renewable energy. In definition, it is energy generated from solar, wind, biofuels, geothermal, hydropower and ocean resources[1]. Sustainability is a worldwide concern that must be given major attention. Consumption of natural resources, pollution, global warming, climate change, everlasting interest of mankind, are the reasons why the shift to renewable energy is significant for the future generation.

1.1 Background of the Study

A community of firms settling to work while enhancing sustainability, being linked and organized in an identical area is termed to be Eco-Industrial parks (EIPs). Even though Industrial Parks (IPs) are similar in ways such as sharing location and joint management, they are invested in the aim of economic performance rather than giving concern to the environment [2].

Study regarding renewable energy power supply potential for industry park is an area of study where it needs various expertise to work on. It also requires several assessments to have a precise final output. For a better economical level, developing countries are considering industrial park as a major option. Industrial parks can play a great role in enhancing economic improvement by alluring investment, technological promotion, innovation, and increasing employment. However, industrial park faces challenges in designing precise pathways towards reaching its goal of development [2].

As of the first growth and transformation plan of the Government of the Federal Democratic Republic of Ethiopia, assertive result can be attained regarding the increment of economic growth [3]. Ethiopia's plan in taking a sustainable and environmentally friendly growth path, the Climate Resilient Green Economy Strategy (CRGE) was embarked in 2011.

While assuring climate resilient system for production, the industrial sector of the growth and transformation plan (GTP) is the main driver for growth (increase the share of industrial sector in the GDP from 15.1 percent to 22.3 percent by 2020). Industrial Park Development Corporation (IDPC) was established in 2014, to support this goal [4] .

Seventeen industrial parks are intended to be roll-out across the country by 2025. Five industrial parks are currently operational, namely: Hawassa IP, Makelle IP, Bole Lemi IP, Komblocha IP and Adama IP [5]. Table 1.1 portrays the list of EIPs in Ethiopia which has already started operation as well as those in the plan to start operation. Similarly, Figure 1.1 shows the respective locations of industrial parks in Ethiopia. It shows the current operational and soon to be launched industries located in different parts of Ethiopia.

Table 1.1 List of Eco-Industrial parks in Ethiopia

Name of Industrial parks	Location from Addis Ababa	Eligible industries	Develope d by	Remark
Addis Industrial Village	Addis Ababa	Apparel	IPDC	Operation al
Bolle Lemi phase I	Addis Ababa	Apparel	IPDC	Operation al
Bolle Lemi II	Addis Ababa	Textile and Apparel	IPDC	-
Kilinto	Addis Ababa	Mixed (agro-processing, pharmaceuticals….)	IPDC	-
Hawassa	South	Textile and Apparel	IPDC	Operation al
Dire Dewa	East	Textile and Apparel, Vehicle assembly and Food processing	IPDC	In progress
Kombolcha	North-East	Textile and Apparel, Food processing	IPDC	Operation al
Mekelle	North	Textile and Apparel, Food processing	IPDC	Operation al
Adama	South-East	Textile and Apparel, Vehicle assembly and food processing	IPDC	-
Bahir Dar	North-west	Textile and Apparel, Food processing	IPDC	-
Jimma	South-West	Textile and Apparel, Food processing	IPDC	-
Debr-Brhan Industrial park	North West		IPDC	-
Arerti Industrial Park	Eastern Central	Construction materials and household appliance manufacturing	IPDC	-
Air Lines Logistic Park	Addis Ababa	Logistics service	Private	-
Eastern industrial zone	Addis Ababa		Private	-
Hujian industrial park	Addis Ababa	Shoes, foot ware, handbags and accessories	Private	-

Kombolcha Industrial Park (KIP), is in the debub wello zone of the Amhara Region, about 400 km from the federal capital, Addis Ababa. The park occupies 75 hectares of land, and has 12 sheds, where it is expected to create 20,000 new jobs. The park is dedicated to apparel products. The park also has plans to expand in phase two where it will occupy up to 1000 hectares of land in the future.

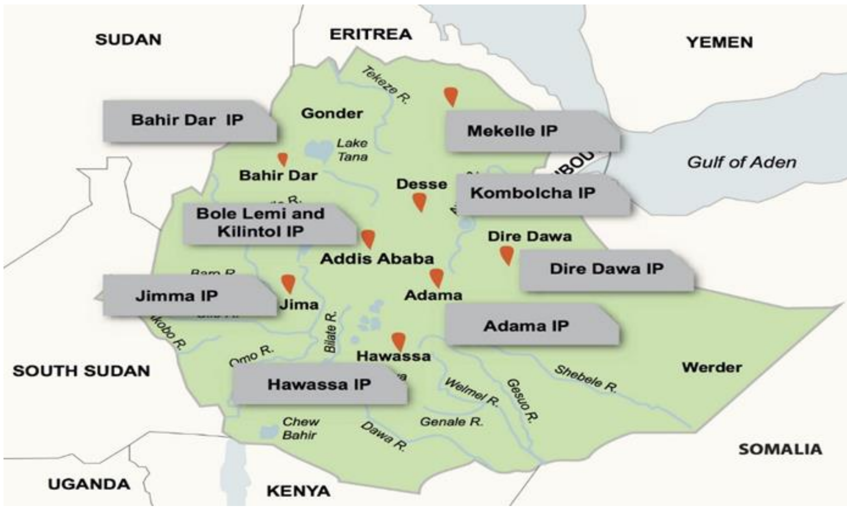


Figure 1.1 Industrial Parks in Ethiopia [5]

As Ethiopia is one of the developing countries, the work being done on industry parks have taken biggest investment from the country and is expected to bring a much bigger and better solution for the economy. Nevertheless, the fact that the population is increasing enormously, and many other private and government investments are currently in role, the power supply system from the government is struggling to reach out the nation.

Thus, studying on renewable energy for not only KIP but for other mega projects is one of the options for a better way of dealing with the shortage of power supply in Ethiopia. Afterwards the success of installing and using economical renewable energy will benefit the government in the role of saving power reaching out the nation in power supply.

Inability for Ethiopia's power supply to have 100% coverage of power to the industry park and usage of fossil fuel like diesel for running generators has its own major consequence. It not only affects the big hope Ethiopia has on improvement of economy based on the concept of green Industrial Park, but it also affects the attraction of foreign investors to come to Ethiopia and invest.

1.2 Statement of the Problem

An adequate and reliable power supply system is essential for any industry to be productive. Currently the energy demand of Kombolcha Industrial Park (KIP) is 2.8 MW. The park is not working at its full potential for the reason of different factors, and the energy demand is so much less than the expected. Even with the much lesser energy demand of the park, there is still power interruption almost every day. Since the industry park is aimed to continuously run and the available power is insufficient, diesel engines are used. Nonetheless, generator usage to cover power shortage at KIP can cause problem in contradicting the ideology of eco-industry. Investigating the exact energy demand of the park and assessing renewable energy-based technology to generate electricity is an option. The possibility to have an off-grid system while considering renewable source of energy is the main background. With the range of challenges to properly analyze the input parameters for the specific site location and challenging emission reduction potentials for the renewable energy appliance, industrial parks can be a basic focus point to analyze this topic. This paper aims to address this gap through different procedures and investigation and focus on solar and wind energy potential for electrification of KIP.

1.3 Objective of the Study

1.3.1 General Objective

The general objective of the thesis is to assess the solar and wind energy potential for the electrification of Kombolcha Industrial Park.

1.3.2 Specific Objective

- Energy demand assessment
- Investigation of the viability of solar and wind energy for KIP, and to simulate solar PV energy for KIP
- Assessment of wind Energy for KIP
- Optimization of solar and wind energy system for KIP
- Estimation of emission reduction potential and economic aspect of the optimized system

1.4 Research Questions

This research questions have been raised to be investigated in this study.

1. What is the solar PV energy potential for KIP?
2. What is the wind Energy potential for KIP?
3. The optimization of solar PV and wind energy for KIP?
4. What would be the potential of emission reduction and economic benefit using the optimized system of solar and wind?

1.5 Significance of the Study

Renewable energy in general is the road to build better future for the next generation. As Ethiopia struggles to reach out energy throughout the nation, studying renewable energy for any means is vital. This research study will have the following significances:

- It will be taken as a base input for further studies
- Similar research can be done for all the industrial parks in Ethiopia
- It will help demonstrate what sort of renewable energy is suitable for KIP

1.6 Scope of the study

This study investigates the industrial park located in Kombolcha. It studies the actual energy demand of the park and assesses the techno economic feasibility of solar and wind energy potential. With the use of two software, namely, Matlab and HOMER, it aims to estimate the potential to cover the energy demand from the chosen renewable energy as an off-grid system.

1.7 Outline of the Thesis

This study is organized in five chapters. The first chapter contains the introduction of the study, which comprises; background of the study, statement of the problem, objectives of the study, significance and scope of the study. The second chapter explores the theoretical, empirical review and related studies of related literatures. The third chapter deals with a detailed aspect of procedures and methodology for this study. It is comprised of: description of the study area, Solar energy analysis procedure, wind energy analysis procedure and the homer optimization. Following is chapter four, presenting the result and discussion. Finally, chapter five includes the conclusion and recommendation for future work and followed by bibliography and appendix.

Chapter Two

2. Literature Review

This chapter reviews different literatures related to this thesis. It discusses various literatures of similar works done in both developed and developing countries. Related studies of similar methodologies are also discussed.

Firms sorted out and connected in a similar region targeting to enhance sustainability are termed to be Eco-Industrial parks (EIPs). As far as shared location and joint management, Industrial Parks (IPs) have identical features from EIPs. However, IPs are regularly invested to boost financial execution instead of natural concerns. It was characterized that EIPs as a community of manufacturing and service businesses in a specific geographic area and common property pursuing enhanced environmental, economic and social performance through shared administration of environmental and social issues [6]. Building blocks of the EIPs approach, incorporate a green design of park infrastructure, cleaner production, contamination counteraction, energy efficiency, and inter-company partnering. After the advancement of EIPs in the 90s, the first evidence of the concept emerged in 1989 in Kalundborg, Denmark, while different nations, for example, Australia and Japan followed later [7].

In the last decade, climate change has without a doubt brought about extreme drought, for example, the El Nino in numerous areas of our planate. Solar power stands out as the single most abundant energy resource available on earth and harnessing this renewable energy source will bring the required energy security for developing countries [8].

As this thesis is a case study, the solar PV and wind potential for the Kombolcha Industrial Park and its techno-economic feasibility is the major research gap. It investigates the actual energy demand at the site and aims estimate the potential to cover the sites energy demand by selected renewable energy systems and using software.

Since around half of the world energy is devoured by the industrial process, renewable energy development (particularly solar energy) in such sectors is indispensable. The nature of industrial parks makes them the best hotspots for applying alternative energy sources such as solar energy. Solar Energy technologies appropriate for industrial parks can be of the following; Thermal Collector Systems, Photovoltaics, Solar Ponds, Central Receivers. Photovoltaics (PV) systems is a technology that uses solar cell, which converts sunlight energy in photons to electricity by means of the photoelectric phenomenon. The most well-known PV system in developing countries is the stand-alone PV. The Stand-alone PV produces energy that is coordinated by the load and is supported by energy storage systems such as batteries to give electricity when there is a sun-light shortage [9].

Trends in different countries can be viewed for instance. Industrial parks in Vietnam by 2016 were over 300, with more than 200 already operational. Hydropower and coal are the significant energy sources. As per the nation's capacity improvement plan, the solar PV capacity is expected to increase from 6-7 MW in 2015 to 850 by 2020 and 4,000 MW by 2025, making solar energy source the largest compared to wind and biomass [10].

Cambodia has likewise encountered an increasing electricity demand in its industrial sectors. In 2015, as indicated by the Electricité du Cambodge, power consumption by industries was 1.13GWh. To accomplish its green development strategy and stay aware with the agreement of climate in Paris, the country has begun renewable sources particularly solar energy as electricity source [11].

Rwanda has been practicing industrial zones since 2006. Different Industrial parks have been initiated in Kigali. In 2009 after the promotion of Rwanda toward East African Community, "Kigali Special Economic Zone" was initiated, holding up to nine industrial parks. The country has a plan to support its energy demand with sustainable sources, particularly solar energy which is freely available in nature [12].

At the point when Ethiopia is thought about, industrial parks are being practiced all over the nation. Five industrial parks are currently launched and are in operation [13]. All are basing on electricity from the grid. These parks run by Industrial Parks Development Corporation (IPDC), can possibly catalyze the development in urban communities, advance economic change and create jobs while sustaining the environment.

Kenya moreover has an arrangement to be globally industrialized middle-income country through its manufacturing sector by 2030. In 2014, Changoi tea farm, owned by Williamson Tea, installed a 1MW solar PV by the British Solar Energy company Solarcentury as can be seen in Figure 2.1. It shows that solar PV was installed possessing ground area. The project reduces the company's energy cost by 30% and allows it to use an environmentally friendly system. [14].

Figure 2.1 Red Lands Roses Solar Project, Kenya *[14]*

2.1 Solar PV Systems

2.1.1 Sources of Solar Energy

Solar energy is the energy that is found from the Sun. The sun is a sphere of intensely hot gaseous matter with a diameter of 1.39×10^9m and is, on average 1.5×10^{11}m from the earth. [15]. The Sun's spectral distribution is the range and intensity of the wavelengths in its emitted radiation. This is a significant issue because different types of solar cells respond differently to the various wavelengths in sunlight. It is notable that the Sun's spectrum is similar to that of a perfect emitter, known as a black body, at a temperature of about 6000 K. [16].

Direct and indirect solar radiation are received by solar cells when installed. The diffuse component represents light scattered by clouds and dust particles in the atmosphere; the albedo component represents light reflected from the ground or objects such as trees and buildings. The combined effect of direct, diffuse and albedo are the components the electrical output of cells basically relies upon.

2.1.2 Components of Photovoltaic System

The solar energy conversion into electricity takes place in a semiconductor device that is known as solar cell. A solar cell is a unit that conveys a certain quantity of electrical power. In order to use solar electricity for practical devices which require a specific voltage or current for their operation, a number of solar cells must be connected together to form a solar panel, also known as a PV module. As Figure 2.2 shows the component of a photovoltaic system, PV modules are the core of the framework and are usually called the power generators. For large-scale generation of solar electricity, the solar panels are connected together into a PV array.

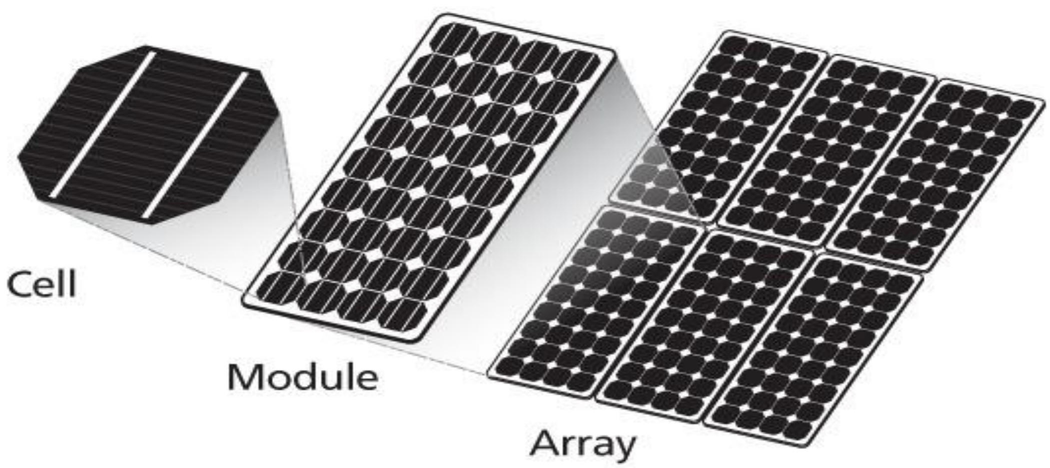


Figure 2.2 Components of Photovoltaic System [17]

The essential gadget of a PV system is the PV cell. A photovoltaic cell is a semiconductor diode with p–n junction exposed to sunlight. Photovoltaic cells are made of several types of semiconductors utilizing diverse manufacturing processes. PV devices represent a nonlinear I–V attribute with adjustment of numerous parameters. The voltage of a solar cell does not rely firmly on the solar irradiance however relies basically on the cell temperature. PV modules may be designed to function at various voltages by joining solar cells in series. At the point when solar cells absorb sunlight, free electrons and holes are created at positive/negative junctions [17].

2.1.3 Solar Energy Resource in Ethiopia

The daily average radiation is considered to be 5.26 kWh/m^2 on yearly basis for Ethiopia according to studies. This varies significantly during the year, ranging from a minimum of 4.55 kWh/m^2 in July to a maximum of 5.55 kWh/m^2 in February and March. On regional basis, the yearly average radiation ranges from values of 4.25 kWh/m^2 in Western Ethiopia (Itang, Gambella) to values as high as 6.25 kWh/m^2 Northern Ethiopia (Adigrat, Tigray) [15]. When Ethiopia is considered a whole, Studies show that the average daily solar radiation reaches to 5.2 kWh/m^2 [18].

2.1.4 Solar PV System Use

Solar energy found from the sun can be utilized as photovoltaic for electric production. The fortunate conditions, developing innovation and declining investment cost leads Photovoltaic (PV) systems to play a significant role in providing the developing interest for energy security of upcoming generation [19]. Various investigation has been conducted to assess the economic and environmental importance of alternative energy sources, especially PV systems. It was studied that the economic performance of grid-connected commercial PV systems estimated the Net-Present Value (NPV) and the Internal Rate of Return (IRR) for a 1.2 MW capacity grid connected PV plant installed at the Colorado State University [20]. It was estimated that the IRR of the project to be 10.7% given tax credits and rebates and further suggested a minimum of 4% tax credit to breakeven, and further recommended that apart from favorable climate conditions, cost of the PV system, money related aide program and energy valuing are vital for the economic viability of PV projects. Another study used software programs such as HOMER and Microsoft Excel 2007 to break down the energy and economic viability of domestic solar PV systems in Ireland and found that PV systems are not reasonable given the atmosphere states of Ireland [21]. Another work evaluated the environmental and the energy ramifications of PV installments with strategies, for example, Energy Payback Time (EPBT) and Greenhouse Gas Return on Investment (GROI) and expressed PV's as safe and sustainable [22]. A study following a stochastic approach used a Monte Carlo simulation (used to display the likelihood of various results) to generate data and identified the sites and sizes of high performing plants along with the economic analysis [19].

Levelized cost of energy (LCOE) model was additionally used to evaluate the expense of PV power in Kenya and recommended that LCOE of grid-connected PV systems are beneath the conventional power plants in Kenya [23].

2.2 Wind Energy

2.2.1 Overview of Wind Power

Wind is the movement of air, caused by the rotation of the earth and by the uneven heating of the planet’s surface by the sun. Wind energy converts kinetic energy that is present in the wind into more useful forms of energy, for example, mechanical energy and electricity. This is accomplished using wind turbines, which convert the kinetic energy of wind in to electrical energy. It tends to be portrayed that wind turbine converts the kinetic energy in wind into electricity as follows; The kinetic energy of the wind rotates the blades of a wind turbine. Kinetic energy of wind is converted to mechanical energy when the blades rotate a shaft. Subsequently, the mechanical energy is converted to electrical energy when the shaft is connected to a generator [24].

The kinetic energy in the wind is a promising source of sustainable power source with huge potential in various parts of the world. The amount of power in the wind is profoundly subject to the speed of the wind. Since the power in the wind is directly proportional to the cube of the wind speed, little contrasts in the wind speed have a major effect in the power extracted from it. To arrive at financial practicality of a wind energy installation, a very accurate resource assessment is required to decide the attribute of the wind both in space and time with respect to orography, roughness and climatology conditions [25].

With regards to wind energy off-grid applications in Ethiopia, a company named Ethio Resource Group (ERG), which is a renewable energy research company, designed and implemented a small wind powered system. This wind powered system was done for off grid rural electrification in Ethiopia. The location of the project is named Menz Gera Midir Wereda, north Shewa zone, Amhara regional State, Ethiopia. The offgrid system consisted of micro wind turbine with storage batteries. The project is comprised of six wind turbine each having 1.4 kW generating capacity. Making a total generating capacity of 8.4 kW. This project beneficiaries are 200 household within six villages [26]

2.2.2 Wind Energy Resource in Ethiopia

Ethiopia likewise has exploitable hold of 1,350GW wind energy with an average speed of 3.5–5.5m/s, 6 hours/day. Small towns, villages, farms and other scattered loads in remote areas provide ideal situation in which electricity generation from wind is helpful contrasted with traditional diesel generation or grid connection.

From an investigation, the data recognizes two basic zones with homogenous periodicity separated by the rift valley. In the first zone of the study, there are two well characterized high wind speed occurring respectively, between March and May and between September and November, according to location. In the second zone, covering the greater part of the Ogaden and the eastern lowlands, average wind velocity reaches maximum values between May and August [24].

2.3 Homer Model

HOMER (Hybrid Optimization of Multiple Energy Resources) is a computer model developed by the National Renewable Energy Laboratory, USA, to support in the design of micropower systems and to encourage the correlation of power generation technologies across a wide range of applications. HOMER models a power system's physical conduct and its lifecycle cost, which is the complete expense of installing and operating the system over its lifespan. It very well may be utilized to analyze diverse structure choices, in view of their technical and financial focal points. It likewise helps with comprehension and measuring the impacts of vulnerability or varieties in the sources of information.

HOMER performs simulation, optimization, and sensitivity analyses. In the simulation process, the model decides the specialized achievability and life-cycle cost of a specific energy system configuration during each hour of the year. In the optimization process, HOMER simulates various possible system configurations that fulfil the technical constraints at the most minimal lifecycle cost. In the sensitivity analysis process, HOMER attempts numerous optimizations under a range of input assumptions to quantify the effects of variations in the input parameters. When used for sensitivity analysis, the model supports assessment of the effects of uncertainty or changes in the variables over which the user has no control, such as wind-speed, solar radiation or future fuel prices [27].

2.4 Related Studies

In 2014, Toyota Motor Corporation Australian introduced and completed a 500 kW solar power PV system for its manufacturing plant [28]. Table 2.1 describes the PV System components applied. Portraying that the system size is 500 kW along with various important components. Similarly, Figure 2.3 shows the illustration of the industrial solar system. It can be seen that the rooftop was utilized for the PV panel installation.

Table 2.1 PV system in Toyota Motor Corporation Australian [28]

System Size	500 kW
Annual Energy Production	668,460 kWh
Annual Emissions Reduction	668,460 kg CO_2-e
Solar Inverter	500 kW ABB Central Inverter
Solar Module	2000 Kyocera Modules

Figure 2.3 Illustration of Toyota 500kW Industrial Solar Power System [28]

While assessing wind resources and wind power potential, there is a study done for the city of Ardabil, Iran. The study researched the potential of wind using a long-term data source comprising of six years of a 3-hour period measured mean wind data. Monthly and annual wind speed variation was investigated. The monthly mean value of the shape parameter (k) and the monthly mean value of scale parameter (c) was additionally investigated. In general, the Ardabil site was found to have a good characteristic for wind potential [29].

Small wind turbines and their use in stand-alone power systems with battery storage was also studied. Turbine components, for example, generators, blades and towers are evaluated to feature their impact on turbine performance and safety. A significant issue in designing these systems is the proper characterization of the wind resource. Small turbines, less than about 50 kW in rated power, are utilized for a range of stand-alone applications from small systems for village electrification, to bigger systems for remote power in western countries. The sort and power requirement of the load can have a significant effect on the design of the system and the choice of inverter [30].

In Arkansas, a 100- foot wind turbine close to a western edge of the town remains as a guidepost for instance of sustainable power source for industry application. As can be seen in Figure 2.4 one wind turbine was considered to supply the power demand as the park. Regardless of whether the turbine for around nine years, in 2010 a lightning stroke and made the turbine incapable to work. In general, it was an important trial but it was contemplated that Arkansas is viewed as an unsuitable spot for wind energy [31].

Figure 2.4 Wind turbine for an industry in Arkansas, USA [31]

In Sokoto state Nigeria, investigation was done which prospects and cost-effectiveness of the usage of standalone PV/wind system. In Nigeria, Sokoto is an area with solar radiation of 6kWh/m2/day and wind speed of 5m/s at 10m above height. Utilizing the Homer optimization software, the ideal integrated RE system is 35.21kW PV, 3 x 25kW wind turbines, 12 x 24V lead acid battery and 17.44kW converter. The study led up to a total capital cost of $249910.24, the replacement cost of $82914.85 and maintenance cost of $53,802.80 for 25 years. In spite of the fact that the underlying capital expense is high however the long-term benefits are tremendous, considering the significant expense of executing the rural electrification, combined with a hike in electricity tariff. There is likewise a recompense time of 5 years. The outcomes suggests a standalone PV/wind system is feasible in rural communities of Sokoto with 100% contamination free energy system [32].

