A Thesis
On

(Role of Renewable Energy Technology in Mitigation of Climate Change : A Case Study of Mahabai Village, Kalikot, Nepal)

List of Abbreviations

RM	Rural Municipality
FGD	Focused Group Discussion
DHQ	District Headquarter
RERL	Renewable Energy for Rural Livelihood
NEA	Nepal Electricity Authority
WECS	Water and Energy Commission Secretariat
IPCC	Intergovernmental Panel on Climate Change
AEPC	Alternative Energy Promotion Centre
HSWPS	Hybrid Solar Wind Power System
HOMER	Hybrid Optimization Model for Electric Renewables
GHI	Global horizontal irradiance
DNI	Direct normal irradiance
DHI	Diffused horizontal irradiance
DPSP	Deficiency of power supply probability
COE	Cost of electricity
REPG	Relative excess power generated
RETs	Renewable energy technologies
LCC	Life cycle cost
LEC	Levelized energy cost
LUC	Life cycle unit cost
NREL	National renewable energy laboratory
PV	Photovoltaic
HH	Households
AC	Alternating Current
Ah	Ampere Hour
DC	Direct Current
Wp	Wattpeak

Abstract

Due to technical and financial limitations, Nepal's national grid is unreliable to provide energy to the majority of its distant rural areas. The ward no 3 of Mahabai Rural Municipality in Nepal's Kalikot District is the subject of this study's investigation into rural electrification using renewable/alternative energy sources. The villages are situated in Nepal's Karnali Province's Mahabai Rural Municipality in Kalikot District. The planned site's geographic coordinates (WGS 1984) are 29.06652ºN and 81.747434ºE. The village town is situated at an altitude of 1,929 meters above sea level on a mountainside with a south-facing slope. The Mahabai community has 240 households, a school, a health center, a temple, 40 street lights, and 20 productive end uses (PEU). According to the study, in the base year 2021, the expected average daily peak power consumption of the load is about 25 kW, and the estimated average daily peak energy demand of the load is about 314 kWh/day. About 34% of the overall energy consumption, which will be used for commercial and income-generating activities such as business, is shared by PEU. Using HOMER Pro software, an economic optimization-based simulation is run to choose an appropriate energy system to meet the forcasted energy demand, or that of the year 2021 (314 kWh/day with a peak demand of 30 kW).Two type of system: standalone diesel generator system and solar PV system , battery and converter are designed and examined. The minigrid system to meet this demand shall consist of solar PV panels (370kWp), cyclic charge controller, battery (2V, 1500 Ah, 72 batteries) and a converter (40.6kW). The levelized cost of electricity (LCE) is found to be $0.237/kWh. Similarly diesel generator system to touch the demand shall consist of 57kW genset with cyclic charge controller. The levelized cost of electricity (LCE) for standalone diesel generator system is found to be $1.1/kWh. Through sensitivity analysis it is seen that increase in resource availability would decrease LCE and NPC. The system shall play great role in socioeconomic development of village and as measure for mitigation of climate change. Implementation of Solar PV system instead of standalone diesel generator system would keep away from greenhouse gas emission of 159699 kg of CO_2 per year, carbon monoxide 1007 kg/yr., unburned hydrocarbons 43.9 kg/yr. with other pollutants as particulate matter 6.10 kg/year, Sulphur dioxides 391 kg/year and Nitrogen oxides 946 kg/year.