A study regarding feasibility study of a small hydro/ PV/wind system was done for off grid rural electrification in Dejen, Ethiopia. To make the locale offgrid, an optimization and sensitivity analysis was done using HOMER. Electric load for the fundamental needs of the community for example, for lighting, radio, television, water pumps was assessed [33].

A research done on assessment of wind resource at Adama II wind farm brought about an estimation to evaluate the availability of wind resource. The source data at Adama II wind farm demonstrated the mean wind speed to be 8.62 m/s at 70 m height with mean wind power density of 440 W/m^2. Using the attributes of Sany SE7715 wind turbine, the yearly Energy production ranges from 1.5 to 11.99 GWH at the height of 70 m. The wind turbine has characteristics diameter of 77 m. Placing 102 number of SE7715 wind turbine the gross energy production is evaluated to be 664.7 GWh [34].

On an exploration done in regards to sustainable power source framework for Ethiopian remote area presents its work by designing a hybrid system of wind and photovoltaic power generation. This work comprises of primary work of exploring information of wind and solar irradiation for a remote site that is under study. The data were gathered from the national metrological agency and further analysis was done using HOMER. The analysis revealed that the site has sufficient solar energy potential and the wind potential is also adequate to be exploited for electricity generation using wind turbines with low cut-in wind speed. HOMER was used for simulation and design purpose. The result shows that the PV-wind turbine-generator -battery setup is said to have the lowest net present cost (NPC) making it be furthermost cost-effective. The NPC is $103,914, the cost of energy is 0.302$/kWh [35].

In developing countries such as Colombia, one of the most challenging issues is reaching and electrifying rural and remote areas. For this issue there was a research done regarding a study about a hybrid system of wind, PV and diesel, along with its feasibility. This study was also accomplished with the help of HOMER software. The study was conducted for seven communities searching for optimal design having economic convenience. The proposed configuration was done with economical point of view. The result showed that the combined diesel renewable configurations is the optimal system. The system is found to have an initial capital investment of $ 521,078, NPC of $ 836,210, with 0.473 $/kWh of COE [36].

On another thesis study the feasibility of micro hydro/wind/solar PV and biomass hybrid power system is studied in a selected rural area of Ethiopia. The chosen towns are situated in North west part of the country known as "Kidusyohanes", "Kundab" and "Debre". The study did the feasibility assessment by gathering the essential and analyzing using HOMER (Hybrid Optimization modeling for Electric Renewable) software. Solar and wind data were basically collected from the National Meteorological Agency of Ethiopia. The electric load for the community is evaluated and planned depending on the financial activities of the individuals in the territory. From the study the combination of Hydro/PV, Hydro/Biomass and PV is found with the least cost energy of $0.246/kWh, $0.218/kWh, $0.285/kWh for kidusyohanes, Kundab and Debre respectively [24].

It is a known fact that switching to a renewable source of energy is important to sustain the environment and reach sufficient energy supply. From reviewing different works of literatures, it very well may be seen that both developed and developing countries give a big concern to a study and application of solar energy as a renewable energy source to meet the energy demand for different sectors. Be that as it may, this research focuses on the aspects of renewable energy for industrial application.

Chapter Three

3. Methodology

This chapter describes the methodology applied for the careful execution of this thesis to assess the solar and wind energy potential for Kombolcha Industrial Park (KIP). Figure 3.1 shows an overview of the methodology to be followed. The figure describes the research approach this thesis has taken. It can be seen that the literature review primarily takes place. Then collecting data such as landscape figure using google earth, metrological data, IPDC data regarding KIP, interview for companies while site visit of KIP. After the collection of data, the next step is analyzing the data using excel. Afterward using the general mathematical formulas, the solar energy assessment and wind energy assessment using MATLAB and excel accordingly, takes place. Finally, the modeling and simulation using HOMER software proceeds. On this step, the economic aspect and emission reduction potential are also done.

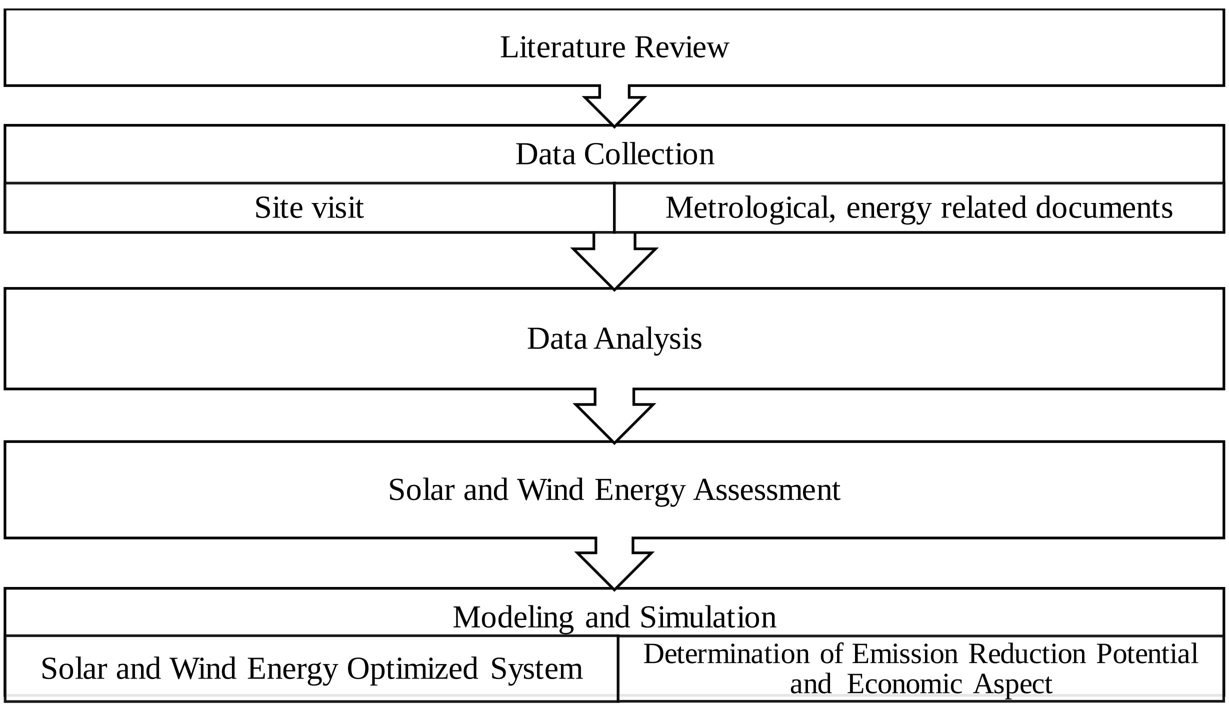


Figure 3.1 Flow Chart of the Study

Regarding data gathering methods and site identification Table 3.1 explains the data collection procedures taken. The approach explains that there are different offices where data is to be collected. The Major offices are Industrial Park Development Cooperation (IPDC), National Metrology Agency of Ethiopia, (NMA), Ethiopian Electric Power Cooperation (EEPCo).

Table 3.1 Data Collection Procedures

Method of Data Collection		
Primary Source		**Secondary Source**
Qualitative Data	Quantitative Data	▪ Information collected from government offices
▪ Interviews ▪ Questionnaires ▪ Observation	▪ Structured observation ▪ Analysis of existing statistics	
Data collected according to various offices		
Industrial Park Development Cooperation (IPDC)		
IPDC Energy Department	For Energy related questions	
IPDC Design Department	For the KIP layout and roof top area of the sheds	
IPDC Land Management Director	For locations of the KIP	
Kombolcha Industrial Park (KIP) Visit	Questionnaire or Interview to the investors or companies residing there	
	Questionnaire or Interview for the IPDC Project Coordinator of KIP	
	Site Observation	
National Metrology Agency (NMA)		
	Data enquiry of metrological data such as Solar radiation, Rainfall, Wind sped for the Kombolcha area	
Ethiopian Electric Cooperation (EEPCo)		
Energy Department	For Energy related questions	

3.1 Description of the Study Area

Here different types of collected data are analyzed. While analyzing data there are different procedures to be followed depending on the type of data collected. On the primary data collected such as; the questionnaire, interview and observation, it is summarized as a report as follows. Secondary data is also used such as metrological data which is analyzed based on the variables and range of data collected.

The Kombolcha Industrial Park (KIP) is located in Kombolcha which is 380 km from Addis Ababa. KIP started working since 2017. The park plans to have six phases. But currently, only the first phase has started working. The first phase covers 75 hectares (750,000 m^2) area of land. There are nine sheds built having different types of shed area. There are two different types of sheds, Shed Type I has an area of 5,500 m^2 and Shed Type II has an area of 11,000 m^2. The estimated power demand currently for the occupied sheds is up to 12 MW. The EEU has a plan to construct a transmission line near the park to meet the energy demand for future expansion.

3.1.1 Location and Site Visit

- Located at : **11°06'34.1" N 39°43'00.5" E**
- Occupies a land of area 750,000m^2 for phase-I
- The KIP is export oriented
- Has nine sheds, eight working;
- Have four companies currently working at the park; namely
    - **Saytex Spinning plc** occupying two sheds
    - **Carvico Ethiopia plc** occupying one shed
    - **Tribus** occupying one shed
    - **Punk kook** occupying four sheds
- Is currently being supplied 12 MW from the EEU.
- In the future plans to require up to 50 MW.
- Has two types of sheds Type I = 5,500 m^2 and Type II = 11,000 m^2.
- There are seven sheds of type I and two sheds of type II.

As can be seen from Figure 3.2 the KIP can be clearly seen as a top view holding the currently nine sheds built. It can also be seen that there are vast agricultural areas around the park. Which the IPDC aims in utilizing the land to build the next phases on agro-industry.

Figure 3.2 Top view of KIP

Different data has been collected based on the interview and questionnaire for the officials in concern. Table 3.2 describes the companies residing at the KIP. It shows that there are five investors which have already started working. From the occupied sheds five of the sheds are Shed type I while the others two are Shed Type II.

Table 3.2 Summary of KIP Site Report

Company Name	No. of shed occupied	Country of origin	Started working since	Type of products produced
Sayntex Spinning PLC	2 (Shed Type I and II)	China	December 2017	Apparel
Carvico Ethiopia PLC	1 (Shed Type I)	Italian	April 2018	Apparel
Seyang Corporation	1 (Shed Type I)	Korea	March 2019	Apparel
Trybus Bridgetex Ethiopia PLC	1 (Shed Type I)	Joint (China and USA)	June 2018	Apparel
Punk Kook PLC	2 (Shed Type I and II)	Korea	February 2018	Leather

The yearly energy consumption is presented in Table 3.3. It shows the energy consumption based on the monthly bills according to the different companies.

Table 3.3 Survey KIP Energy Consumption According to the Companies

Month	Sayntex Spinning PLC	Carvico Ethiopia PLC	Seyang Corporation	Trybus Bridgetex Ethiopia PLC	Punk Kook PLC
August 2018	166,815 kWh	69,894 kWh	-	20,988 kWh	18,513 kWh
September 2018	95,931 kWh	41,580 kWh	-	18,612 kWh	17,919 kWh
October 2018	191,961 kWh	60,885 kWh	-	46,827 kWh	3,168 kWh
November 2018	138,798 kWh	23,562 kWh	-	47,718 kWh	4,851 kWh
December 2018	275,022 kWh	53,856 kWh	-	84,546 kWh	39,303 kWh
January 2019	265,023 kWh	43,461 kWh	-	83,358 kWh	54,945 kWh
February 2019	192,258 kWh	49,995 kWh	-	100,584 kWh	60,687 kWh
March 2019	116,127 kWh	44,055 kWh	3,863 kWh	94,743 kWh	60,291 kWh
April 2019	13,662 kWh	77,814 kWh	4,956 kWh	119,592 kWh	69,003 kWh
May 2019	125,532 kWh	79,398 kWh	10,474 kWh	99,198 kWh	4,455 kWh
June 2019	194,535 kWh	94,446 kWh	11,620 kWh	115,335 kWh	47,520 kWh
July 2019	189,783 kWh	133,452 kWh	13,303 kWh	136,224 kWh	28,908 kWh
Average (kWh)	163,787	64,367	8,843	80,644	34,130
Av. monthly diesel consumption	400 liters	80 liters	100 liters	150 liters	350 liters

According to each companies demand in the industry park, diesel generators are used as a back up to fill the blackout and interruption of power.

Currently, the park works 8h/day and five days a week. Where the actual record from the monthly bill from each company presenting maximum monthly consumption to be 2850.4 kWh. Table 3.4 describes the Summary of total monthly, daily and hourly energy consumption of KIP.

Table 3.4 Summary of KIP Total Energy Consumption

Month	Working Days in Month	Working hours in Month	Monthly Total Energy Consumption (kWh/month)	Daily Total Energy Consumption (kWh/day)	Hourly Total Energy Consumption (kWh)
January	23	184	446,787	19425.52	2428.19
February	20	160	403,524	20176.2	2522.02
March	22	176	319,079	14503.59	1812.95
April	21	168	285,027	13572.71	1696.58
May	23	184	319,057	13872.04	1734.01
June	21	168	463,456	22069.33	2758.66
July	22	176	501,670	22803.18	2850.39
August	23	184	276,210	12009.13	1501.14
September	20	160	174,042	8702.1	1087.76
October	23	184	302,841	13167	1645.87
November	22	176	214,929	9769.5	1221.18
December	21	168	452,727	21558.43	2694.81
		Average	351,771	16173	1996

The average monthly energy consumption is around 352, 000 kWh/month. It was explained that 12 MW is considered to be the required demand when the nine sheds built are to be occupied by investors and started working, Table 3.4.

3.1.2 Metrology for Solar Energy Estimation

Solar radiation and wind speed data was collected from the National Metrology Agency of Ethiopia. The data were collected in an interval of 15-minute for a yearly value based in Komblocha area. The time at which the data recorded was in Coordinated Universal Time (UTC) format. Thus, after converting the time into EAT (East African Time) the data was analyzed. While analyzing the solar data for the reason of accurate record and reliability the record for 2016 was selected. The daily average power/insolation, and the average daily energy were analyzed. It was found that maximum daily average insolation for year 2016 is 8186.4 (W.min/m^2/d)and minimum daily average insolation of 1431.859 (W.min/m^2/d). Figure 3.3 represents the yearly maximum and minimum average daily energy values. It shows that maximum daily average energy is 491 (kJ/m^2/d) on march 14,2016 and the minimum value falls on August 10,2016 having a value of 85.91 (kJ/m^2/d).

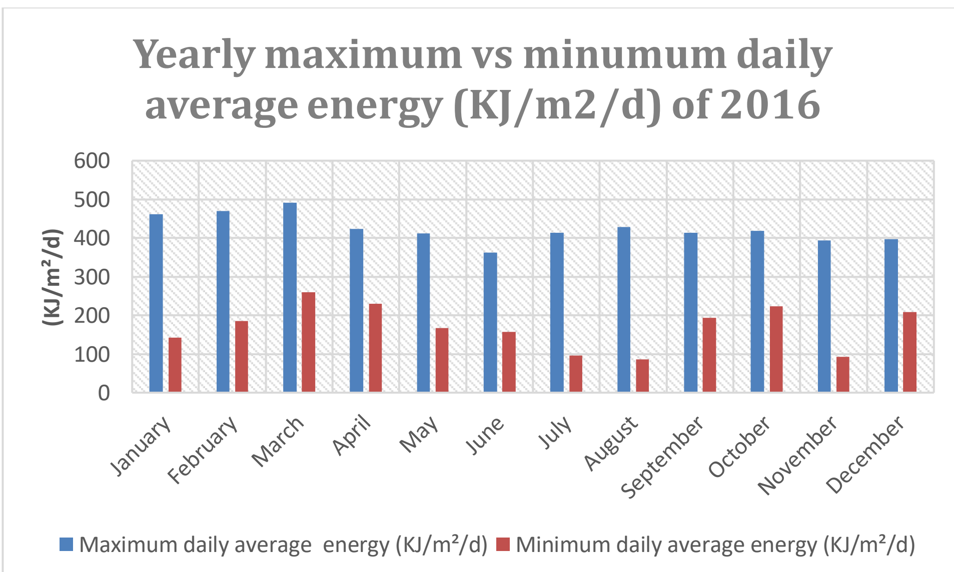


Figure 3.3 Yearly Maximum vs Minimum Daily Average Solar Energy Values of 2016 for Kombolcha

Considering the maximum and minimum energy values, the daily insolation recorded in each 15 minutes interval was evaluated. Figure 3.4 shows the insolation record (W/m^2) for March 14,2016 (which is the maximum value recorded).

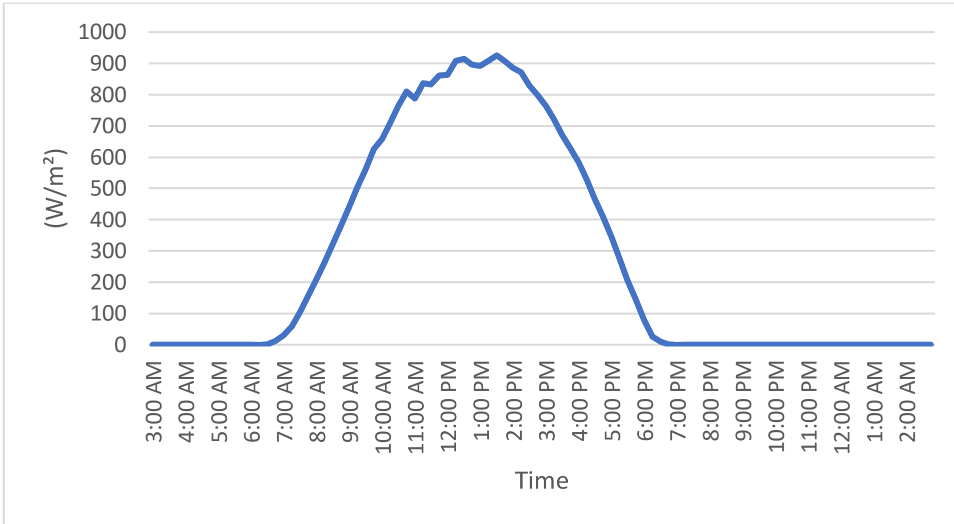


Figure 3.4 Daily Insolation (W/m²) Recording for March 14, 2016

As can be seen clearly from Figure 3.4 the effective time where there is potential insolation lies from 9:00 AM to 4:30 PM. Figure 3.5 represents the minimum value recorded for August 10,2016. It was analyzed that it has the minimum average daily energy value.

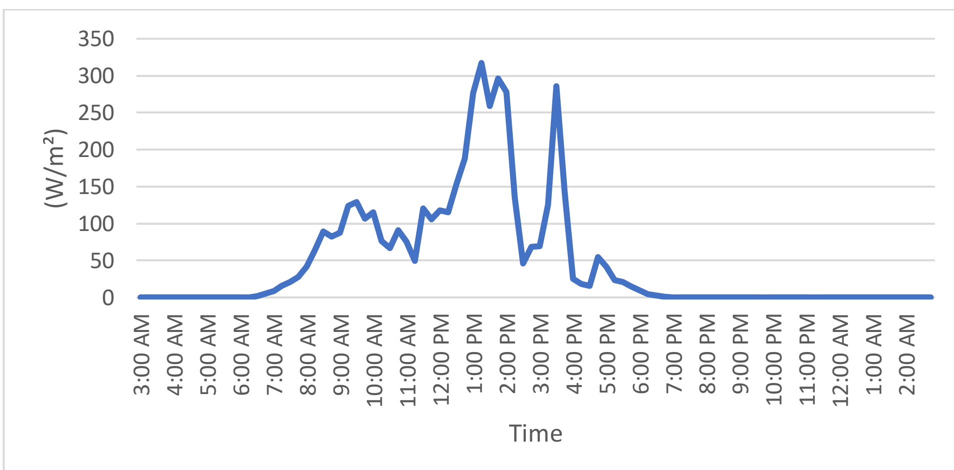


Figure 3.5 Daily Insolation (W/m²) Recording for August 10, 2016

In August, the insolation is less and not exceeding 325 W/m^2 electricity. Hence this is the time where backup is required.

Table 3.5 and Figure 3.6 shows the Average monthly insolation in terms of kWh/m^2/d.

Table 3.5 Average Monthly Insolation (kWh /m^2/d)

`	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
Average monthly insolation (kWh/m^2/d)	6.20	6.61	6.62	6.62	5.69	5.08	4.52	4.95	5.26	5.94	5.61	5.76	5.66

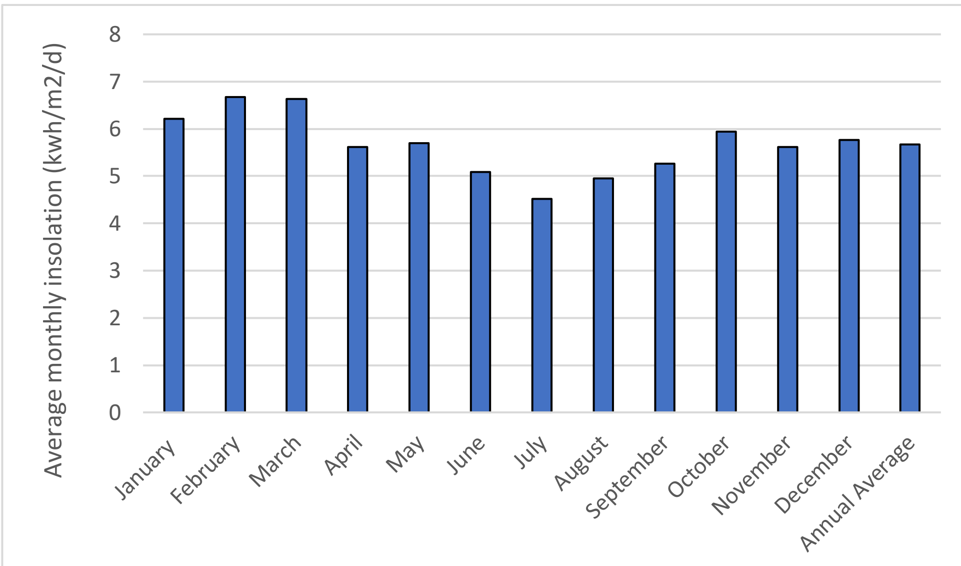


Figure 3.6 Average Monthly Insolation (kWh /m^2/d)

3.1.2 Metrology for Wind Energy Potential Determination

While analyzing the wind speed data, a four-year data was analyzed (2015-2018). Where the detailed analysis will be done for the 15-minute interval data as a whole, a sample daily average for year 2016 was analyzed. Using the 15-minute interval data for the data recorded at 2m for the location of Kombolcha, the maximum daily wind speed (m/s), minimum daily wind speed (m/s), monthly average wind speed (m/s) for each month was analyzed. The maximum daily wind speed is found to be 7.52 m/s on May 26, 2016. The minimum daily wind speed is found to be 1.16 m/s on August 10, 2016. The annual average wind speed (m/s) is around 3.45 m/s. Figure 3.7 presents the illustration of the analysis done.

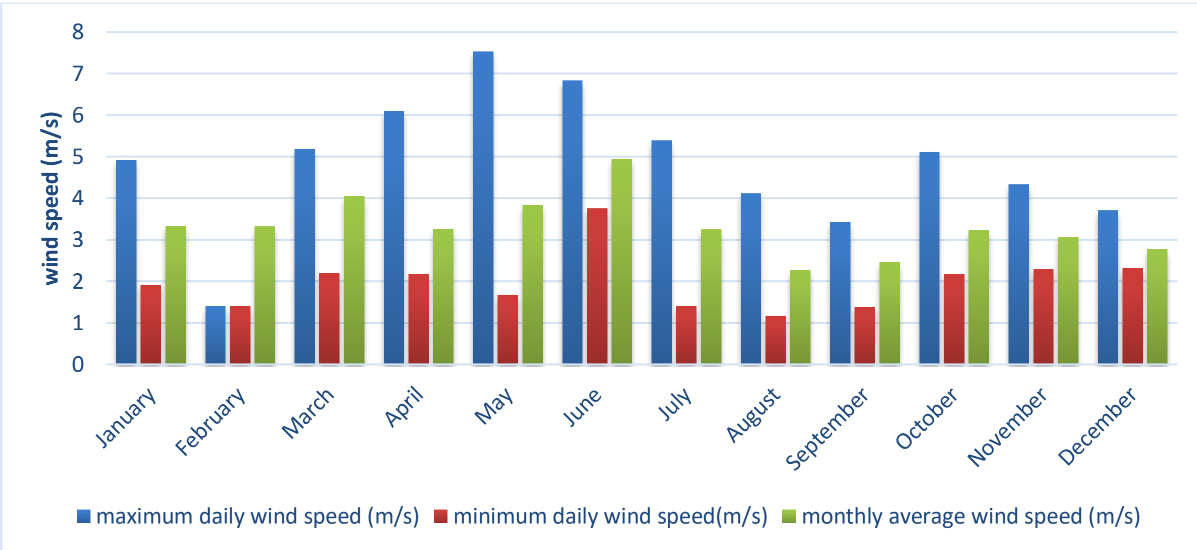


Figure 3.7 Yearly Maximum vs Minimum vs Average Daily Average Wind Speed (m/s) of 2016

Figure 3.7 shows how wind speed varies with time. Though maximum wind speed was in May, the average minimum value was in August.

3.2 Solar Energy Analysis Procedure

Engineering drawing of the Kombolcha industry park shed is shown in Figure 3.8. The rooftop cannot entirely be used to mount PV module, since some of its part is assigned as sunlight band (natural lighting) and ventilation.

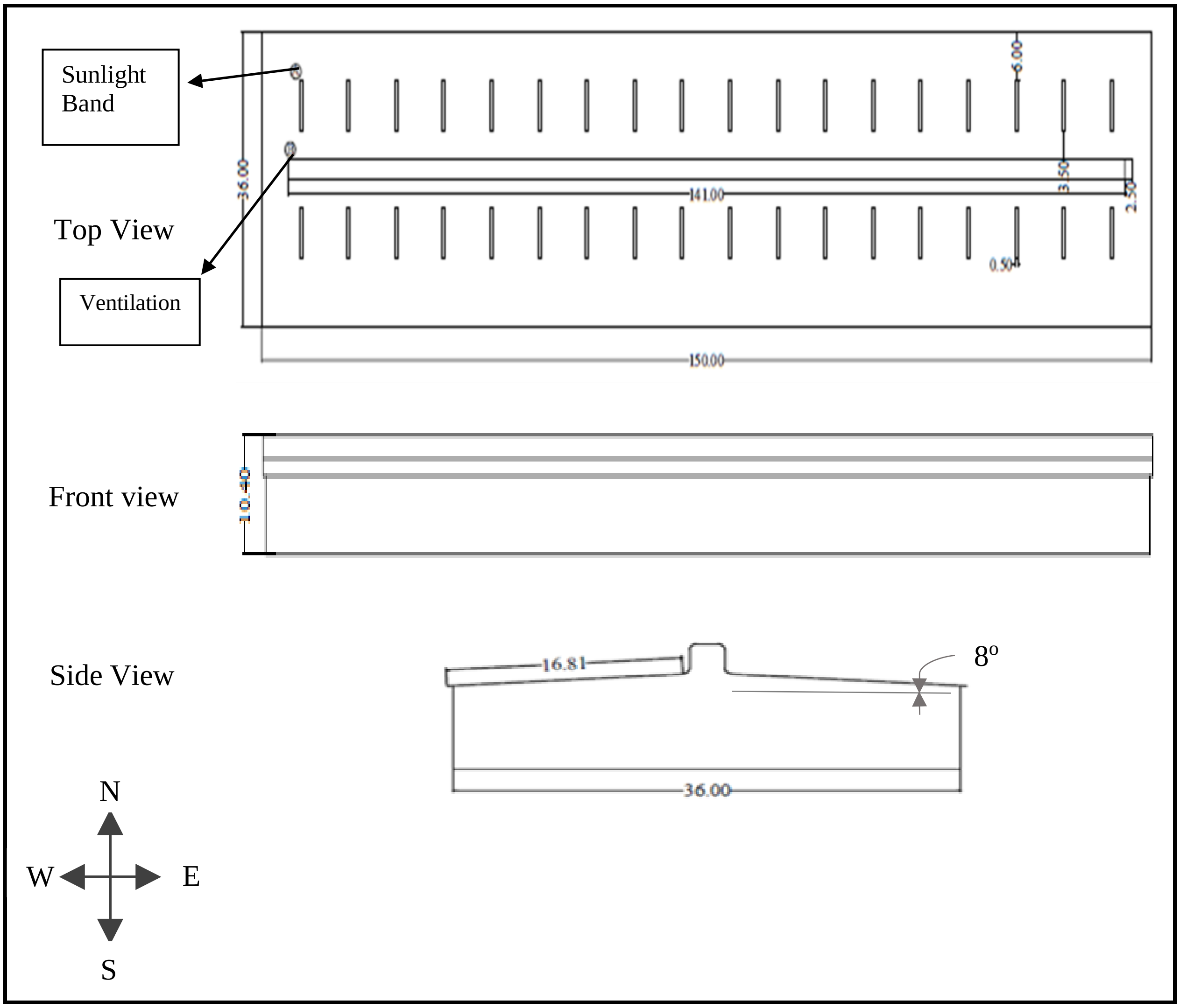


Figure 3.8 Engineering Drawing of the KIP Shed

When the roof top available area for PV is calculated accordance with (a) sunlight band (b) ventilation is represented on Table 3.6.

Table 3.6 Rooftop PV Available Area for Shed Type I and Shed Type II

	Shed Type I	**Shed Type II**
Total Area	5,500 m^2	11,000 m^2
(a) Sunlight Band (1 sunlight band= 5.66 m^2)	203.76 m^2	407.52 m^2
(b) Ventilation	405 m^2	810 m^2
Rooftop Area without (a) and (b)	4805.24 m^2	9632.48 m^2
Rooftop Area without (b)	5009 m^2	10,040 m^2

3.2.1 Optimum Tilt Angle

PV modules are mainly non tracking to minimize the operation cost.

Equation 3.1 describes the incident angle of solar rays for south facing panels [37]

$$\cos(\theta) = \sin(L - \beta)\sin(\delta) - \cos(L - \beta)\, cos(\delta) cos(H) \qquad (3.1)$$

Where: θ is incident angle of solar radiation on the PV panel which is tilted by β angle from horizontal surface facing south, L is latitude angle, H is hour angle, and δ is declination angle.

Declination Angle δ is degrees for an arbitrary day of the year (N), it can be approximated by Equation 3.2.

$$\delta = 23.45 \sin\left[\frac{360}{365}(284 + N)\right] \qquad (3.2)$$

At solar noon [37], the hour angle (H) is zero. So, Equation 3.1 is simplified as follows;

$$\cos(\theta) = -\cos\,(L - \beta + \delta) \qquad (3.3)$$

If the angle s measured in radiation,

$$\theta = \pi - (L - \beta + \delta) \qquad (3.4)$$

For summer solstice or fall equinox when, $\delta = 0$,

$$\theta = \pi - (L - \beta) \quad (3.5)$$

Maximum insolation is when $\theta = 0$, hence for a panel located in the northern hemisphere, the optimum tilt angle at noon can be written as,

$$\beta_{optimum} = L - \pi \text{ , in radian} \quad (3.6)$$

and

$$\beta_{optimum} = L \text{ , in degree}$$

Equation (3.6) indicates the need for tilting of the solar panel at the same latitude angle but to opposite direction.

In the case of Kombolcha, which is located 11.5^{o} of north, the solar panel should face 11.5^{0} to south.

3.2.2 Driving Beam and Diffuse Radiation

Total radiation on tilted surface can be determined where, the global radiation data taken from the Ethiopian metrology agency is split into its beam and diffuse component. The collected data are global radiation measurements on horizontal surface. The model developed by Threlkeld and Jordan (1958), suggested that the diffuse radiation on a horizontal surface (G_{DH}) is proportional to the direct beam radiation (G_B) [38].

$$G_{DH} = CG_B \quad (3.7)$$

Where C is a sky diffuse factor and its convenient approximation for any day of the year (N) is expressed by Equation 3.8:

$$C = 0.095 + 0.04 \sin\left[\frac{360}{365}(N - 100)\right] \quad (3.8)$$

but the beam radiation normal to horizontal surface G_{BH} is expressed as:

$$G_{BH} = G_B \cos(\Phi) \quad (3.9)$$

Where G_B is beam radiation, and G_{BH} is beam radiation normal to a horizontal surface, and Φ is zenith angle (or incident angle on horizontal surface).

Lastly, they have shown the diffuse radiation can be expressed by Equation 3.10 in terms of global radiation measured on horizontal surface (G_H).

$$G_{DH} = \frac{G_H}{1+\cos(\Phi)/C} \tag{3.10}$$

Once we calculated the diffuse radiation, it is possible to get the beam component. By deducting diffused radiation from global radiation, the beam radiation can be expressed in Equation (3.11)

$$G_{BH} = G_H - G_{DH} \tag{3.11}$$

3.2.3 Total Radiation on the (Optimally Tilted) Panel

To optimize solar radiation interception, the panel has been proposed to be tilted at angle equal to the latitude position of the region. However, as it has been mentioned, the provided radiation data was a global radiation measured at horizontal surface. Therefore, we need to generate solar radiation data on the tilted panel, by converting the existing radiation data (on horizontal surface) to radiation on the tilted surface.

Beam radiation, G_{Bt}on tilted surface is [37]:

$$G_{Bt} = G_B cos(\theta) \tag{3.12}$$

3.2.4 Modeling of the PV Module

Primary understanding the electrical characteristics of the PV module is vital. The electrical characteristics of the PV panel varies due to the variation of solar radiation throughout the day and season. Understanding this will help to model the suitable PV system in a real weather condition of Kombolcha.

Manufacturers provide the basic electrical parameters about their PV panel product. These are the voltage at the Maximum power point (V_{mpp}), the nominal open-circuit voltage ($V_{oc,n}$), the nominal short-circuit current ($I_{sc,n}$), the current at Maximum power point (I_{mpp}), temperature coefficient for the short circuit current (K_I), temperature coefficient for the open-circuit voltage (K_V), and the maximum power output ($P_{max,e}$). Those parameters are measured with reference to standard test conditions (STCs) of solar irradiation and cell temperature. The basic electrical parameters are not enough to investigate the performance of a PV panel. Hence, it is crucial to find out detail electrical characteristics which model the performance of PV panel.

Practically, arrays are composed of several connected PV cells and the observation of the characteristics at the terminals of the PV array requires the inclusion of additional parameters to the basic equation as shown Equation 3.13 [39].

$$I = I_{PV} - I_0 \left[exp\left(\frac{V+R_s I}{V_t a}\right) - 1\right] - \frac{V+R_s I}{R_p} \tag{3.13}$$

Where:

I - Current

I_{pv} and I_0 - Photovoltaic (PV) and saturation currents of the array,

R_s - Equivalent series resistance of the array,

R_p - Equivalent parallel resistance,

$V_t = N_s kT/q$ - Thermal voltage of the array with N_s cells connected in series. Cells connected in parallel increase the current and cells connected in series provide greater output voltages. If the array is composed of N_p parallel connections of cells the PV and saturation currents may be expressed as $I_{pv,cell} = I_{pv,cell} N_p$, $I_0 = I_{0,cell} N_p$.

The diode saturation current I_0 and its mathematical relation cell temperature is expressed by Equation 3.14 [40].

$$I_0 = I_{0,n}\left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right] \tag{3.14}$$

Where E_g is the band gap energy of the semiconductor (E_g= 1.12 eV for the polycrystalline Si at 25 ˚C) and $I_{0,n}$ is the nominal saturation current, the value of diode ideality constant is ranges between 1≤ a ≤1.5 and for silicon-poly material is around 1.3.

Meanwhile the nominal diode saturation (reverse) current is given by Equation 3.15 [40].

$$I_{0,n} = \frac{I_{sc,n}}{exp(V_{oc,n}/aV_{t,n})-1} \tag{3.15}$$

With $V_{t,,n}$ being the thermal voltage of N_s series-connected cells at the nominal temperature T_n. The insolation and temperature dependency of light-generated current of the PV cell is given by Equation 3.16;

$$I_{pv}(G,T) = \left(I_{Pv,n} + K_I \Delta T\right)\frac{G}{G_n} \tag{3.16}$$

Where $I_{Pv,n}$ (in amperes) is the light-generated current at the nominal condition (usually 25 ˚C and 1000 W/m^2), ΔT =$T - T_n$ (T and T_n being the actual and nominal temperatures [in Kelvin], respectively), G (watts per square meters) is the irradiation on the device surface, and G_n is the nominal irradiation.

Equation 3.17 expresses the nominal light generated current $I_{Pv,n}$ [39];

$$I_{Pv,n} = \frac{R_P + R_S}{R_P} I_{sc,n} \tag{3.17}$$

So, Equation (3.13) can be formulated with the known electrical parameters given by the manufacturer's data sheet (which are $I_{sc,n}$ and $V_{oc,n}$), the constants (a, q, E_g, K), and the external influential factors of radiation intensity and cell temperature (T, G), but the internal influencing parameters (R_s and R_P) are still unknown.

The internal parameters R_s and R_P are iterated (with mathematical equation which relates the two) until the resulting pair of value (R_s, R_p). It ensures the maximum power calculated by the I–V model ($P_{max,m} = I_{mpp} \times V_{mpp}$) of Equation (3.18) equal to the maximum experimental power

($P_{max,e}$) of the data sheet at the MPP (where MPP is a maximum power point, which means a point where the power output of the solar panel will be maximum) *[39]*.

The calculated maximum current output of the solar panel at nominal temperature and solar radiation (at 25 °C and 1000 W/m^2) could be expressed by Equation 3.18:

$$I_{mpp} = I_{\mathrm{pv,n}} - I_{0,n}\left[exp\left(\frac{V_{mpp}+R_S I_{mpp}}{V_{t,n}a}\right) - 1\right] - \frac{V_{mpp}+R_S I_{mpp}}{R_P} \tag{3.18}$$

Where V_{mpp} is voltage at MPP (maximum power point), the thermal voltage of the panel at STC I_{mpp} is current at MPP.

From Equation (3.19) R_P is expressed not only in terms parameters such as $I_{\mathrm{pv,n}}$, $I_{0,n}$, and $V_{t,n}$, but also the nominal maximum power point (i.e. I_{mpp} and V_{mpp}) and the R_S, hence the resulting graph due to the pair values (i.e. R_S and R_P) will surely pass through the nominal maximum power points.

$$R_P = \frac{V_{mpp}+R_S I_{mpp}}{I_{\mathrm{pv,n}} - I_{0,n}\left[exp\left(\frac{V_{mpp}+R_S I_{mpp}}{V_{t,n}a}\right) - 1\right] - I_{mpp}} \tag{3.19}$$

3.2.5 Operating Temperature and Efficiency of PV Module

Performance of PV systems highly depend on the operating temperature. The cell operating temperature (T) can be estimated quite accurately in °C with the linear approximation as expressed by Equation 3.20 [41].

$$T = T_a + \frac{G}{G_{NOCT}}\left(T_{NOCT} - T_{a,NOCT}\right) \tag{3.20}$$

Where T is the cell operating temperature of the PV module which determines the performance of the PV panel along with solar radiation intensity G, T_{NOCT} is nominal operating cell temperature which is a reference temperature for particular PV module to calculate cell operating temperature (T) and it is given by the manufacturer's specification. The nominal cell temperature (T_{NOCT}) is defined as the temperature of the cell at the conditions of the nominal terrestrial environment (NTE)[41]; Solar irradiance G_{NOCT} = 800 W/m^2, ambient temperature $T_{a,NOCT}$ = 20 °C, and average wind speed 1 m/s. Hence equation (3.20) can be expressed by Equation 3.21.

$$T = T_a + \frac{G}{800\ W/m^2}\left(T_{NOCT} - 20\,^oC\right) \tag{3.21}$$

3.3 Wind Energy Analysis Procedure

The Kombolcha Industrial park gets a future expansion area of 25 hectare. Hence with proper land management, there is an opportunity to the appliance of wind energy.

3.3.1 Wind Shear

Wind speed increases with height roughly in a logarithmic pattern. The wind speed at a certain height above ground level is determined from the expression of Equation (3.22) [42]. Around KIP, the surface roughness [43] is considered and wind velocity is calculated.

$$V = \frac{V_{ref} \ln \left(\frac{z}{z_o}\right)}{\ln \left(\frac{z_{ref}}{z_o}\right)} \tag{3.22}$$

Where; V = Wind velocity at height z above ground level,

V_{ref} = Reference velocity, i.e. a wind velocity at height Z_{ref},

Z = Height above ground level for the desired velocity, V,

Z_o = Surface roughness length of the site,

Z_{ref} = Reference height, i.e. the height where the exact wind velocity V_{ref} is known

3.3.2 Average Wind Velocity

Average wind velocity gives a preliminary indication for a site wind energy potential. Using Equation (3.23) [42] the average wind velocity can be estimated. Long term wind data from a metrological station near the site was used for this paper. However, a one-year wind data recorded at the site is sufficient to represent the long-term variations in the wind profile within accuracy level of 10%.

$$V_m = \left[\frac{1}{n}\sum_{i=1}^{n} {v_i}^3\right]^{1/3} \tag{3.23}$$

Where; v_i- wind velocity, n- number of wind data

3.3.3 Wind Power Density

The amount of energy which wind transfers to the rotor depends on density of the air ρ, the rotor area A_T, and wind speed. Thus, to understand the impact on power generation of the statistical distribution of wind speed, considering its impact on power density is important. The Wind power density is

$$P = {}^{1}\!/_{2}\, \rho v^{3} \tag{3.24}$$

where ρ is the standard air density at sea level with a mean temperature of 15 °C and a pressure of 1 atm (1.225 kg/m^3) and v is the mean wind speed (m/s).

3.3.4 Weibull Probability Density Function

The Weibull factors k and c can also be estimated from the mean and standard deviation. Using Equation (3.25) and (3.26), the values of k (Weibull shape factor) and c (scale factor) can be primarily determined.

$$k = \left(\frac{\sigma_v}{v_m}\right)^{-1.090} \tag{3.25}$$

$$c = \frac{2v_m}{\sqrt{\pi}} \tag{3.26}$$

Where the standard deviation is determined using Equation (3.27)

$$\sigma_v = \sqrt{\frac{\sum_{i=1}^{n}(v_i - v_m)^2}{n}} \tag{3.27}$$

The probability density function f(v) indicates the fraction of time (or probability) for which the wind is at a given velocity and is expressed by Equation (3.28).

$$f(v) = \frac{k}{c}\left[\frac{v}{c}\right]^{k-1} e^{-({}^{v}/_{c})^{k}} \tag{3.28}$$

Where k is the Weibull shape factor and c is the scale factor.

3.3.5 Power Curve

Power curve is the output of the turbine as a function of wind speed. The power curve data is calculated by Equation (3.29)

$$P_v = P_r * \frac{V - Vc}{V_r - V_c} \quad (3.29)$$

Where; P_v is power at velocity v, V_c is cut in wind speed, V_r is rated wind speed, P_r is rated power, and.

Actual power produced by a rotor would be decided by the efficiency with which the energy transfer from wind to the rotor takes place. The performance is usually determined by coefficient (Cp).

$$c_p = \frac{2P_T}{\rho_a A_T v^3} \quad (3.30)$$

Where P_T is the power developed by the turbine, ρ_a is the air density, A_T is the area of the turbine, υ is the wind speed.

3.4 Hybrid Optimization of Multiple Electric Renewables (HOMER)

This section is basically to assess the potential of Kombolcha Industrial Park (KIP) to be electrified by hybrid system of solar, wind and diesel generation, for reliability improvement and cost minimization. The KIP depends on the grid system to meet its power demands.

To develop the elements of the hybrid system, primary energy demand data were collected through a structured survey questionnaire, focal group discussions, and observations in the field.

Techno-economic parameters were also collected as inputs of the HOMER (Hybrid Optimization of Multiple Electric Renewables) model. Primary data were used to establish a daily load profile for the HOMER model to develop an off-grid system that offers an optimal and least-cost way to meet the daily electricity demand in KIP. Sensitivity analyses were performed, considering variations of key parameters such as solar radiation, wind speed and diesel price. The study provides insights about the possible contribution of hybrid systems in the industrial park to support the government's ultimate goal of universal electrification by 2025. The algorithm HOMER uses considers possible combinations of the resources and determines the feasible combination which can meet the required system load and constraints. Moreover, the performance, cost of energy, and sensitivity results are observed as output of HOMER.

3.4.1 Basic Mathematical Description Homer Uses

The output of a PV array depends on the rated capacity of the PV array, the module derating factor, the solar radiation incident on the P array, the incident radiation at standard test conditions, the temperature coefficient of power, PV cell temperature and the PV cell temperature under standard test conditions. HOMER uses the following equation to calculate the output of the solar PV array on a tilted surface [27].

$$P_{PV} = Y_{PV} f_{PV} (G_T / G_{T,STC}) \left[1 + \alpha_P \left(TC - T_{C,STC}\right)\right] \tag{3.31}$$

where, Y_{PV} is the rated capacity of the PV array, meaning its power output under standard test conditions [kW], f_{PV} is the PV derating factor [%], G_T is the solar radiation incident on the P array in the current time step [kW/m^2], $G_{T,\ STC}$ is the incident radiation at standard test conditions [kW/m^2], α_P is the temperature coefficient of power [%/ ^oC],T_C is the PV cell temperature in the current time step [^oC], and $T_{C,\ STC}$ is the PV cell temperature under standard test conditions [25 ^oC].

The fundamental equation governing the mechanical power of the wind turbine is given by;

$$Pw = \frac{1}{2} Cp(\lambda, \beta) \rho A V^3 \tag{3.32}$$

where, ρ is air density (kg/m^3), C_p is the power coefficient, A is the intercepting area of the rotor blades (m^2), V is average wind speed (m/s), and λ is the tip speed ratio. The theoretical maximum value of the power coefficient Cp is 0.593, also known as Betz's coefficient.

The Tip Speed Ratio (TSR) for wind turbines is calculated as the ratio of rotational speed of the tip of a blade to the wind velocity. Mathematically, this can be represented by:

$$\lambda = R\omega / V$$

where, R is the radius of the turbine (m), ω is angular speed (rad/s), and V is average wind speed (m/s). The energy generated by wind at a certain height can be obtained by the Hellman exponential law as given in Equation (3.33).

$$VZ/Vzref = \left[\frac{Z}{Zref}\right]^{\alpha} \tag{3.33}$$

where, V_z is mean wind speed at height Z; V_{zref} is mean wind speed at the reference height of the study terrain; Z is study height above the ground; and Z_{ref} is reference height.

The battery state of charge (SOC) is the cumulative sum of the daily charge or discharge transfers. Therefore, SOC is current integration, which expresses the ratio of the available current capacity to the nominal capacity, Equation (3.34) [27].

$$SOC = 1 - \int \frac{i\eta dt}{Cn} \tag{3.34}$$

Where: i is the battery current; C_n is the nominal capacity; t is time; η and is the coulombic efficiency defined as the ratio of energy required for charging to the discharging energy needed to regain the original capacity.

System cost is defined as the sum of Photovoltaic array cost (CPV), Wind generator cost (CWG), battery cost (CBAT), and convertor cost (CCON).

$$CSYSTEM = CPV + CWG + CBAT + CCONV$$

Homer calculates the total Net Present Cost (NPC):

$$C_{NPC} = C_{ann,tot}/CRF(I, R_{proj}) \tag{3.35}$$

Where $C_{ann,tot}$ is the total annualized cost, I is the annual real interest rate and R_{proj} is the project lifetime and CRF is the Capital recovery factor given by Equation 3.36, where N is the project lifetime in years:

$$CRF(i, N) = \frac{i(1+i)^N}{(1+i)^N} - 1 \tag{3.36}$$

To calculate the cost of electricity (COE), HOMER divides the annualized cost of producing electricity (the total annualized cost minus the cost of serving the thermal load) by the total useful electric energy production as shown in Equation 3.37.

$$COE = (C_{ann,tot} - C_{boiler}E_{thermal})/(E_{prim,AC} + E_{prim,DC} + E_{def} + E_{grid,sales}) \tag{3.37}$$

Where C_{boiler} is boiler marginal cost, $E_{thermal}$ is the total thermal load served, $E_{prim,AC}$ is the AC primary load served, $E_{prim,DC}$ is the DC primary load served, E_{def} is deferable load served and $E_{grid, sales}$ is total grid sales. In our case, since we do not have a thermal load, $E_{thermal}$ will be zero.

To compare and evaluate the environmental impacts of the power generation technologies, a useful indicator of Greenhouse Gas (GHG) emission rate has been introduced. GHG emission rate denotes that how many greenhouse gases would emit while per unit of electricity power is generated. For PV power systems, the GHG emission rate can be expressed as the total GHG emissions of PV system, Equation 3.38 [44].

$$GHG_{e-rate} = \frac{GHG_{e-total}}{E_{LCA-Output}} \tag{3.38}$$

Where, $GHG_{e\text{-}rate}$ is the GHG emission rate of per unit electricity power generated by the PV system (g CO_2 -eq./kWh); $GHG_{e\text{-}total}$ is the total amount of GHG emission throughout the life cycle (g CO_2 -eq.); and $E_{LCA\text{-}output}$ is the total electricity power generated by PV system during its life cycle (kWh).

3.4.2 Input Parameters

The load profile for this analysis was created from the survey outcomes. Using the questionnaire provided (Appendix C) to the manager and to each individual company, the hourly electrical load was analyzed and presented as an input by Figure 3.9. The park has five companies having a maximum of 2850 kWh energy consumption record. The total yearly maximum demand is taken for designing.

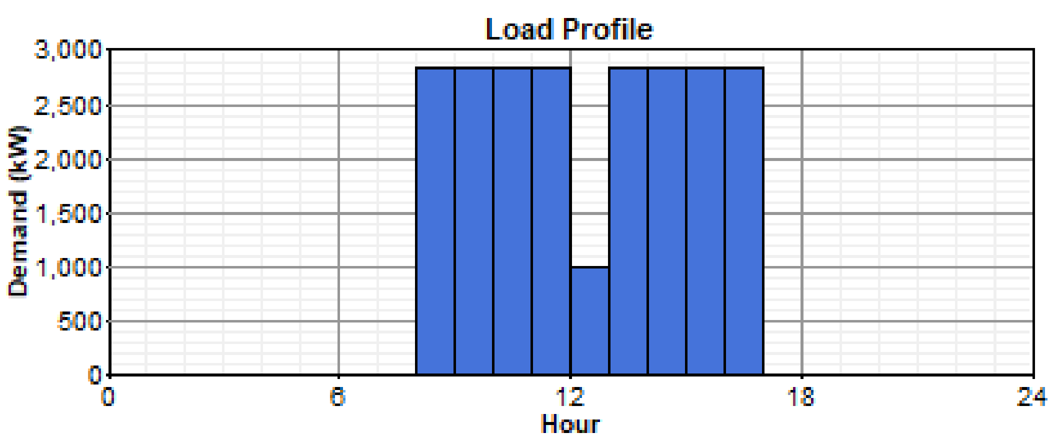


Figure 3.9 Hourly Load Profile of KIP

The types and volumes of energy demand in the surveyed park (i.e KIP) are simple and the working hour is standardly the same. Currently, all the companies residing in the park work eight hours per day and 5 days a week. Figure 3.10 explains the monthly load profile of KIP as an input for the analysis.

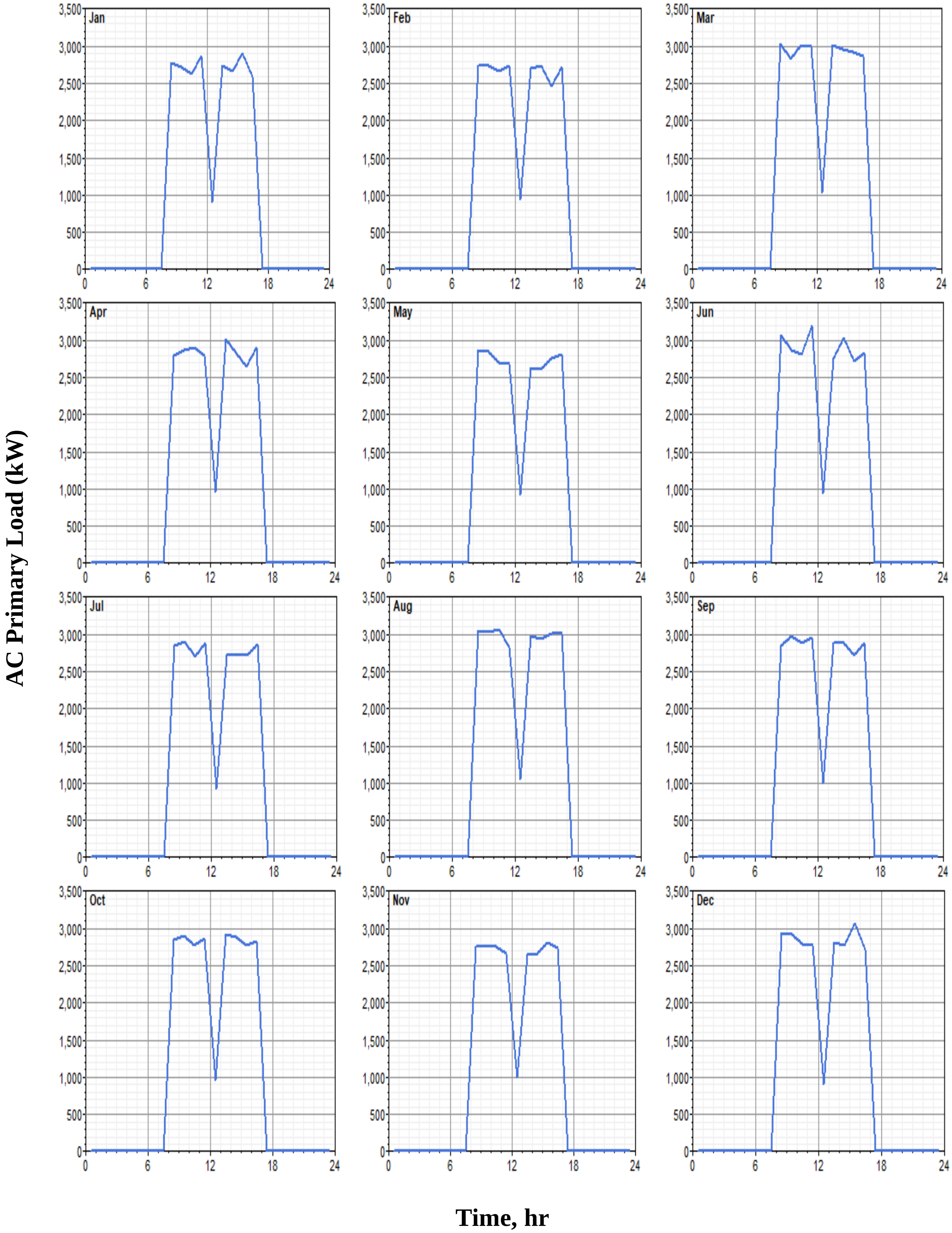


Figure 3.10 Monthly AC Load Profile of KIP

The monthly load profile also shows that starting from 8:00 am to 12:00 pm and after 1:00pm to 5:00 pm, the total average hourly energy consumption is around 2850 kW.

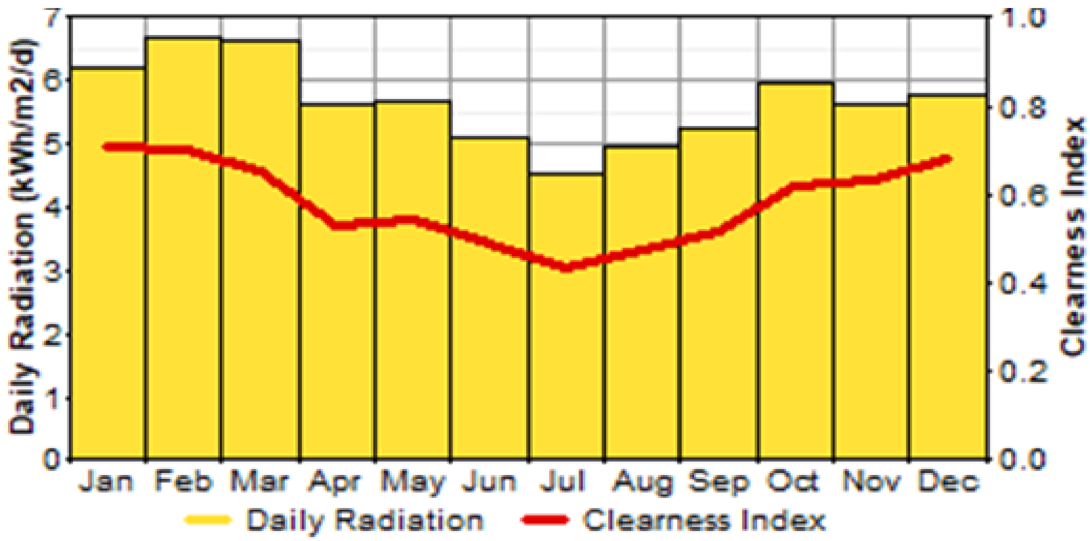


Figure 3.11 Solar Resource Input

Along with the clearness index (i.e clearness of the atmosphere), Figure 3.11 shows the solar resource input for HOMER analysis. It can be seen that the solar radiation varies seasonally. Based on the data source collected from the national metrology agency, the yearly average solar radiation for the location, Kombolcha is 5.65 $kWh/m^2/d$.

Figure 3.12 signifies the wind resource input for HOMER analysis. It shows that wind speed also varies seasonally.

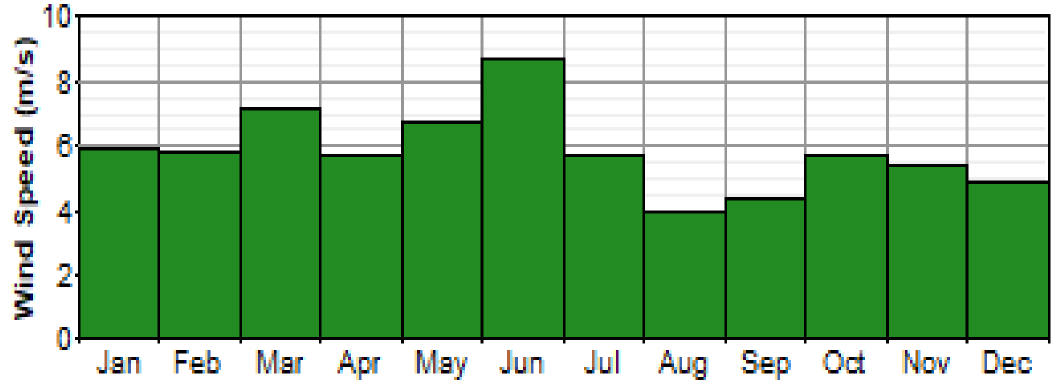


Figure 3.12 Wind Resource Input

The wind speed was minimum in August around 4 m/s and it maximum in June about 8.7 m/s. The yearly average wind speed is 5.8 m/s. This shows with HOMER analysis and selection of siemens wind turbine which has a cut in wind speed of 3-4 m/s, there is a potential to generate electricity using wind energy.

Figure 3.13 shows the proposed hybrid system. This system is taken as a primary analysis. The system comprises of a solar PV, wind turbine, diesel generator and battery storage with a hybrid AC to DC bus bar. HOMER simulates the operation of a system by calculating the energy balance for each 8760 h in a year.

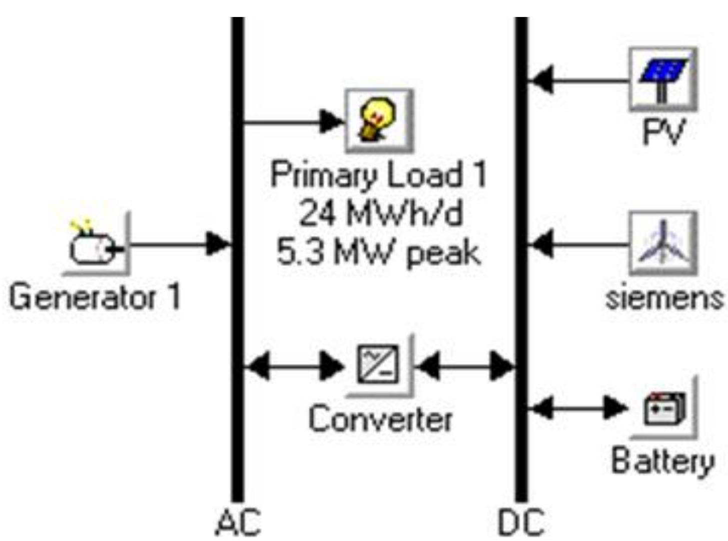


Figure 3.13 Configuration of Proposed Renewable Energy Integrated Off-Grid System for KIP

The diesel generator and battery are considered in this system design for continuous power supply when electricity is not being generated from the wind turbine and solar PV. Different sizes and combination of components are simulated to find the optimal design of the hybrid system to meet the projected energy demands.

A 20-year proposed project life was considered. The annual interest rate is assumed to be fixed at 7% [45]. The maximum renewable fraction was considered to range between 0% to 100%. The maximum annual capacity shortage was assumed as 7%. The hybrid system control parameters applied in the simulation run are summarized in Table 3.7 considering related study [27] .

Table 3.7 Hybrid System Control Parameters Used in HOMER

Parameter	Option available in HOMER (Yes or No)
Load following	Yes
Cycle charging	Yes
Apply set point	Yes
Set point state of charge e	80
Allowing multiple generators	Yes
Multiple generators can operate in parallel	Yes

This shows that the system will operate considering the best optimum result while reliability of the system is at stake.

3.4.3 Technical Parameters

There are five major system input components: wind turbine, solar PV-module, diesel generator, power converter and battery bank. Cost is one of the most important factors that determine the market penetration of renewable energy technologies in the power generation system. The parameter and price considered are an interpolation of data obtained from online distributors and previously published literatures [27]. The following sections discuss available hybrid system components and their technoeconomic parameters.

The HOMER model deals with solar PV array in terms of rated kW, not in m^2. The model considers that the output of the PV array is linearly proportional to the incident solar radiation. If the solar radiation is 0.80 kW/m^2, the array will produce 80% of its rated output. The temperature effect is also considered in this simulation as the electricity production is roughly anti-linear in the temperature range under which solar panels are exposed or solar PV becomes less efficient when temperature increases. A derating factor of 95% is applied in this modeling to take into account varying effects of temperature and dust on the panels. A slightly lower derating factor can be applied in very hot climate areas. The technical and economic parameters of the selected PV array are presented in Table 3.8 Capital cost of solar PV is at USD 1500/kW, which includes other associated costs such as transport, labor, logistics and installation of the PV system.

Table 3.8 Technical Parameters and Cost Consideration of Solar PV.

Parameter	Unit	Value
Tilt angle	Degree	0
Azimuth angle	Degree	0(W of S)
Ground reflectance	Percent (%)	20
Derating factor	Percent (%)	95
Capital cost	USD/kW	1500
Replacement	USD/kW	1000
Operation and maintenance (O and M)	USD/year	50
Tracking System	_	No tracking
Lifetime	year	20

Wind turbines normally generate electricity when the wind speed is between and 3-4 m/s (the turbine blade starts to spin) and 25m/s (cut-off wind speed) [46]. Based on the available wind potential, the study showed the wind potential is around 2,300kW nominal power at 80 m height.

Technical parameters and cost assumptions of the selected wind turbine are presented in Table 3.9.

Table 3.9 Techno-Economic Specifications of Wind Turbine.

Parameter	Unit	Value
Rated Power	kW	2300
minimum wind speed	m/s	3
Cut-off wind speed	m/s	25
Capital cost	USD/kW	2000
Replacement	USD/kW	1600
Operation and maintenance (O and M)	USD/year/turbine	50
Lifetime	year	20

The fuel consumption by the diesel generator in HOMER is modeled by a linear curve characterized by a slope and an intercept at no load. The slope and intercept for a 5 kW diesel generator is about 0.33 l/h/kW. A lower heating value of 43.2 MJ/kg, density of 820 kg/m^3, carbon content of 88% and sulfur content of 0.33% was taken. Technical and economic parameters of the diesel generator are presented in Table 3.10.

Table 3.10 Technical Parameters and Cost Assumptions for Diesel Generators.

Parameter	Unit	Value
Capital cost	USD/kW	250
Replacement	USD/kW	200
Operation and maintenance cost	USD/h	0.3
Operational lifetime	hours	15,000
Minimum load ratio	Percent (%)	30
Fuel curve intercept	l/h/kW rated	0.05
Fuel curve slope	l/h/kW rated	0.03
Fuel (diesel) price	USD	0.7

The battery is one of the important parts of a hybrid system since it stores surplus energy and supplies deficit energy, thus maintaining stability in a microgrid operation. HOMER uses the kinetic battery model to find the amount of energy that can be absorbed by or withdrawn from the battery storage for each time step. The maximum charge and discharge power provide the allowable range for the power into and out of the battery storage in any time step. The battery used for the system is the Hoppecke model with a rating of 2 V, 3000 Ah nominal capacity, with lifetime throughput of 10,222 kWh. The specification of battery storage is presented in Table 3.11.

Table 3.11 Specifications of Battery Storage.

Parameter	Unit	Value
Nominal Voltage	Volt	2
Nominal capacity	Ah(kWh)	3000
Maximum charge current	A	1
Round trip efficiency	Percent(%)	86
Minimum State of charge	Percent(%)	30
Capitalcost	USD/kWh	400
Replacement	USD/kWh	300
Operation and maintenance cost	USD/year	20
Lifetime	Year	6

A power converter was used in this simulation to maintain the flow of energy between the AC and DC components. A bidirectional converter connects the DC and AC bus which converts the DC voltage to AC voltage to supply energy to the load. Table 3.12 gives the technical and economic parameters of the converter.

Table 3.12 Technical Parameters and Cost Assumptions for Converter.

Parameter	Unit	Value
Inverter efficiency	Percent (%)	90
Rectifier relative capacity	Percent (%)	75
Rectifier efficiency	Percent (%)	85
Capital cost	USD/15kW	1300
Replacement	USD/15kW	1000
Operation and maintenance cost	USD/year	5
Lifetime	Year	10

HOMER uses various concepts, technical parameters along with their mathematical descriptions in the background. For a start the proposal of integrated renewable energy systems takes place. In this case wind turbine, PV, battery and convertor are taken in consideration. The basic and most important base for the analysis primarily takes place with the load profile of KIP as an input parameter. Other basic input parameters are solar resource and wind resource of Kombolcha.

Chapter Four

4. Result and Discussion

This chapter deals with the final result of all the analysis done in this thesis. It discusses all the result according to all the subject matters. Such as results from solar PV assessment, wind assessment, and homer analysis comprising the optimization, sensitivity, emission reduction potential and economic analysis.

4.1 Result for Solar PV Assessment

In the industry park there are two different types of sheds built. Shed Type I has an area of 5,500m^2 and Shed Type II has an area of 11,000 m^2. The sheds that are in use at the KIP are seven in number. Five are type I and two are of type II.

The total available area for solar arrays are 4,907.12 m^2 and 9,836.74 m^2 for type -I and type -II, respectively. Having a total available rooftop area of 43,291 m2. When considering the rooftop structure Figure 4.1 and Figure 4.2 illustrates the possible area available for the PV panels on both types of sheds. Excluding the area of the sunlight band and the ventilation, and considering the rooftop side facing south, it can be seen there is sufficient available area.

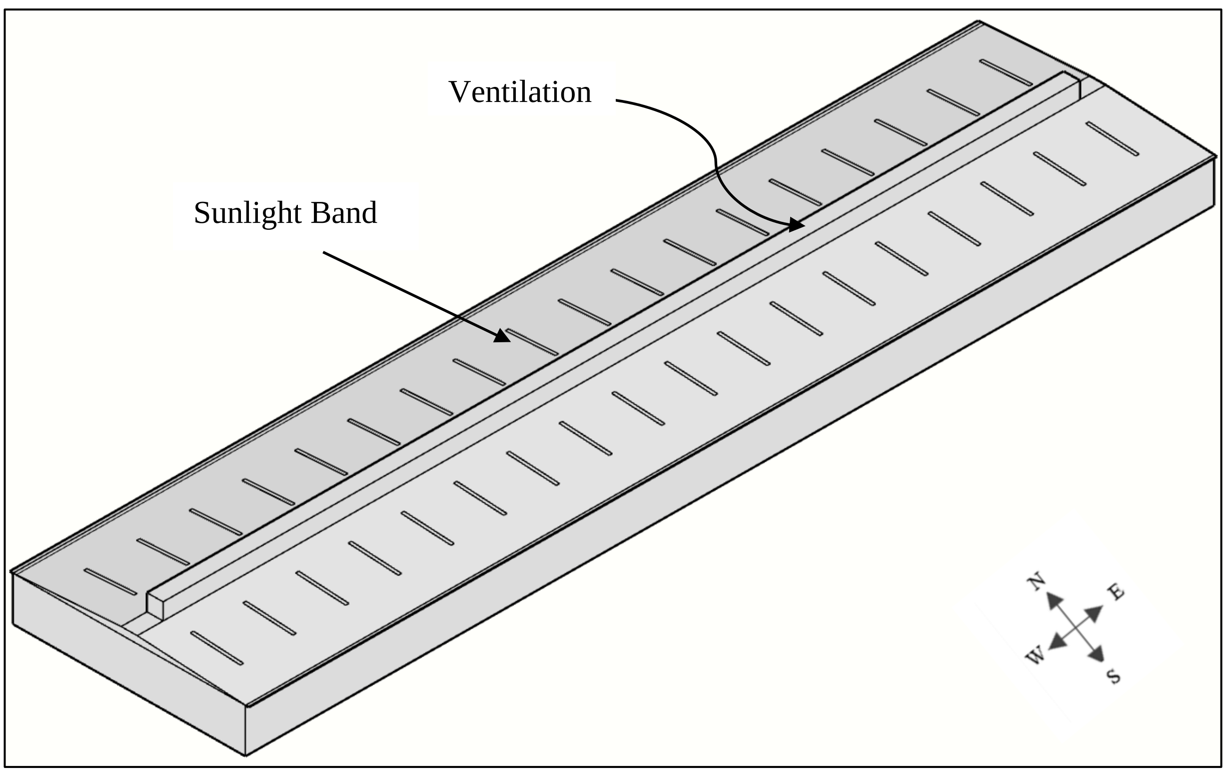


Figure 4.1 3-D Representation for the Rooftop Solar PV of Shed Type I

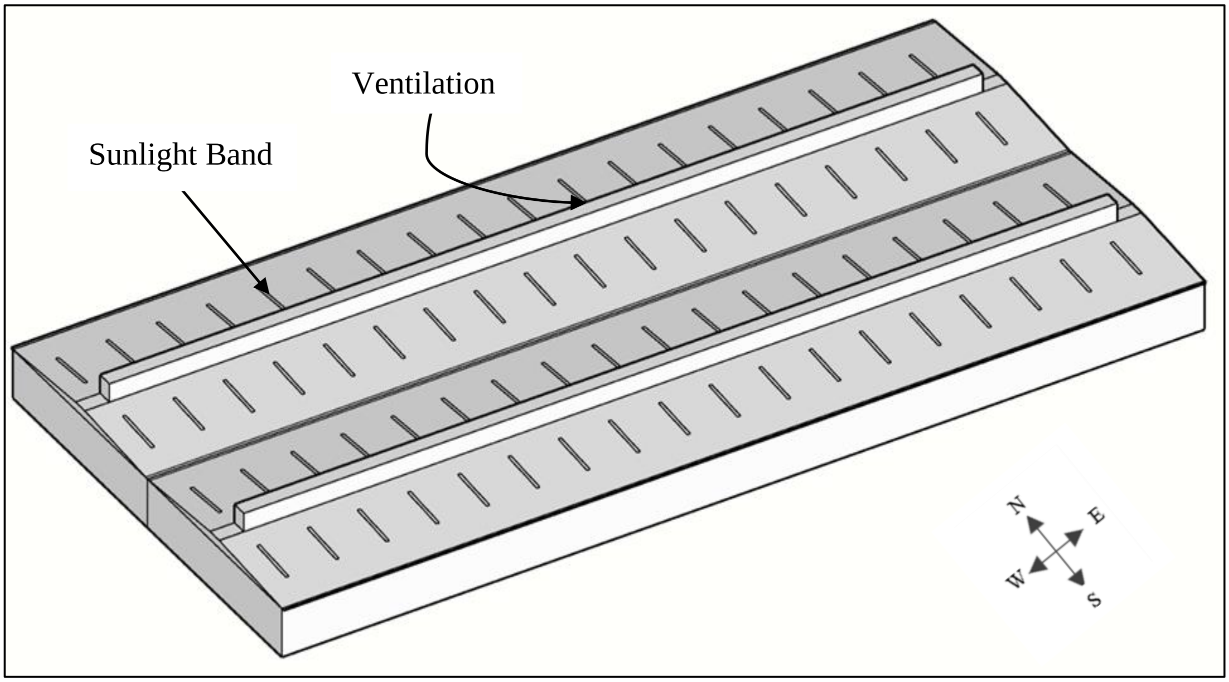


Figure 4.2 3-D Representation for the Rooftop Solar PV of Shed Type II

The panel type selected (Kyocera KC 200GT) has an area of 1.41 m^2 for a single PV module. All the sheds have V-shaped celling. One side of the celling is facing towards the south and the other half is facing towards the north. Considering to generate the designed power of 2.8 MW, the roof top facing south occupies an area of 20,000 m^2. Thus, a total number of 14,250 PV panels can be mounted on the roof top each having a maximum power of 200 W under standard test conditions.

As per the manufacturers specification of [47], a computer program based result for the selected PV module are presented as shown in the figures below using MATLAB programming.

The I-V and P-V curves as shown in Figure 4.3 and Figure 4.4 describes the simulation results for current versus voltage and power versus voltage characteristics of the photovoltaic modules, with the operating cell temperature of 25 ^oC and the effective irradiance level changing of 200 W/m^2, 400 W/m^2, 600W/m^2, 800 W/m^2, and 1000 W/m^2. The I-V curve illustrates that at a constant module temperature and with increasing radiation gives a massive effect on the current but comparatively small effect on the voltage. On the increase in irradiation, it can also be seen that the P-V curve has a significant increment in the output power of the PV module.

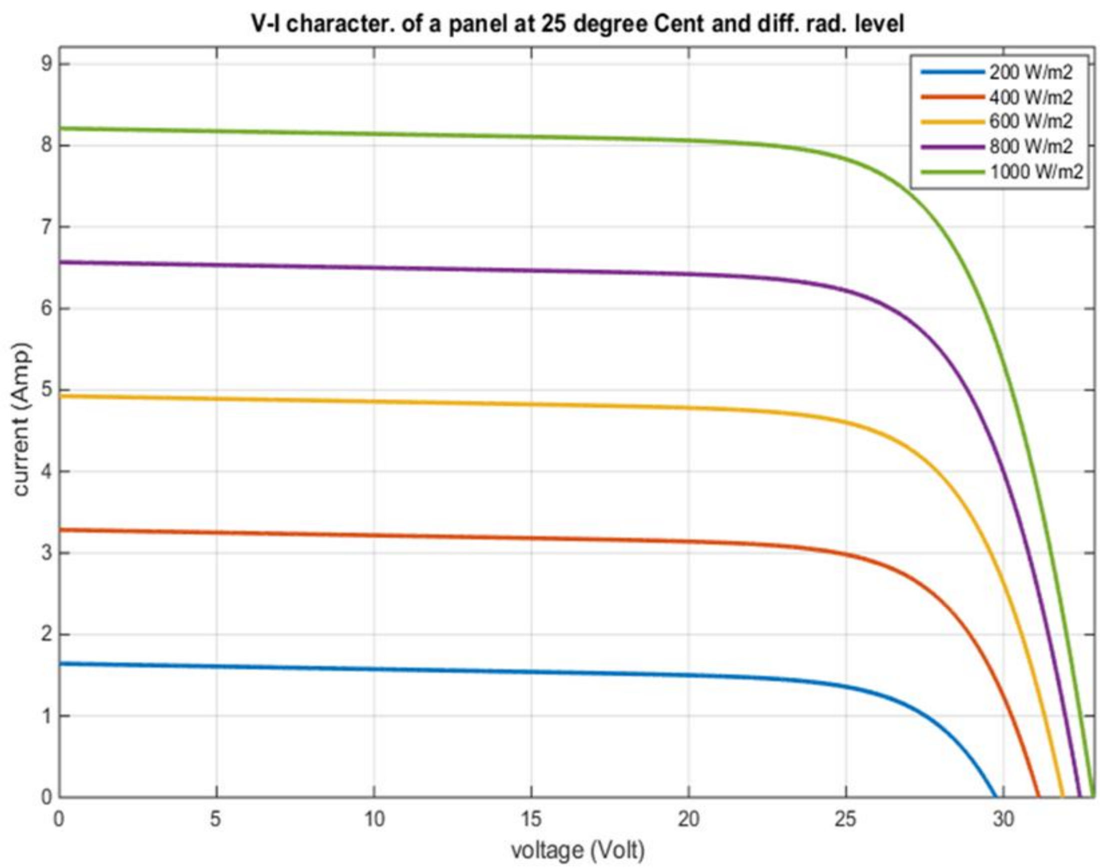


Figure 4.3 V-I Characteristics of a Panel at 25 ^{o}C and Different Radiation Level

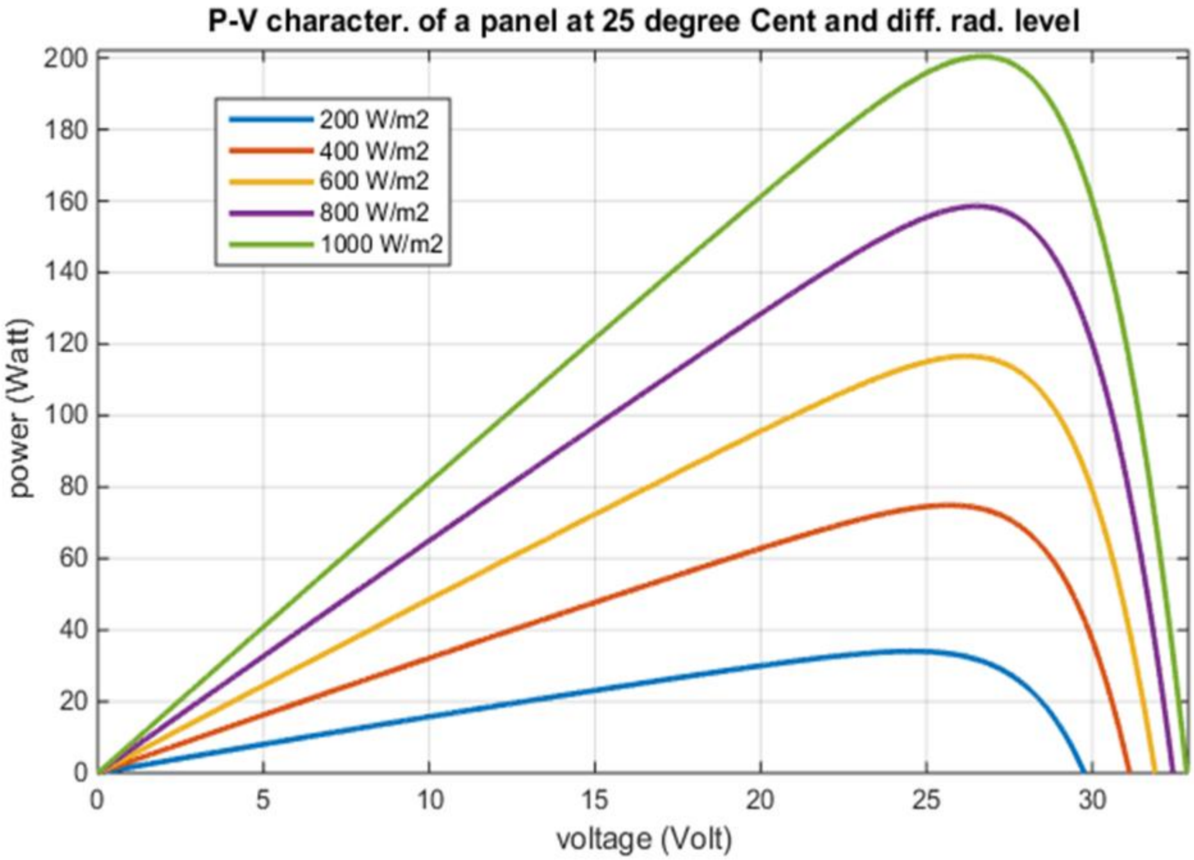


Figure 4.4 P-V Characteristics of a Panel at 25 °C and Different Radiation Level

These results showed that solar radiation has high influence on electrical power generation. It ranges between 35W and 200W for radiation varying from 200 W/m^2 to 1000 W/m^2.

Likewise, Figure 4.5 shows the simulation result for I-V curve of the photovoltaic module under different temperatures of operation (i.e. 25°C, 50°C, 75°C) with the irradiation level at 1000 W/m^2. With an increase in the cell temperature, the figure depicts a significant rise in the current while a significant drop in the voltage of the PV panel. On Figure 4.6, it shows how the temperature effect on the maximum power supplied by the PV module under a constant irradiance level of 1000 W/m^2. It shows that as the working temperature decreases it can be seen that the voltage also increases. Meanwhile increasing of module temperature at a constant irradiation will have an effect on decreasing the output power of the PV module.

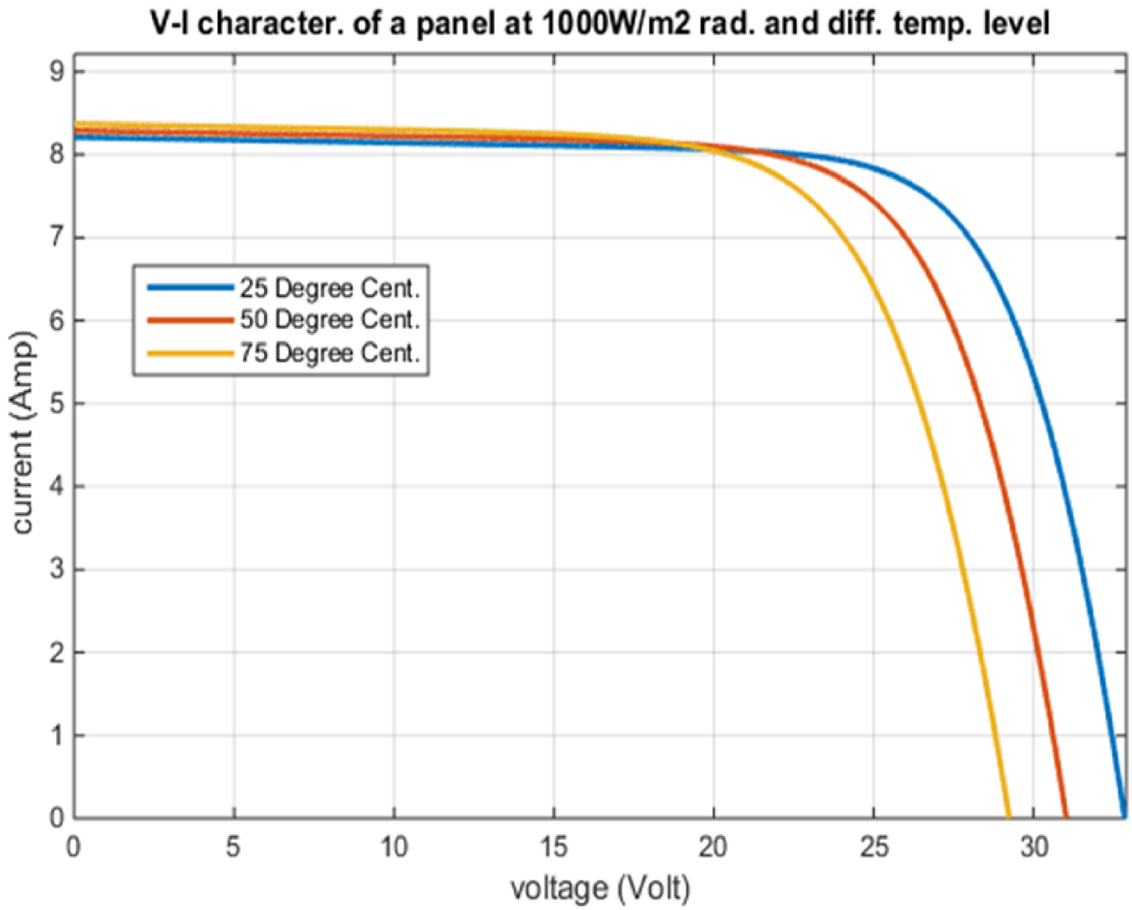


Figure 4.5 V-I Characteristic of Panel at 1000 W/m^2 Radiation and Different Temperature Level

When the operating temperature is kept low, the power on optimum temperature is higher. The high optimal voltage increases the power generation as shown in Figure 4.6.

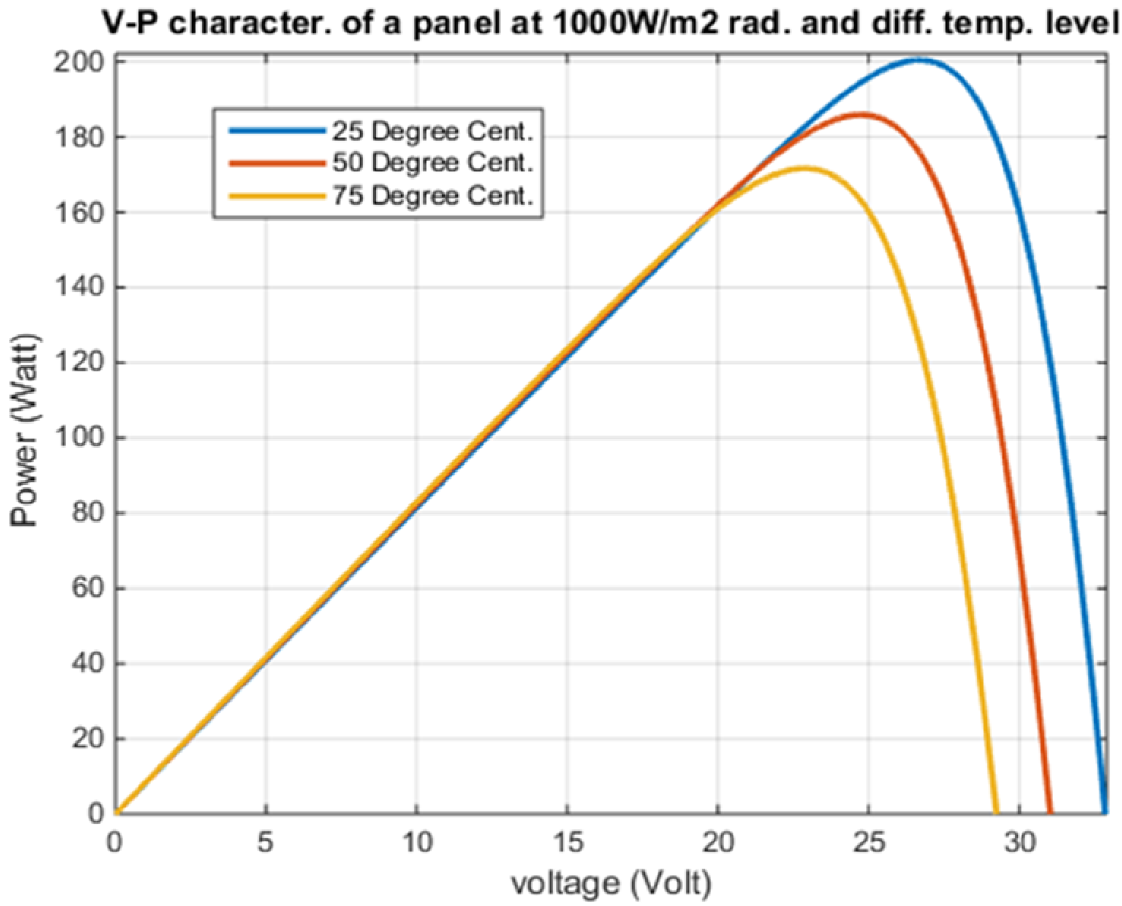


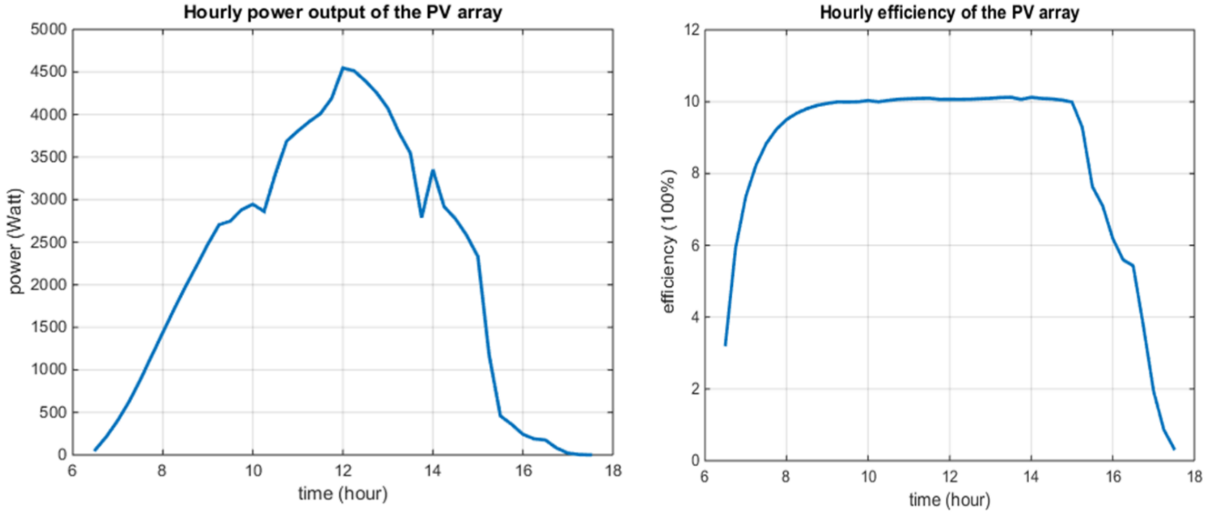
Figure 4.6 V-P Characteristic of Panel at 1000 W/m^2 Radiation and Different Temperature Level

It can be validated with similar work [39], that the results of I-V curve in Figure 4.3 and Figure 4.4 and P-V curve of Figure 4.5 and Figure 4.6 are very similar results plotted.

Figure 4.7 presents the hourly power output and accordance efficiency for selected seasonal changing dates of the year (i.e. January 17, May 15, September 15. It shows the performance simulation of the selected KC200GT module, demonstrating the hourly power output variation and efficiency using the real weather data of Kombolcha.

The PV array output, in noon time reaches up to 4,500 W which is the maximum output throughout a day. Since solar radiation is less during the morning and evening, the power out put will be almost zero. The efficiency similarly reaches its maximum point during maximum solar radiation time and stays almost constantly during this time.

Jan 17



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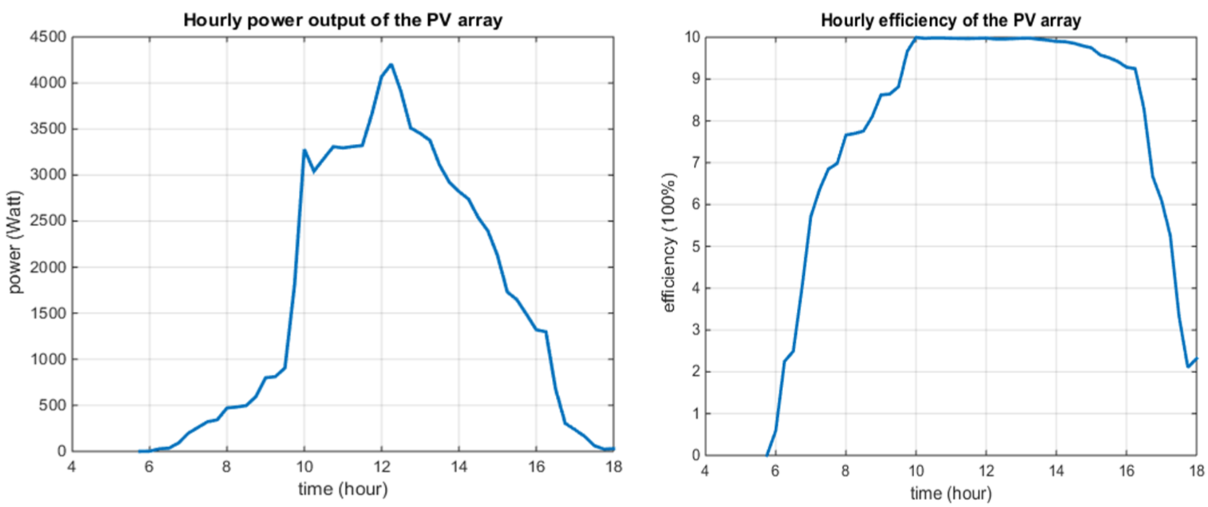

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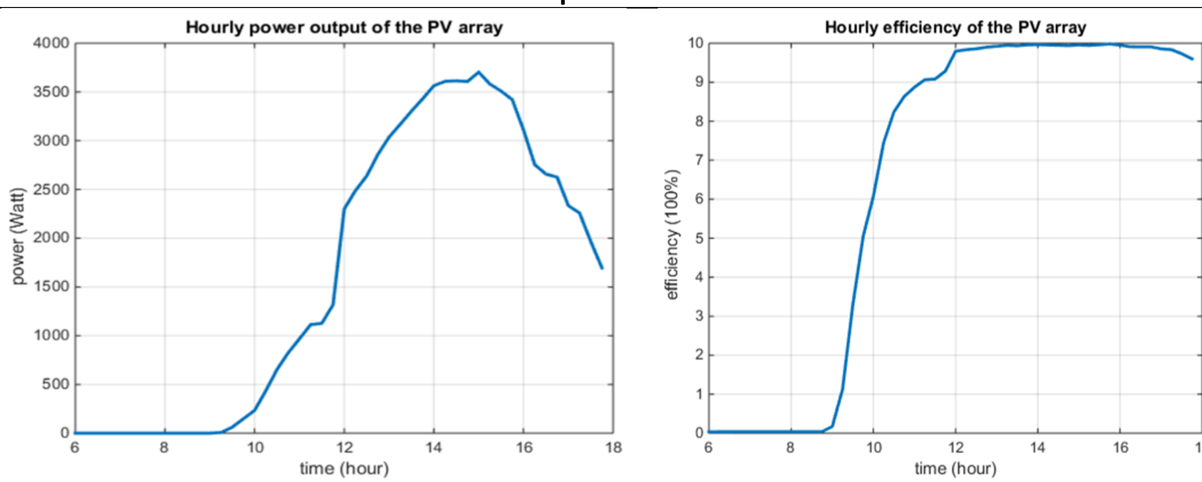

Figure 4.7 Hourly Power Output and Efficiency of the PV Array for Different Dates

4.2 Result for Wind Assessment

In this study, wind speed for the four-year period 2015-2018 were analyzed. The monthly Weibull distribution parameters c and k, mean wind speed and mean wind power densities were determined. Wind turbine was selected and the histogram as well as the power curve was developed.

When the four- year data is taken in consideration, the average monthly maximum and minimum value of wind speed are found to be 9.89 m/s (in January 2015) and 4.9 m/s (in August 2018) respectively. Using equation (3.40) and equation (3.41) annual and monthly values of k and c are also presented in Table 4.1 and Table 4.2, respectively.

Table 4.1. Annual Average Wind Speed and Weibull Parameters from A Record of 2 m Height Above Ground Level for Kombolcha.

Year	v_m(m/s)	k	c
2015	8.43	1.58	9.51
2016	6.69	1.33	7.55
2017	6.16	1.36	6.95
2018	5.70	1.33	6.43

This shows the monthly average wind speed (v_m), c and k for 2015-2018 are shown in Table 4.1 for the city of Kombolcha for 2015-2018.

Table 4.2. Monthly Mean Wind Speed and Weibull Parameters from A Record of 2m Height Above Ground Level for Kombolcha.

Month	Parameters	2015	2016	2017	2018
January	v_m	6.07	5.37	6.74	5.76
	k	1.41	1.36	1.32	1.32
	c	6.84	6.06	7.60	6.49
February	v_m	6.89	6.01	6.51	5.72
	k	1.49	1.40	1.29	1.31
	c	7.77	6.78	7.34	6.45
March	v_m	7.12	7.03	6.70	6.82
	k	1.53	1.44	1.35	1.29
	c	8.04	7.93	7.56	7.69
April	v_m	9.46	6.71	7.02	5.39
	k	1.65	1.32	1.41	1.25
	c	9.68	7.57	7.92	6.08
May	v_m	9.89	7.99	5.65	6.85
	k	1.62	1.34	1.30	1.40
	c	9.16	9.02	6.37	7.73
June	v_m	9.74	8.50	7.91	6.94
	k	1.74	1.52	1.59	1.43
	c	10.90	9.60	8.93	7.83
July	v_m	9.66	6.28	6.42	4.93
	k	1.78	1.37	1.44	1.36
	c	10.90	7.09	7.25	5.56
August	v_m	-	5.23	4.75	4.65
	k	-	1.27	1.27	1.33
	c	-	5.90	5.36	5.25
September	v_m	-	5.31	5.06	5.13
	k	-	1.29	1.26	1.26
	c	-	5.99	5.06	5.79
October	v_m	8.18	6.98	5.39	5.13
	k	1.39	1.29	1.20	1.27
	c	9.23	7.87	6.08	5.79
November	v_m	7.73	6.28	4.98	4.68
	k	1.32	1.29	1.27	1.24
	c	8.73	7.09	5.62	5.28
December	v_m	-	6.13	5.00	4.94
	k	-	1.26	1.28	1.29
	c	-	6.92	5.64	5.57

Taking in consideration of the worst case or the minimum annual average wind speed record, which is recorded in the year 2018, the wind power is analyzed.

The wind power density is shown in Figure 4.8. The wind power output as a function of wind velocity shows that the maximum average wind speed as well as the maximum value of power lies on the month June having a value of 205 W/m^2 for the case of 2018 data.

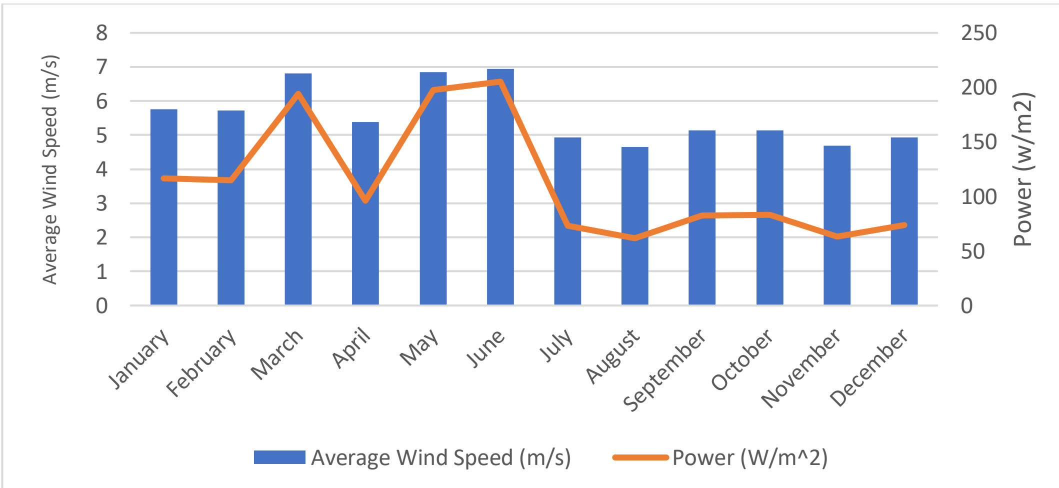

Figure 4.8 Power Output as a Function of Wind Velocity

After careful analysis and consideration of extrapolation using Equation 4.1 the monthly average wind speed for year 2018 is represented by Figure 4.9 This was done due to the extrapolation of wind speed at 50m for Kombolcha.

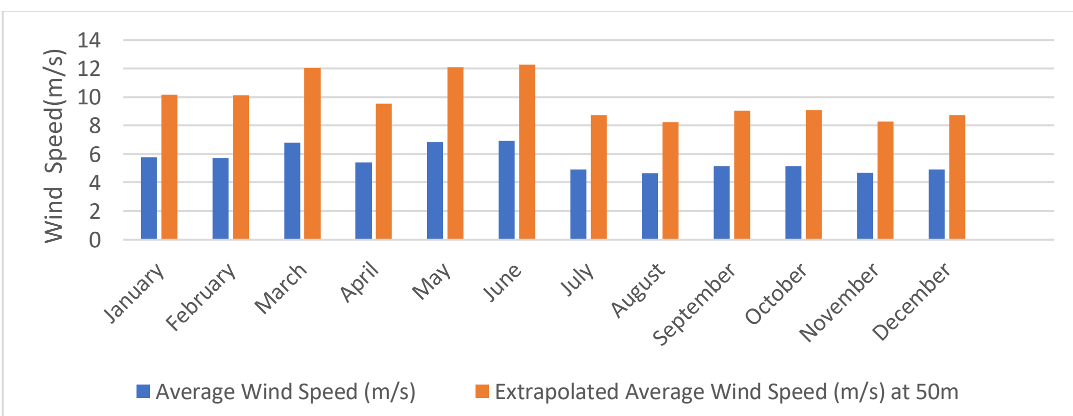

Figure 4.9 Annual Monthly Average Wind Speed Data at 50m Above Ground Level.

Based on the fraction of time for the wind speed recorded the histogram of wind speed can be represented by Figure 4.10 It can be seen that yearly on 2018 the average wind speed occurs for more than 15 % of the time.

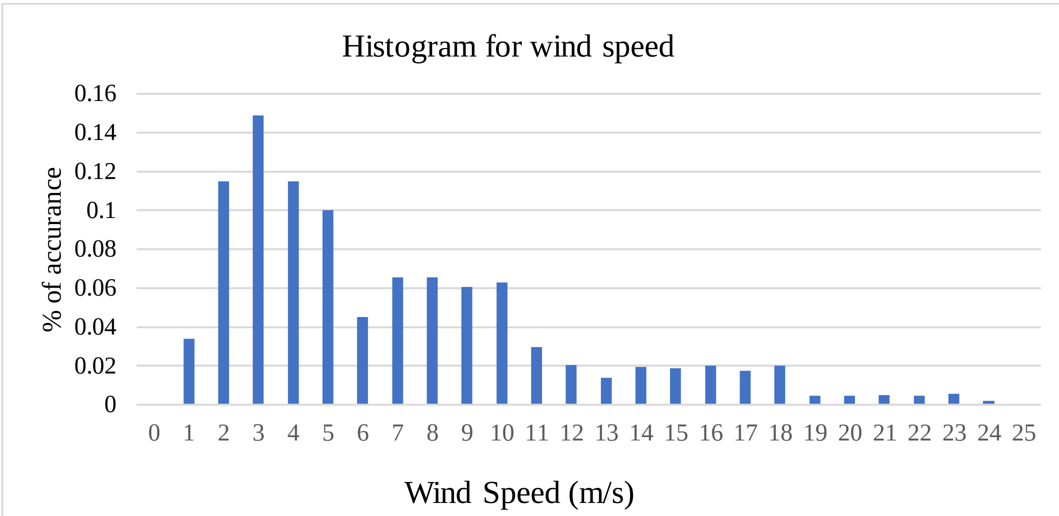

Figure 4.10 Histogram for Wind Speed

The Weibull distribution curve is also represented by Figure 4.11. the Weibull distribution curve is presented below for the wind data for Kombolcha having a mean shape factor of 1.3 and a mean scale factor value of 6.43.

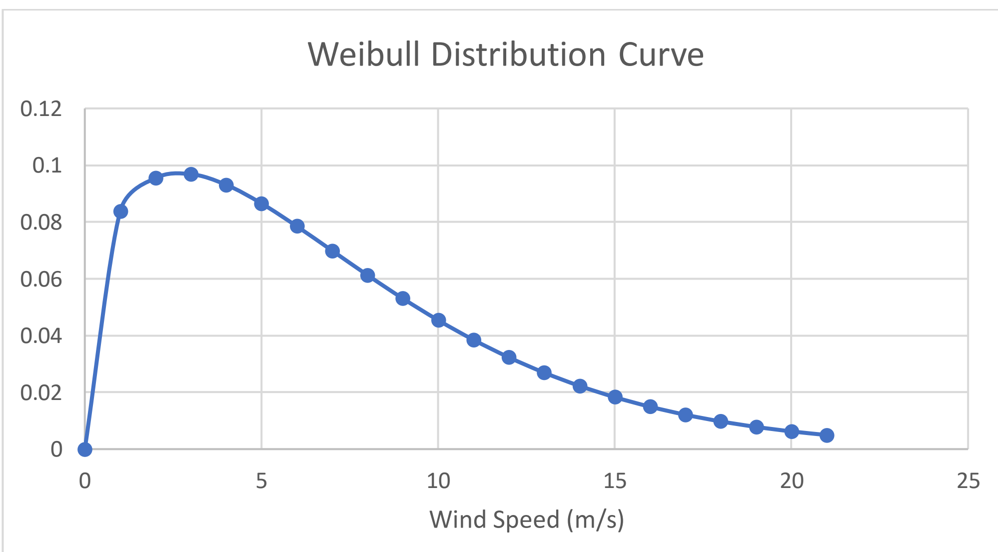

Figure 4.11 Weibull Distribution Curve

Considering the four-year data the annual mean wind speed ranges from 5.7m/s up to 8.4 m/s. Thus, with the range of annual mean wind speed of the real weather of Kombolcha, the power density ranges from 120 W/m^2 up to 365 W/m^2.

Taking in consideration that the site has a potential for wind power one more step was taken. In view of a specific wind turbine specifications along with the average wind speed of Kombolcha the power curve is represented in Figure 4.12. The a specific siemens wind turbine SWT-2.3, generates a maximum power of 2.3 MW as can be seen on the graph. Where in the case of Kombolcha the minimum possible power of 1,000 KW can be generated using this turbine.

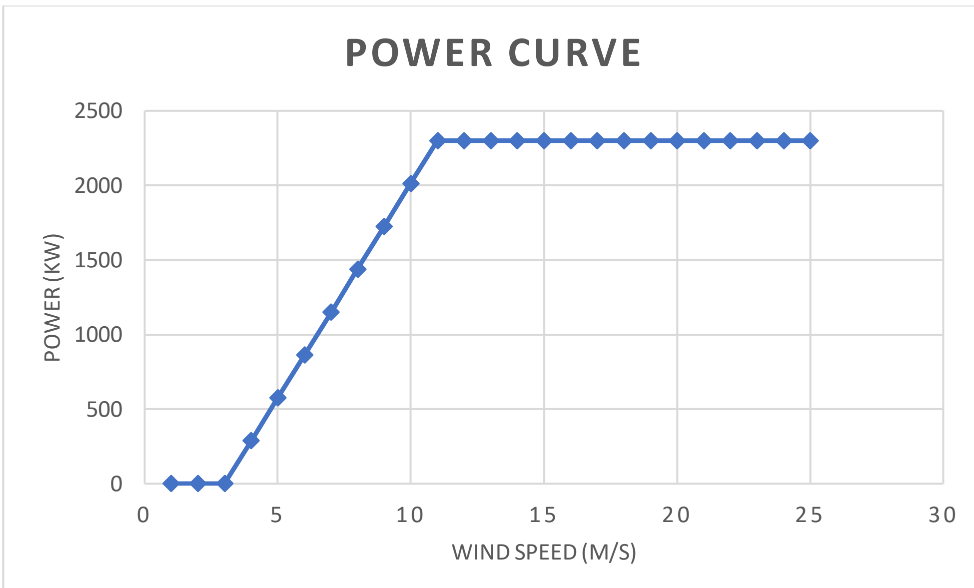

Figure 4.12 Power Curve for Seimens Wind Turbine Specifications with 2300 kW Capacity.

Regarding wind resource potential for a site, the results above can be validated using similar researches [29]. Determining the mean wind speed, wind power, and the Weibull parameters such as the monthly mean shape and scale parameters are said to be necessary procedures for stating the wind power potential of a site.

4.3 Result of Homer Analysis

This section presents optimization results generated by the HOMER model as well as results for electricity production for the optimal hybrid system. Sensitivity analysis is also performed in this section considering variation of data for key parameters such as diesel price, solar radiation and wind speed. Figure 4.13 shows the total energy consumption kWh for the KIP. It shows the maximum monthly bill reading is to be 2,850 kWh. This demand was used for the homer analysis.

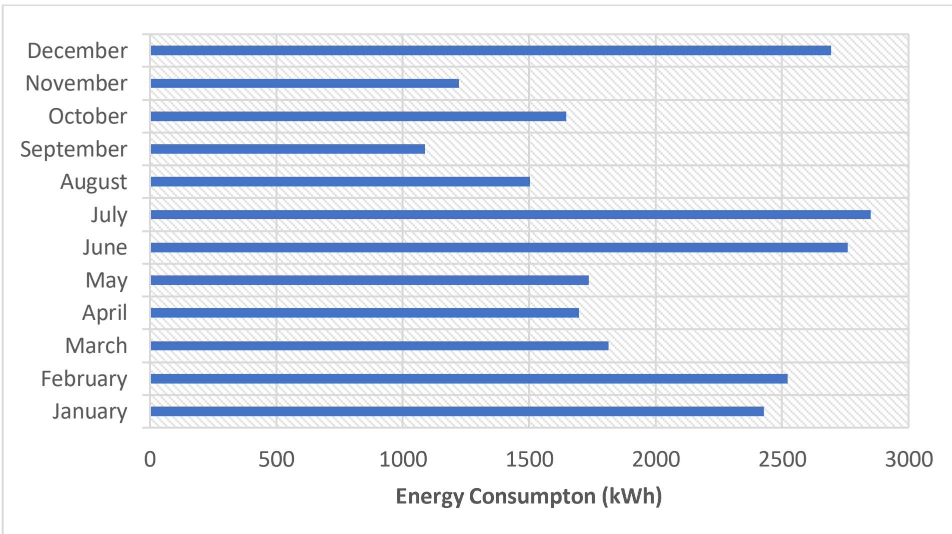

Figure 4.13 Total Energy Consumption Per Hour for KIP

4.3.1 Optimization Result

The HOMER model performs simulations, optimization and sensitivity analysis in order to identify the most feasible hybrid system combination in terms of cost and technical aspects, based on the given constraints and inputs. The model presents optimum results under two categories: overall optimization and categorized optimization result tables according to their initial capital, NPC, COE, dispatch type, renewable energy penetration or fraction, and capacity shortage.

Figure 4.14 shows the overall optimization results with many possible system configurations whose total NPC is higher than that of the optimal configuration. Figure 4.19 basically presents optimization result by category. It shows top-ranked, least-cost systems from each optimal system configuration.

Components	PV (kW)	Swt	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Diesel (L)	Gen1 (hrs)
PV, Battery, Convertor	5500			5000	5000	CC	$ 5,183,334	$ 6,648,806	0.070		
PV, Battery, Convertor	5500			5000	5000	LF	$ 5,183,334	$ 6,648,806	0.070		
PV, Battery, Convertor	5500			5000	6000	CC	$ 5,270,000	$ 6,759,426	0.071		
PV, Battery, Convertor	5500			5000	6000	LF	$ 5,270,000	$ 6,759,426	0.071		
PV, Battery, Convertor	6000			5000	5000	CC	$ 5,433,334	$ 6,898,805	0.071		
PV, Battery, Convertor	6000			5000	5000	LF	$ 5,433,334	$ 6,898,805	0.071		
PV, Battery, Convertor	6000			5000	6000	CC	$ 5,520,000	$ 7,009,426	0.072		
PV, Battery, Convertor	6000			5000	6000	LF	$ 5,520,000	$ 7,009,426	0.072		
PV, Battery, Convertor	5500			6000	5000	CC	$ 5,583,334	$ 7,317,947	0.076		
PV, Battery, Convertor	5500			6000	5000	LF	$ 5,583,334	$ 7,317,947	0.076		
PV, Battery, Convertor	5500			6000	6000	CC	$ 5,670,000	$ 7,428,566	0.077		
PV, Battery, Convertor	5500			6000	6000	LF	$ 5,670,000	$ 7,428,566	0.077		
PV, Battery, Convertor	6000			6000	5000	CC	$ 5,833,334	$ 7,567,947	0.078		
PV, Battery, Convertor	6000			6000	5000	LF	$ 5,833,334	$ 7,567,947	0.078		
PV, Battery, Convertor	6000			6000	6000	CC	$ 5,920,000	$ 7,678,566	0.079		
PV, Battery, Convertor	6000			6000	6000	LF	$ 5,920,000	$ 7,678,566	0.079		
PV, Wind Turbine, Battery, Convertor	6000	1		1000	6000	CC	$ 6,920,000	$ 19,028,534	0.198		
PV, Wind Turbine, Battery, Convertor	6000	1		1000	6000	LF	$ 6,920,000	$ 19,028,534	0.198		
PV, Wind Turbine, Battery, Convertor	3000	1		5000	5000	CC	$ 6,933,333	$ 20,082,438	0.208		
PV, Wind Turbine, Battery, Convertor	3000	1		5000	5000	LF	$ 6,933,333	$ 20,082,438	0.208		
PV, Wind Turbine, Battery, Convertor	3000	1		5000	6000	CC	$ 7,020,000	$ 20,193,166	0.210		
PV, Wind Turbine, Battery, Convertor	3000	1		5000	6000	LF	$ 7,020,000	$ 20,193,166	0.210		
PV, Wind Turbine, Battery, Convertor	4000	1		5000	5000	CC	$ 7,433,334	$ 20,460,262	0.207		
PV, Wind Turbine, Battery, Convertor	5500	1		6000	5000	CC	$ 8,583,334	$ 21,879,404	0.218		
PV, Wind Turbine, Battery, Convertor	5500	1		6000	5000	LF	$ 8,583,334	$ 21,879,404	0.218		
PV, Wind Turbine, Battery, Convertor	5500	1		6000	6000	CC	$ 8,670,000	$ 21,990,024	0.219		
PV, Wind Turbine, Battery, Convertor	5500	1		6000	6000	LF	$ 8,670,000	$ 21,990,024	0.219		
PV, Wind Turbine, Battery, Convertor	6000	1		6000	5000	CC	$ 8,833,334	$ 22,129,406	0.221		
PV, Wind Turbine, Battery, Convertor	6000	2		6000	5000	LF	$ 11,833,334	$ 36,690,864	0.365		
PV, Wind Turbine, Battery, Convertor	6000	2		6000	6000	CC	$ 11,920,000	$ 36,801,480	0.366		
PV, Wind Turbine, Battery, Convertor	6000	2		6000	6000	LF	$ 11,920,000	$ 36,801,480	0.366		
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	1	100	6000	6000	LF	$ 8,933,470	$ 45,033,880	0.449	2,353	145
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	1	100	6000	6000	LF	$ 8,683,470	$ 45,726,624	0.456	2,463	151
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	1	100	5000	6000	LF	$ 8,533,470	$ 47,036,868	0.469	2,791	162
PV, Wind Turbine, Battery, Convertor	5500	3		6000	6000	LF	$ 14,670,000	$ 51,112,940	0.509		
PV, Wind Turbine, Battery, Convertor	6000	3		6000	5000	CC	$ 14,833,334	$ 51,252,324	0.510		
PV, Wind Turbine, Battery, Convertor	6000	3		6000	5000	LF	$ 14,833,334	$ 51,252,324	0.510		
PV, Wind Turbine, Battery, Convertor	6000	3		6000	6000	CC	$ 14,920,000	$ 51,362,944	0.511		
PV, Wind Turbine, Battery, Convertor	6000	3		6000	6000	LF	$ 14,920,000	$ 51,362,944	0.511		
PV, Wind Turbine, Diesel Generator, Battery, Convertor	4000	1	100	6000	6000	LF	$ 7,933,470	$ 54,250,820	0.544	4,025	210
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	1	100	5000	6000	CC	$ 8,533,470	$ 55,686,088	0.556	4,711	217
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	1	100	5000	6000	CC	$ 8,283,470	$ 57,636,828	0.576	5,092	231
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	2	100	5000	6000	LF	$ 11,283,470	$ 58,519,228	0.583	2,354	144
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	2	100	6000	6000	LF	$ 11,683,470	$ 58,559,404	0.583	2,223	140
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	2	100	6000	6000	CC	$ 11,683,470	$ 58,559,976	0.583	2,293	140
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	2	100	5000	6000	LF	$ 11,533,470	$ 58,611,712	0.584	2,287	143
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	2	100	6000	6000	LF	$ 11,933,470	$ 58,809,408	0.586	2,223	140
PV, Wind Turbine, Diesel Generator, Battery, Convertor	4000	2	100	6000	6000	LF	$ 10,933,470	$ 58,909,684	0.587	2,401	147
PV, Wind Turbine, Diesel Generator, Battery, Convertor	4000	1	100	5000	6000	LF	$ 7,533,470	$ 60,184,684	0.607	5,264	252
PV, Wind Turbine, Diesel Generator, Battery, Convertor	4000	2	100	5000	6000	LF	$ 10,533,470	$ 60,283,700	0.602	2,708	160
PV, Wind Turbine, Diesel Generator, Battery, Convertor	5500	2	100	5000	6000	CC	$ 11,283,470	$ 60,878,444	0.607	2,919	159

Where: - PV - Wind Turbine - Diesel Generator - Battery - Convertor

Figure 4.14 Overall HOMER Optimization Results

Components	PV (kW)	Swt	Gen1 (kW)	Batt.	Conv. (kW)	Disp. Strgy	Initial Capital	Total NPC	COE ($/kWh)	Diesel (L)	Gen1 (hrs)
PV, Battery, Convertor	5500			5000	5000	CC	$ 5,183,334	$ 6,648,806	0.070		
PV, Wind Turbine, Battery, Convertor	6000	1		1000	6000	CC	$ 6,920,000	$ 19,028,534	0.198		
PV, Wind Turbine, Diesel Generator, Battery, Convertor	6000	1	100	6000	6000	LF	$ 8,933,470	$ 45,033,880	0.449	2,353	145
Wind Turbine, Battery, Convertor		3		5000	5000	CC	$ 11,433,333	$ 48,290,992	0.511		
PV, Diesel Generator, Battery, Convertor	6000		100	6000	6000	LF	$ 5,933,470	$ 62,227,860	0.637	8,082	347
Wind Turbine, Diesel Generator, Battery, Convertor		3	100	6000	6000	LF	$ 11,933,470	$ 105,363,504	1.092	8,567	359
Diesel Generator, Battery, Convertor			5500	6000	5000	CC	$ 3,566,803	$ 17,010,481,152	169.275	3,571,845	1,986

Where: - PV - Wind Turbine - Diesel Generator - Battery - Convertor

Figure 4.15 Categorized HOMER Optimization Results

Figure 4.15 presents the categorized optimum result. It shows top ranked, least-cost system from each optimal system configuration.

The result show that the PV-Battery system is the best least-cost optimal configuration to meet the KIP electricity demand. The system consists of 5500 kW of the solar PV array and 5000 strings of batteries with cycle charging dispatch strategy. It has a total NPC of USD 6,648,806 and COE of USD 0.070/kWh. The system requires no use of generator being the most environmentally friendly option emitting zero CO_2 to the environment. Therefore, it can be considered as the best system configuration from a reliable, economic and environmental point of view.

The PV- WT- Battery system consists of 6000 kW of the solar array, one unit of wind turbine (2,300 kW), and 1000 string of batteries having a NPC of USD 19,028,54 and COE of USD 0.198/kWh.

The PV-WT-DG-Battery system consists of 6000 kW PV array, one unit of the wind turbine (2300kW), 6000 string of batteries and 100 kW of DG (2,353 liters of diesel per year), with load flowing dispatch strategy. This system has a NPC of USD of 45,033,880 and USD of 0.449/kWh for COE.

The WT-Battery system consists of three units of wind turbine, 5000 stings of batteries with a cycle charging load flow. This system has a NPC of USD 48,290,992 and a COE of USD 0.511.

The PV-DG-Battery option consists of a 6000 kW capacity of PV array, 6000 strings of battery, 100 kW of generator capacity (8,082 liters per year) with a load-flowing dispatch strategy. This system has a total NPC of USD 62,227,860 and COE of USD 0.637.

The WT-DG -Battery system consists of three units of wind turbine along with a 6000 strings of batteries, and 100 kW for DG (Diesel Generator) (8,567 liters of diesel per year), having a load flowing dispatch strategy. This system also has a NPC of USD 105,363,504 and COE of USD 1.092. Hence, this system is not viable.

The last and least categorized option is the DG-Battery system. having a 5,500 kW capacity of generator (3,571,845 liters of diesel per year), 6000 strings of batteries with cycle charging dispatch strategy. The NPC for this system is USD of 17,010,481,152 and COE of USD 169.275/kWh. This system being the poorest result has an immense amount of NPC and CO_2 emission for this system has an enormous value of 10369 tons/year along with the other pollutants. Therefore, this fossil fuel-based system is neither economically viable nor environmentally friendly to meet the electricity demand

In general, the categorized optimization result shows that the WT-DG-Battery, DG-Battery, PV-WT_DG-Battery, PV-DG-Battery systems are highly dependent on fossil fuel(diesel), which increases the COE compared to the PV-Battery, and PV-WT-Battery system.

Electricity Production

Figure 4.16 and Figure 4.17 presents monthly mean electricity production for the PV-Battery system and PV-WT- Battery system, respectively.

The PV-Battery optimum combination results indicate that the PV array has 100% contribution to the electricity production, with a total of 13% excess electricity production, 5% unmet electricity and 16% capacity shortage. The PV-WT-Battery optimum system shows that the PV array and wind turbine has 69% and 31% electricity contribution, respectively. With a total of 46% excess electricity, 4% unmet electric load and 19% capacity shortage.

4.3.2 Sensitivity Result

The main advantage of sensitivity analysis is the effect of variability of key resource components and fuel prices on the total NPC of the generation mix and levelized COE. The key sensitive parameters considered in this study are diesel price values of USD of 0.4, 0.7 and 1 per liter, wind speeds of 3, 5.85, and 8 m/s and solar radiation values of 2, 5.66, and 7 kWh/m^2/day.

Figure 4.16 shows sensitivity results for variation value of 5.66 kWh/m^2/day. In this scenario, it is observed that a variation of solar radiation has no effect to increase the levelized COE and maintain being on optimal system. As clearly shown in Figure 4.16 a PV- Battery system is very attractive with a reasonable levelized COE of 0.0698 USD/kWh.

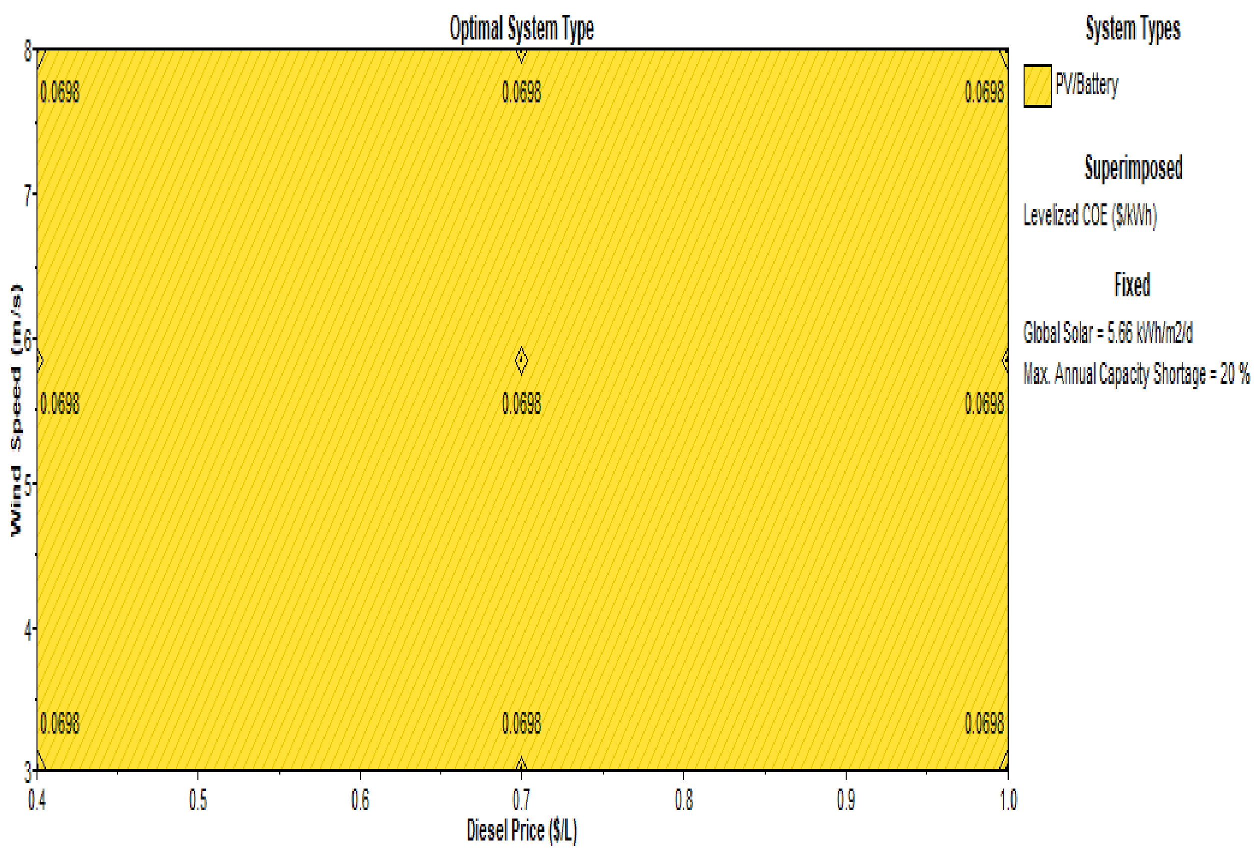

Figure 4.16 Optimal Systems in Terms of PV-Battery with Global Solar Radiation of 5.66 kWh/m2/day.

Figure 4.17 shows sensitivity results for variation of solar radiation and a constant wind speed of 5.85 m/s. the figure comprises of two systems, namely the PV-Battery and PV-WT-Battery system. It can be seen that from a small increase of solar radiation can cause a significant reduction in NPC and levelized COE for optimal system ranging from USD 0.372-0.068/ kWh.

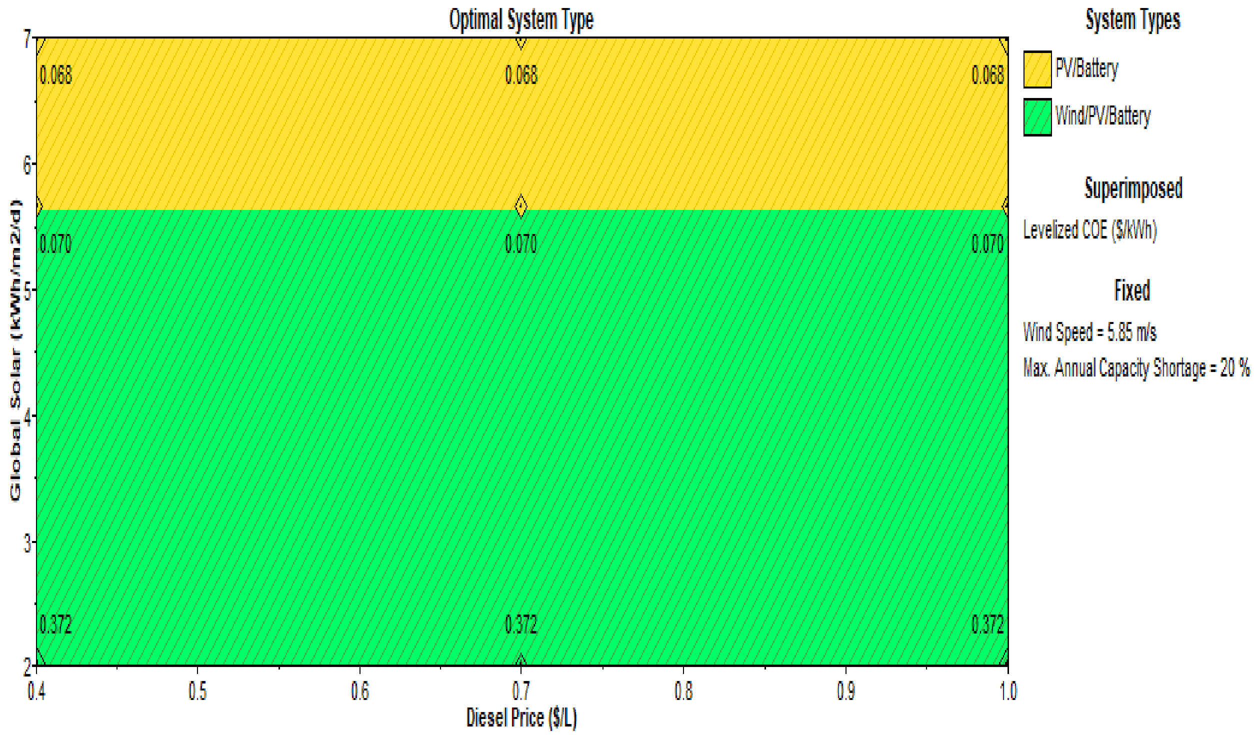

Figure 4.17 Optimal Systems in Terms of Solar Radiation and Diesel Price with a Constant Wind Speed of 5.85 m/s

Figure 4.18 shows the sensitivity analysis for the system types PV-battery, WT-PV-Battery and WT-PV-DG-Battery, along with the total net present cost. It can be recalled that the yearly average solar and wind resource for Kombolcha are 5.65 kWh/m^2/d and 5.85 m/s, respectively. Hence the figure signifies the sensitivity analysis. Where HOMER scales the load data so that the averages with the sensitivity options of possible yearly average wind speed upto 8 m/s and yearly average solar radiation upto 7 kWh/m^2/d.

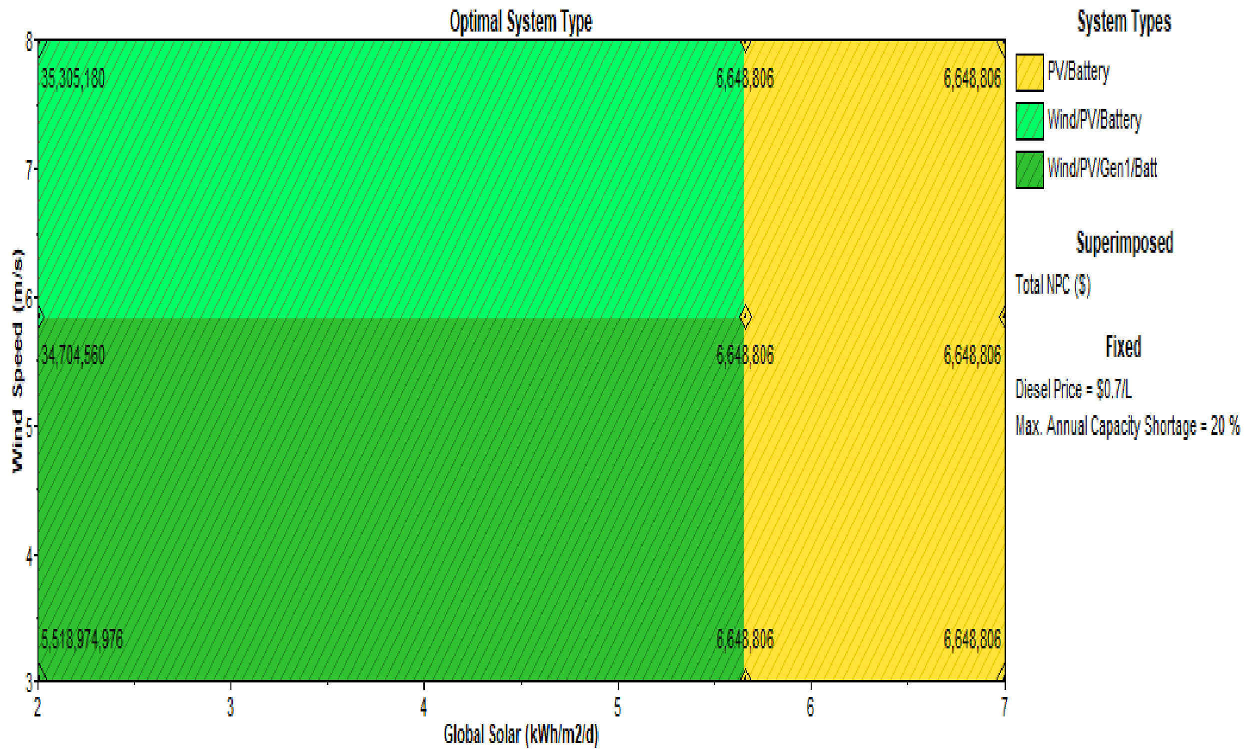

Figure 4.18 Sensitivity for Optimal System Graph

4.3.3 Emission Reduction Potential and Economic Analysis

When the emission reduction potential of these analysis is considered CO_2 emission is a key factor. Thus, using the optimal results for further procedure according to the Homer software is given to be zero as can be seen on Figure 4.19.

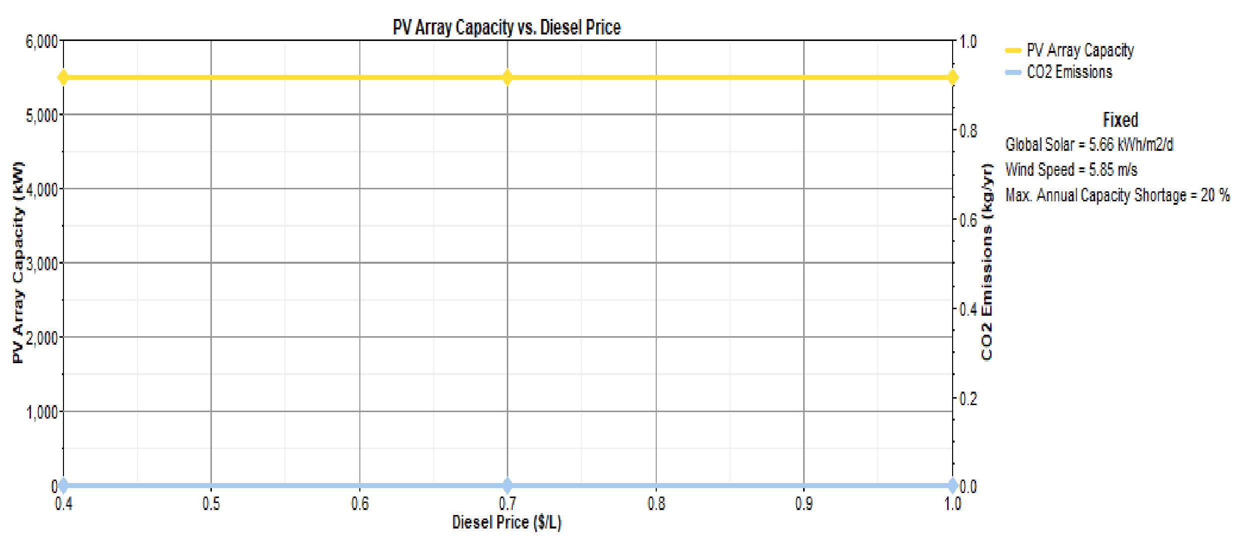

Figure 4.19 Total Electricity Production vs CO_2 Emission

Whereas if diesel (generator) was considered to be as a baseline input to run the park with the current electricity demand at the KIP, Table 4.3 shows how much of emission can be reduced with the usage of the optimized system.

Table 4.3 Emission when Generator is Considered as A Baseline Input for Power at KIP

Pollutant	Emissions (kg/yr)
Carbon dioxide	9,405,845
Carbon monoxide	23,217
Unburned hydrocarbons	2,572
Particulate matter	1,750
Sulfur dioxide	18,889
Nitrogen oxides	207,167

When the economic analysis is taken in consideration Levelized cost of energy is very important. Figure 4.20 shows the output homer software analyzed for total electricity production vs levelized cost of energy.

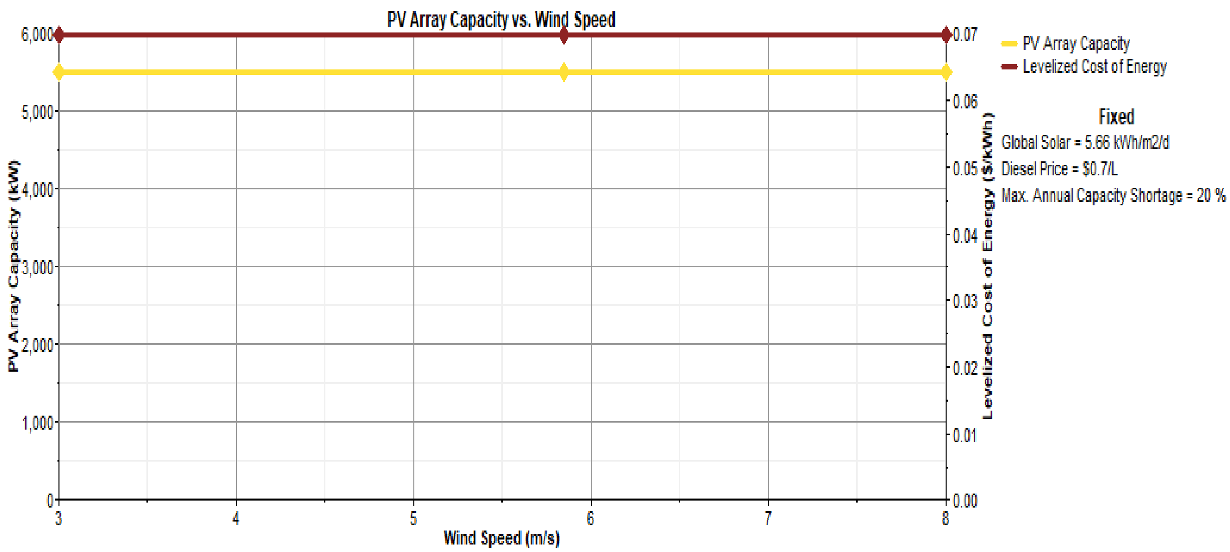

Figure 4.20 Total Electricity Production VS Levelized Cost of Energy

It can be validated that similar works has an output of comparable to this work [27]. The procedures and the results regarding the optimization and sensitivity result has generated similar graphs with HOMER. The energy generation cost was found to be 0.207 USD per kilowatt hour which is not far from the result of this assessment.

For the seven sheds occupied at the KIP, analysis has been done regarding solar PV. Considering the available rooftop area and a specific PV panel type (i.e Kyocera KC200 GT) the possible number of panels that can be installed is calculated to be 14,250 in number. Each having a maximum power of 200 W under standard test condition. Using MATLAB various characteristics such as I-V and P-V curves considering different radiation level was simulated for the solar panel considered. The PV module under different temperatures of operation was also simulated. Considering the power output and efficiency of the PV module was also simulated. The wind assessment was carried out with analytical procedures. The monthly, annual average wind speed and Weibull parameters were evaluated for the years 2015, 2016, 2017 and 2018. Taking the minimum annual average wind speed record, the power was analyzed based on the wind speed. The wind speed was also extrapolated at 50 m height to see the potential of the site which reached up to 12 m/s. On the HOMER analysis, the optimization and sensitivity procedures were done. It gave a result that the optimum system type for the KIP considering various factors such as resource availability, cost and other parameters PV-Battery was chosen to be the best. The optimization result gave an output comprising a categorized and overall result. The categorized result shows the top-ranked, least-cost system from each optimal configuration. Whereas the overall optimization result holds various system types. The other important feature of HOMER analysis is the sensitivity results. It has given output for system types PV-Battery and WT-PV-Battery along with the levelized COE ($/kWh) as an optimal option. The sensitivity result for optimal graph for the system types PV-Battery, WT-PV-Battery, and WT-PV-DG-Battery along with the net present cost is discussed. The other HOMER result includes the emission reduction and the economic analysis for the optimal system type.

Chapter Five

5. Conclusion and Recommendation

This chapter deals with the conclusion mentioning all the necessary points from the result according to the objective of the study. It also remarks the recommendation of this thesis for future works.

5.1 Conclusion

This research reached its objectives putting in on top priority on the assessment of solar and wind energy potential for Kombolcha Industrial Park (KIP). From the total discussions good results are achieved; based on the results of the investigation, the following conclusions were drawn.

The simulation of PV module performance was done considering a specific PV module. The following can be stated as a conclusion regarding the solar PV assessment.

- ❖ Currently functioning, the KIP demands 2.8 MW. The park has two different types of shed having an area of 5,500 m^2 (Qty=5) and 11,000m^2 (Qty=2). Excluding the rooftop unwanted structures (i.e ventilation and light band), the total rooftop area is calculated to be 43,291 m^2. And while considering the roof top side only facing south, the available rooftop area becomes 20,000 m^2. With the selected specific type of PV module (i.e KC 200GT), the number of PV modules according to the available rooftop area is 14,250 in number.
- ❖ This paper models a particular PV module (i.e. KC 200GT) under the weather condition of Kombolcha for KIP. Hence considering the annual temperature and global radiation data from Ethiopian National Mereology Agency which was measured in a 15-minute difference is used.
- ❖ From the simulation of the solar energy, the developed model is capable of predicting the parameter of the hourly power output and efficiency. It was simulated to give up to 4,500 W of maximum power output along with 10% efficiency of the PV module. The hourly power output explains that it reaches maximum at noon and decreases in the morning and evening.

The wind speed and wind energy potential for KIP are successfully investigated. Using the metrological data collected from the National Metrology Agency of Ethiopia, the recorded data was from a height of 10 m above ground level and a period of four- year data was analyzed. The wind energy potential of this study location is studied based on the Weibull parameters; monthly and annual wind speed variation was examined.

- The average monthly maximum and minimum value of wind speed are found to be 9.89 m/s (in January 2015) and 4.9 m/s (in August 2018), respectively.
- The monthly mean value of the Weibull scale parameter is between 5.1 and 9.5, while the monthly mean value of the shape parameter is between 1.3 and 1.58.
- Considering the worst-case scenario June has the highest mean power density 240 (W/m^2) and the lowest in August having 150 (W/m^2).

Using HOMER, this paper considers to simulating the KIP off-grid electrification system, with the basis of previous results of the availability of solar and wind energy potential for KIP. This study was investigated based on the load requirement of the occupied/ currently working sheds in KIP. Having a considerable annual average global solar radiation 5.66 kWh/m^2/day as well as a substantial wind-speed 5.85 m/s is a good perspective candidate for the deployment of a hybrid system comprising of solar photovoltaic (PV) array, wind turbines, a diesel generator and batteries.

- The simulation results indicate that the two systems are to be the most economical, technical and reliable system for the off-grid system.
- PV-Battery system is found to be the foremost optimum result to provide a power production of 10,794,3 kWh.
- PV-WT (wind turbine)-Battery is the second-best option being another optimum result. Where 69% is covered by PV and 31% is covered by wind energy. Giving a result of total power production 17,067,114 kWh.
- The proposed system would help to reduce the emission of greenhouse gases, reducing the dependency of imported diesel and enhance system reliability and affordability.
- The cost of energy for the most optimized system is USD 0.070 kWh (for PV-Battery system), and USD 0.198 kWh (PV-WT- Battery system). This result is slightly higher than

the current COE of the grid system that is USD 0.018 kWh. Taking in concern that the renewable source of energy is reliable the cost difference may be taken off consideration.

- The total NPC is USD 6,648,806 for the system of PV-Battery. Also USD 19,028,534 for the system of PV-WT-Battery.
- Considering the best optimum results from HOMER, it suggested that no use of diesel power making the optimization result to be free of greenhouse gases.

Lastly, from the data collected at the KIP, it can be recalled that the total monthly consumption of diesel to run the generator for the current working sheds is 1,080 liters per month of diesel. Contributing with an estimation of 2.86 tCO_2e per month (24 tCO_2e per annum). Hence, if the shortage of energy and need for usage of the generator is substituted with this study results of usage of renewable energy, it can contribute a portion in avoidance of greenhouse gas emission.

5.2 Recommendation

When coming to recommendation, this study provides a good understanding and inspiration to have a separate source of renewable energy for the industrial parks in Ethiopia. And thus, the energy aligned to be supplied for these parks can be allocated to reach out to the rural and urban households. More work can be carried out in order to achieve perfection in providing energy in the form of excellence. The following can be taken as a recommendation.

- With the outcome of this thesis and further development regarding the solar PV assessment, wind assessment, and HOMER optimization, it is expected to predict a more detailed structure of results.
- Consider the effect of the power output by installing small scale PV/ Wind turbine at the selected location to see the practical outcomes and evaluate the study.
- With the participation of different stakeholders like MOWIE/ EEA to plan and provide assistance for industrial parks to be off-grid.
- Different governmental stakeholders need to permit independent power producers and providing excess energy to the grid system and prevent waste of energy.

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Appendices

Appendix A Solar Module Specification

THE NEW VALUE FRONTIER

KYOCERA

KC200GT

HIGH EFFICIENCY MULTICRYSTAL
PHOTOVOLTAIC MODULE

UL LISTED

HIGHLIGHTS OF KYOCERA PHOTOVOLTAIC MODULES

Kyocera's advanced cell processing technology and automated production facilities produce a highly efficient multicrystal photovoltaic module.
The conversion efficiency of the Kyocera solar cell is over 16%.
These cells are encapsulated between a tempered glass cover and a pottant with back sheet to provide efficient protection from the severest environmental conditions.
The entire laminate is installed in an anodized aluminum frame to provide structural strength and ease of installation.
Equipped with plug-in connectors.

APPLICATIONS

KC200GT is ideal for grid tie system applications.

- Residential roof top systems
- Large commercial grid tie systems
- Water Pumping systems
- High Voltage stand alone systems
- etc.

QUALIFICATIONS

- **MODULE** : UL1703 certified
- **FACTORY** : ISO9001 and ISO 14001

QUALITY ASSURANCE

Kyocera multicrystal photovoltaic modules have passed the following tests.

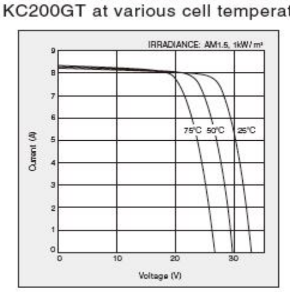
- Thermal cycling test ● Thermal shock test ● Thermal / Freezing and high humidity cycling test ● Electrical isolation test
- Hail impact test ● Mechanical, wind and twist loading test ● Salt mist test ● Light and water-exposure test ● Field exposure test

LIMITED WARRANTY

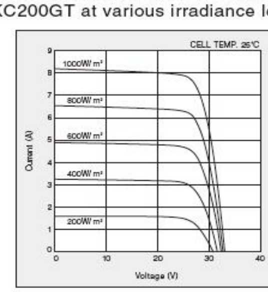
※1 year limited warranty on material and workmanship
※20 years limited warranty on power output: For detail, please refer to "category IV" in Warranty issued by Kyocera
(Long term output warranty shall warrant if PV Module(s) exhibits power output of less than 90% of the original minimum rated power specified at the time of sale within 10 years and less than 80% within 20 years after the date of sale to the Customer. The power output values shall be those measured under Kyocera's standard measurement conditions. Regarding the warranty conditions in detail, please refer to Warranty issued by Kyocera)

ELECTRICAL CHARACTERISTICS

Current-Voltage characteristics of Photovoltaic Module KC200GT at various cell temperatures



Current-Voltage characteristics of Photovoltaic Module KC200GT at various irradiance levels

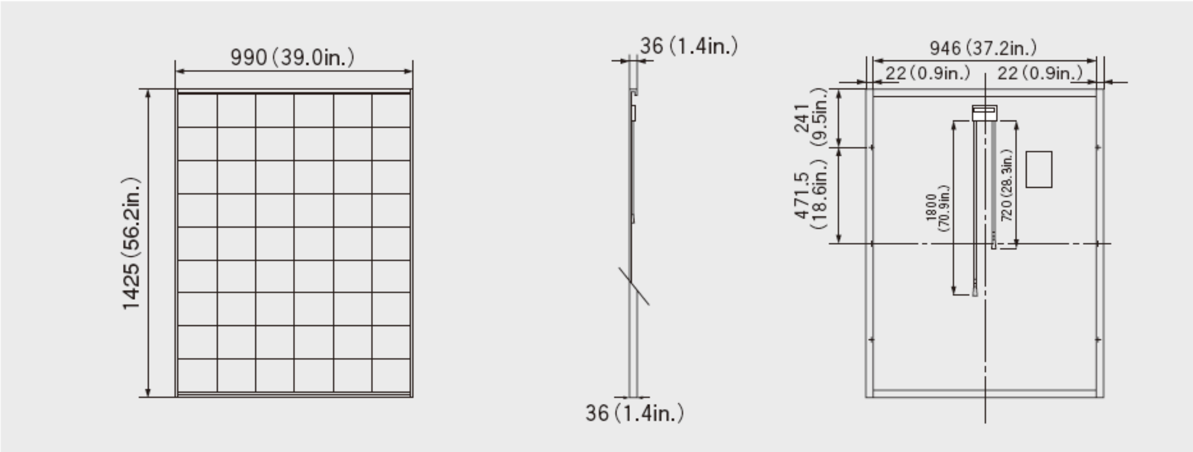


SPECIFICATIONS

KC200GT

Physical Specifications

Unit : mm (in.)



Specifications

■ Electrical Performance under Standard Test Conditions (*STC)	
Maximum Power (Pmax)	200W (+10%／−5%)
Maximum Power Voltage (Vmpp)	26.3V
Maximum Power Current (Impp)	7.61A
Open Circuit Voltage (Voc)	32.9V
Short Circuit Current (Isc)	8.21A
Max System Voltage	600V
Temperature Coefficient of Voc	-1.23×10^{-1} V/℃
Temperature Coefficient of Isc	3.18×10^{-3} A/℃

*STC : Irradiance 1000W/m², AM1.5 spectrum, module temperture 25℃

■ Electrical Performance at 800W/m², NOCT, AM1.5	
Maximum Power (Pmax)	142W
Maximum Power Voltage (Vmpp)	23.2V
Maximum Power Current (Impp)	6.13A
Open Circuit Voltage (Voc)	29.9V
Short Circuit Current (Isc)	6.62A

NOCT (Nominal Operating Cell Temperature) : 47℃

■ Cells	
Number per Module	54

■ Module Characteristics	
Length × Width × Depth	1425mm(56.2in)×990mm(39.0in)×36mm(1.4in)
Weight	18.5kg(40.7lbs.)
Cable	(+)720mm(28.3in),(-)1800mm(70.9in)

■ Junction Box Characteristics	
Length × Width × Depth	113.6mm(4.5in)×76mm(3.0in)×9mm(0.4in)
IP Code	IP65

■ Reduction of Efficiency under Low Irradiance	
Reduction	7.8%

Reduction of efficiency from an irrandiance of 1000W/m² to 200W/m² (module temperature 25℃)

Please contact our office for further information

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Kyocera reserves the right to modify these specifications without notice

LIE/I09M0703-SAGKM

Appendix B Wind turbine Specification- Siemens SWT-2.3-108

Technical Specifications

SWT-2.3-108

Rotor	
Type	3-bladed, horizontal axis
Position	Upwind
Diameter	108 m
Swept area	9144 m²
Speed range	6-16 rpm
Power regulation	Pitch regulation with variable speed
Rotor tilt	6 degrees
Blade	
Type	Self-supporting
Blade length	53 m
Root chord	3.4 m
Aerodynamic profile	NACA 63.xxx, FFAxxx, SWPxxx
Material	GRE
Surface gloss	Semi-gloss, <30 / ISO2813
Surface colour	Light grey, RAL 7035
Aerodynamic brake	
Type	Full-span pitching
Activation	Active, hydraulic
Load-Supporting Parts	
Hub	Nodular cast iron
Main bearing	Spherical roller bearing
Main shaft	Alloy steel
Nacelle bed plate	Steel
Transmission system	
Coupling hub - shaft	Flange
Coupling shaft - gearbox	Shrink disc
Gearbox type	3-stage planetary/helical
Gearbox ratio	1:91
Gearbox lubrication	Splash/forced lubrication
Oil volume	Approx. 400 l
Gearbox oil filtering	Inline and offline
Gearbox cooling	Separate oil cooler
Gearbox designation	PEAB 4456 (Winergy) or EH851 (Hansen)
Coupling gear - generator	Double flexible coupling
Mechanical brake	
Type	Hydraulic disc brake
Position	High speed shaft
Number of callipers	2

Canopy	
Type	Totally enclosed
Material	Steel
Surface gloss	Semi-gloss, 25-45, ISO2813
Colour	Light grey, RAL 7035
Generator	
Type	Asynchronous
Nominal power	2,300 kW
Protection	IP 54
Cooling	Integrated heat exchanger
Insulation class	F
Grid Terminals (LV)	
Nominal power	2,300 kW
Voltage	690 V
Frequency	50 Hz or 60 Hz
Yaw system	
Type	Active
Yaw bearing	Externally geared slew ring
Yaw brake	Passive friction brake
Yaw drive	Eight electric gear motors with frequency converter
Controller	
Type	Microprocessor
SCADA system	WPS via modem
Controller designation	KK WTC 3.0
Controller manufacturer	KK Electronic A/S
Tower	
Type	Cylindrical and/or tapered tubular
Hub height	80 m or site-specific
Corrosion protection	Painted
Surface gloss	Semi-gloss, 25-45, ISO2813
Colour	Light grey, RAL 7035
Operational data	
Cut-in wind speed	3-4 m/s
Rated power at	11-12 m/s
Cut-out wind speed	25 m/s
Maximum 3 s gust	59.5 m/s (IEC version)
Weights (approximately)	
Rotor	60,000 kg
Nacelle	82,000 kg

Appendix C Questionnaire and Interview

Questionnaire for Assessment of Alternative Renewable Energy Power Supply Potential for Kombolcha Industrial Park

1. Company Name : ______________________________
2. Type of product produced : ______________________________
3. When did your company start working? ______________
4. Does Ethiopian Electric Utility supply your Energy?

   ☐ Yes ☐ No ☐ Other Specify: ______________________________

5. How much energy does your company require? ______________
6. Is your company satisfied with the energy supply?

   ☐ Yes ☐ No ☐ Other Specify: ______________________________

7. Is there interruption of power?

   ☐ Yes ☐ No

8. If there is interruption, how do you resolve this problem?

   ____

   ____

9. How many machines are in use?

   ____

10. Are the machineries installed energy efficient?

    ☐ Yes ☐ No ☐ Other Specify: ______________________________

11. If there has been interruption of power, has it affected your production?

    ☐ Yes ☐ No

12. If your production has been affected, how do you describe the rate of your production being negatively affected due to the energy supply?

    ☐ Extremely ☐ Highly ☐ Moderately ☐ Not at all

13. If there has been interruption of power, do use generator to resolve the problem?

    ☐ Yes ☐ No

14. If your answer is yes for Q.13, on average how much fuel do you use per month to run the generator?

    ____

Questionnaire for Assessment of Alternative Renewable Energy Power Supply Potential for Kombolcha Industrial Park

15. Are you aware of renewable energy?

☐ Yes ☐ No

16. If solar energy supply is provided, would you prefer to use this source of energy?

☐ Yes ☐ No

17. If no, can you state your reason?

____

18. Does your company reside in another country's industrial park, where there is alternative renewable energy being supplied?

☐ Yes ☐ No

19. If yes, what kind of renewable energy was being supplied?

☐ Solar PV
☐ Solar thermal
☐ Wind
☐ Other Specify: ____________________________

20. Do you contribute to a renewable energy projects?

☐ Yes ☐ No

21. Does your company properly treat waste?

☐ Yes ☐ No

Thank you again for your time!

Name & Signature **Date**

________________________ ________________________

Interview for Assessment of Alternative Renewable Energy Power Supply Potential for Kombolcha Industrial Park Add a heading to your document

Interview Questions

Kip Director

1. What is the current, the first phase constructed shed area?

2. How many sheds are built? What area does each shed occupy?

3. How many companies are currently enrolled? What kind of products are being produced? For detail answer use the following table.

Name of company at KIP	Type of product produced	Started working since

4. How much energy does the EEU provide KIP?

5. Is there full power supply? On the expansion plan of KIP, what will be the total energy demand?

6. How much is the monthly energy consumption data of the companies at the KIP?

Monthly Energy Consumption for company ____________	
Month	**Energy consumption (KWh)**
January 2018	
February 2018	
March 2018	
April 2018	
May 2018	
June 2018	
July 2018	
August 2018	
September 2018	
October 2018	
November 2018	
December 2018	

Appendix D MATLAB Code for PV Panel Characteristics

```
clear,clc
Iscn=8.21;%nominal short circuit current
Voc_n=32.9;%nominal open circuit voltage
KI=0.0032;%Isc current temperature cofficient
KV=-0.123;%Voc temperaute coefficeint
K=1.3806503e-23;%Boltzman constant
q=1.60217646e-19;%charge of an electron
a=1.30;%value of doid constant
Tn=273+25;%nominal tepmerature in kelvin
Gn=1000;%nominal solar insolation
Ns=54%number of cells in serouse
Eg=1.12;%Energy band gap of semiconductor
Vmmp=26.3;
Immp=7.61;
Pmax=Vmmp*Immp;
I11=Iscn+1;
Pl=Pmax+2;%a value to limit the axis of the graph
Vtn=Ns*K*Tn/q;% Nominal thermal voltage of array
Rs=0;%initialization of the iteration;
Io_n=Iscn/(exp(Voc_n/(a*Vtn))-1);%diod nominal saturation current
Rp=(Vmmp+Rs*Immp)/(Iscn-Io_n*(exp((Vmmp+Rs*Immp)/(Vtn*a))-1)-Immp);
In=1;%to initaite the iteration since the I(V) function is implicit
I=1;
format short
for i=1:2000;
    Rs=Rs+.0001;
    Ipvn=(Rp+Rs)*Iscn/Rp;
Rp=(Vmmp+Rs*Immp)/(Ipvn-Io_n*(exp((Vmmp+Rs*Immp)/(Vtn*a))-1)-Immp);
for j=1:500;
In=Ipvn-Io_n*(exp((Vmmp+(In*Rs))/(Vtn*a))-1)-((Vmmp+(Rs*In))/Rp);
end
Pn=In*Vmmp;
error=abs(Pn-Pmax);
V=0:.01:Voc_n;
I=Ipvn-Io_n*(exp((V+(I*Rs))/(Vtn*a))-1)-((V+(Rs*I))/Rp);
P=V.*I;
Pmaxx=max(P);
err=abs(Pmaxx-Vmmp*In);
if  err<.3
    break
end
end

G=0;
T=Tn;
Ipvn=(Rp+Rs)*Iscn/Rp;
I12=4*Iscn+3;
V12=6*Voc_n+3;
P12=24*Pl;
for l=1:5
    G=G+200;
    Ipv=(Ipvn+KI*(T-Tn))*(G/Gn);
V=0:.01:Voc_n;
Vv=6*V;%this for array (6 panels in series)
```

```
for ii=1:500;
I=Ipv-Io_n*(exp((V+(I*Rs))/(Vtn*a))-1)-((V+(Rs*I))/Rp);
end
Ii=4*I;
P=V.*I;
Pp=Vv.*Ii;
R=V./I;
figure(1)
plot(V,I,'LineWidth',2)
title('V-I character. of a panel at 25 degree Cent and diff. rad. level')
xlabel('voltage (Volt)')
ylabel('current (Amp)')
grid on
hold on
axis([0 Voc_n 0 I11])
figure(2)
plot(V,P,'LineWidth',2)
hold on
axis([0 Voc_n 0 Pl])
title('P-V character. of a panel at 25 degree Cent and diff. rad. level')
grid on
xlabel('voltage (Volt)')
ylabel('power (Watt)')
figure(3)
plot(V,R,'LineWidth',1.5)
title('R-V character. of a panel at 25 degree Cent and diff rad. level')
axis([0 Voc_n 0 I11])
xlabel('voltage (Volt)')
ylabel('Module Resistance (ohm)')
grid on
hold on
figure(4)
plot(Vv,Ii,'LineWidth',2)
title('V-I character. of solar array at 25 degree Cent and diff. rad. level')
xlabel('voltage (Volt)')
ylabel('current (Amp)')
grid on
hold on
axis([0 V12 0 I12])
figure(5)
plot(Vv,Pp,'LineWidth',2)
title('V-P character. of solar array at 25 degree Cent and diff. rad. level')
xlabel('voltage (Volt)')
ylabel('Power (Watt)')
grid on
hold on
axis([0 V12 0 P12])
end
hold off
hold off
Ta=table(V',I')

for l=1:3
Ipv=(Ipvn+KI*(T-Tn))*G/Gn;
Vt=Ns*K*T/q;%thermal voltage of array
Io=Io_n*(Tn/T)^3*exp(q*Eg*(1/Tn-1/T)/a/K);
```

```
for ii=1:500;
I=Ipv-Io*(exp((V+(I*Rs))/(Vt*a))-1)-((V+(Rs*I))/Rp);
end
P=V.*I;
R=V./I;
for j=1:length(V)
   if I(j)==min(I)
        break
   end

end
I(j:length(V))=NaN;
P(j:length(V))=NaN;
R(j:length(V))=NaN;
figure(6)
plot(V,I,'LineWidth',2)
title('V-I character. of a panel at 1000W/m2 rad. and diff. temp. level')
xlabel('voltage (Volt)')
ylabel('current (Amp)')
grid on
hold on
axis([0 Voc_n 0 I11])
figure(7)
plot(V,P,'LineWidth',2)
title('V-P character. of a panel at 1000W/m2 rad. and diff. temp. level')
xlabel('voltage (Volt)')
ylabel('Power (Watt)')
grid on
hold on
axis([0 Voc_n 0 Pl])
figure(8)
plot(V,R,'LineWidth',2)
title('V-R character. of the panel at 1000W/m2 rad. and diff. temp. level')
xlabel('voltage (Volt)')
ylabel('Resistance (Ohm)')
grid on
hold on
axis([0 Voc_n 0 9])
T=T+25;
end
```

Appendix E MATLAB Code for Power Output and Efficiency

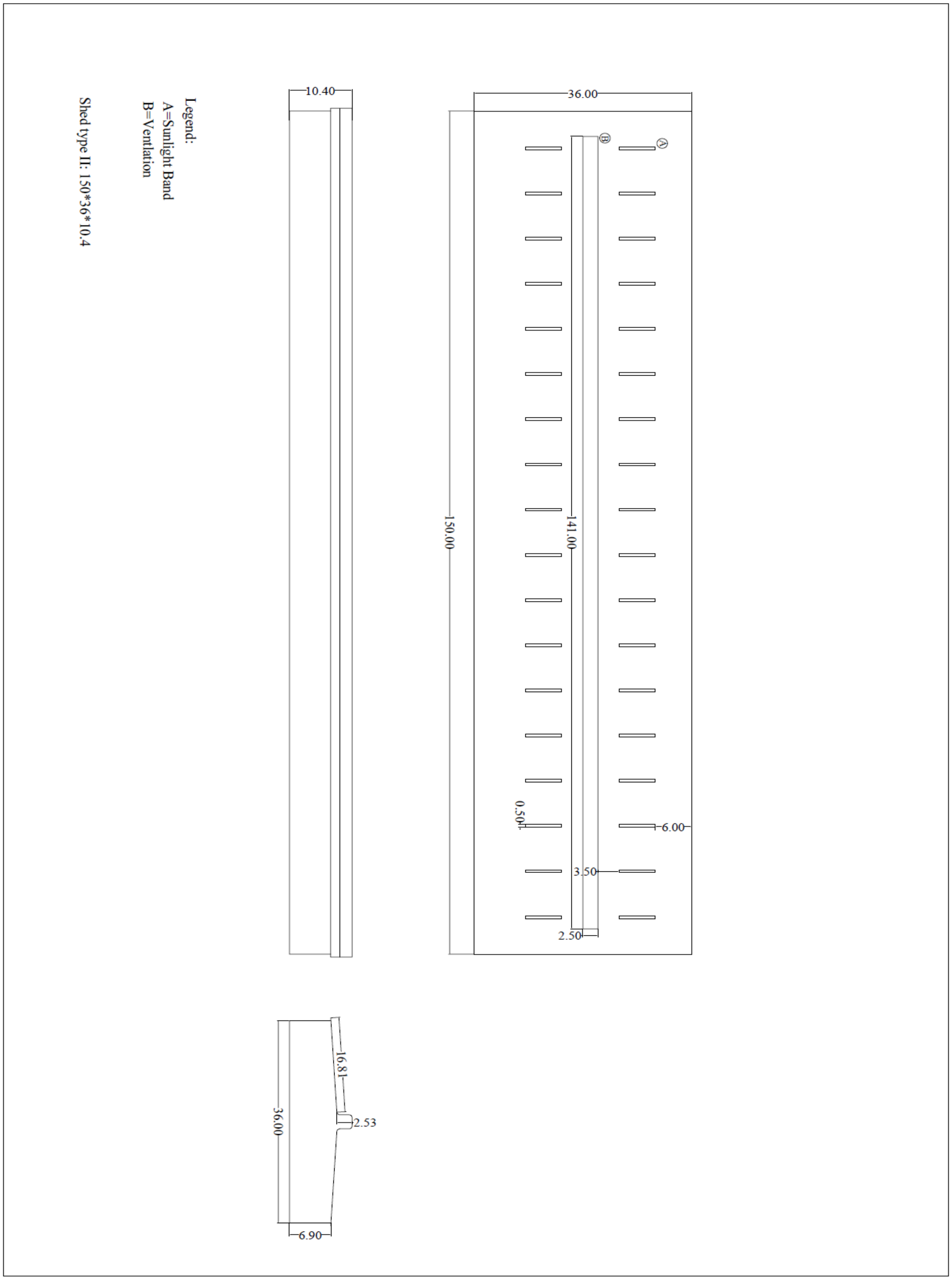
```
%This code will sort out a daily data for specfic month and date
clc
i=input('enter a month at which you need a data,in number: ');
j=input('enter the date for the selected month: ');
TNOCT=45; %nominal operating cell temp. in degree cent
SL=38;
LL=39.4;%latitude of the site
L=11.5;%longtude of the site
beta=L;
ref=0.2;
Area=2*0.9*24051; % Area of panel

%%%

Pmax=nan; % to reset the values after each run
PPmax=nan; % to reset
Tc=nan;  % to reset
VVmmp=nan;  % to reset
IImmp=nan;  % to reset
Pp=nan;  % to reset
Gt=nan;  % to reset
GH=nan;  % to reset
y=nan;   % to reset
z=nan;   % to reset
m=nan;   % to reset
if j>30; % 4th line j
    disp('Note: only the first 12 days of each month have a data')
else
    A=Mekdi(96*30*(i-1)+96*(j-1)+1:96*30*(i-1)+(96*j),[1,2,3]);
    B=Mekdi(96*30*(i-1)+96*(j-1)+1:96*30*(i-1)+(96*j),[1,2,4]);
    disp('Here is the soretd data for radiation')
disp(A)
disp('here is the sorted data for temperature')
disp(B)
yyy=A(:,3);
zzz=B(:,3);
y=table2array(yyy);  % table for temp.
z=table2array(zzz);  % table for rad.
%
GH=y; % measured rad. on hor. surface
m=z;  % measured yemp. data
end   % 24th line if
ee=[0 31 28 31 30 31 30 31 31 30 31 30 31];% month array
e=ee(1);% initialization
for j=1:i
    e=e+ee(j);
end
N=e+j;% nth date of the year
Delt=23.45*sind(360*(284+N)/365); %declination angle in degree at nth date
Ba=(N-81)*360/364;
ET=9.87*sind(2*Ba)-7.53*cosd(Ba)-1.5*sind(Ba);%equation of time in minutes
LSN=12-((LL-SL)/15)-(ET/60);%time reading for local solar noon
count=0;
```

```
 Gbt=zeros(length(GH),1);
 cosdh=zeros(1,length(GH));
 tim=zeros(1,length(GH));
 for j=1:length(GH);
        count=count+1;
        tim(j)=count/4-.25;

        cosdh(j)=cosd(15*(tim(j)-LSN));%cosine of hour angle
       h=acosd(cosdh);%hour angle
 end
  cos_delt=cosd(Delt);%cosine of the declination angle
sin_delt=sind(Delt);%sine of the declination angle
cosdelta=zeros(length(GH),1);
sindelta=zeros(length(GH),1);
cosdelta(:,1)=cos_delt;%matrix vector of declination angle
sindelta(:,1)=sin_delt;%matrix vector for declination angle
 costeta=cosdelta.*cosdh';%cosine of the incident angle
cosfi=sind(L)*sindelta+(cosd(L)*cosdelta.*cosdh');
C=0.095+.04*(sind((360*(N-100)/365)));
for i=1:length(GH); % to set -ve value to 0 for fi
    if cosfi(i,1)>0
        cosfi(i,1)=cosfi(i,1);
    else
        cosfi(i,1)=0;
    end
end % end line 71
for i=1:length(GH); % to set -ve value to 0 for teta
    if costeta(i,1)>0
        costeta(i,1)=costeta(i,1);
    else
        costeta(i,1)=0;
    end
end % end line 78
teta=acosd(costeta);
GdH=GH./(1+(cosfi/C));
GbH=GH-GdH;
Gb=GbH./cosfi;
Gbt=GbH.*costeta./cosfi;
Gdt=GdH*(1+cosd(beta))/2;
GRt=GH*.2*(1-cosd(beta))/2;
Gt=GRt+Gdt+Gbt; % global rad. on tilt
Tc=m+Gt/800*(TNOCT-20); % cell temperature
%%%

Rs=0.2000;
Rp=84.5570;
Iscn=9.35;%nominal short circuit current
Voc_n=47.3;%nominal open circuit voltage
KI=2.06e-3;%Isc current temperature cofficient
KV=-.077;%Voc temperaute coefficeint
K=1.3806503e-23;%Boltzman constant
q=1.60217646e-19;%charge of an electron
a=1.3;%value of doid constant
Tn=273+25;%nominal tepmerature in kelvin
Gn=1000;%nominal solar insolation
Ns=24051;%number of cells in serouse
```

```
Vtn=Ns*K*Tn/q;% Nominal thermal voltage of array
Eg=1.12;%Energy band gap of semiconductorVtn=Ns*K*Tn/q;% Nominal thermal
voltage of array
Io_n=Iscn/(exp(Voc_n/(a*Vtn))-1);%diod nominal saturation current
Ipvn=(Rp+Rs)*Iscn/Rp;
for i=1:length(Gt); % i moves through dayly data
T=Tc(i)+273;
G=Gt(i);
Vt=Ns*K*T/q;%thermal voltage of array
Ipv=(Ipvn+KI*(T-Tn))*G/Gn;
Io=Io_n*(Tn/T)^3*exp(q*Eg*(1/Tn-1/T)/a/K);
V=0:.01:Voc_n; % array for V-axis
Vx=6*V;%X6 in seriese
I=1;
for ii=1:500;
I=Ipv-Io*(exp((V+(I*Rs))/(Vt*a))-1)-((V+(Rs*I))/Rp);% iteration for eq.3
end % hence I will be array with same size to V
for j=1:length(V)
   if I(j)<0
        break
   end

end
I(j:length(V))=NaN;
P(j:length(V))=NaN;

Ix=4*I;%X4 in parallel
Px=Vx.*Ix;
if Ix(1)<0 | Ix(1)==0
    PPmax(i)=0;
    VVmmp(i)=0;
    IImmp(i)=0;
else
    Pmax=max(Px);
    PPmax(i)=Pmax;
    for k=1:length(Vx)
        if (Px(k)==Pmax)
            break
        end
    end
    IImmp(i)=Ix(k);

end
end
VVmmp=PPmax./IImmp;
eff=PPmax./(Gt'*Area)*100;
figure(1)
plot(tim,PPmax,'LineWidth',2)
title('Hourly power output of the PV array')
grid on
xlabel('time (hour)')
ylabel('power (Watt)')
figure(2)
plot(tim,IImmp,'LineWidth',2)
title('Hourly current output of the PV array')
```

```
grid on
xlabel('time (hour)')
ylabel('Current (Amp)')
figure(3)
plot(tim,VVmmp,'LineWidth',2)
title('Hourly voltage output of the PV array')
grid on
xlabel('time (hour)')
ylabel('Voltage (Volt)')
figure(4)
plot(tim,eff,'LineWidth',2)
title('Hourly efficiency of the PV array')
grid on
xlabel('time (hour)')
ylabel(' efficiency (100%)' )
```

Appendix F AutoCAD Representation of Shed Type I



Appendix G AutoCAD Representation of Shed Type II