Chapter 1
INTRODUCTION

1.1 Background

Climate change is a climate transition events. It is the increase of mean temperature in the atmosphere. The increase in greenhouse gases such as carbon dioxide, methane, nitrous oxides, ozone as a result of burning fossil fuel results in climate change. Climate change refers to a change in the state of the climate that can be identified using statistical tests i.e., by changes in the mean and/or the variance of its properties, and that go on for an extended period, usually decades or longer. Climate change may be due to natural processes or by artificial processes on rising emissions such as change in suns energy, volcanic eruptions, and industrial revolution. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. (IPCC, 2014)

Most people agree that the focal cause of current global warming trend is due to increase in highly consumption of fossil fuel that releases the harmful greenhouse gases causing greenhouse effect. It results, when the atmosphere traps heat radiating from Earth toward space. A greenhouse gas in the atmosphere absorbs heat from escaping causing increase in temperature of earth. Deforestation, farming, consumption of fuel and other human activities continues to contribute to climate change. Production, transmission and distribution of electricity in Nepal is being done by NEA which was established on August 16, 1985 (Bhadra 1, 2042) under the Nepal Electricity Authority Act 1984, through the merger of the Department of Electricity of Ministry of Water Resources, Nepal Electricity Corporation and related Development Boards. Having more than 2.9 million customers, NEA is still unable to make large number of population and communities electrified. (DLRMP, NEA, 2016). The power supply system of Nepal is suffering from lack of production forcing the distributor to practice regular load shedding. Hence, Rural Electrification based on Solar Mini Grid system, micro hydro based mini grid could substantially contribute in making the national power supply system more diversified and independent, and more ecologically and economically sustainable. Total energy consumption in FY 2014/15 is 500 million Giga Joule (GJ); among which, fuel-wood is the largest energy resources and occupies about 70.47% of the total energy demand. Other sources of bio-masses are agricultural residues and animal dung which contribute about 3.48% and 3.68%, respectively. Share of petroleum fuels in the total energy system is about 12.53 %. Other sources of commercial energy are coal and electricity, which contribute about 3.97% and 3.39%, respectively in the total energy supply. In aggregate, the share of traditional fuel is 77.63%, Commercial (coal, petroleum and electricity) is 19.88 % and Renewable (Solar, Biogas, Micro hydro, Wind) is 2.49% (WECS, 2017).Tradition fuels are main source for cooking in rural communities which causes indoor and outdoor pollution. Commercial fuels sources aren't present in Nepal as they are imported. In Nepal, there is monopoly system that drives commercial fuel market; its price is increasing day by day causing difficulty for countries having poor economy like Nepal. Burning of fossil fuel causes increase in the concentration of carbon in atmosphere. Due to Global warming, the sea level is increasing day by day. The amounts of snow and ices have diminished and are due to human activities. The planet is already facing its impact on biodiversity, water resources and local livelihood. Reducing carbon pollution from the hydropower plant, diversifying the alternative energy economy, building alternative energy infrastructure, removing energy waste in homes, business and factories, reducing other greenhouse gas emission etc. are the alternative plans that has been applying by different countries to tackle with climate change. Renewable/Alternative energy, energy resources that occur naturally and frequently in environment and can be used for human benefit, a favorable technology for the mitigation of climate change generates 19.1% of global final energy consumption in 2013 and its growth continued to expand in recent years (REN21, 2015). Alternative energy has become a mainstream energy and the rapid growth of alternative energy in these years was dominated by wind, solar photovoltaic hydropower and micro hydro technologies.

Therefore, rural electrification using renewable energy sources can increase the diversity and independence of the nation's power supply system, make it more environmentally and economically sustainable, and help to slow down global warming as mitigating climate change.

1.2 Project location

Kalikot District is the province capital of Karnali Province. Surkhet is the one of the ten districts of Karnali located about 700 kilometers west of the national capital Kathmandu. The district's area is 1,741 square kilometers. The total household in Kalikot district is 23008. Out of which the average household size is 5.95 and 95.6 % household were own their own home. It had population of 105,580 population in 2001 and 136,948 in 2011 which male and female comprised 50/50%. Of these, 99.5% spoke Nepali as their first language. The majority of the peopleChettris(29%),Thakuri(25%),Kaami(19%).Bhramin(17%),Damai/Dholi(5%),Sarki(3%), Synasi(1%), Kumal(1%), Lohar(1%)..Majority of the people are Hindu(99%). In line with the latest federal structure, Kalikot comprises of 4 municipality and rural municipalities as shown in Figure 1.

1. Khandachakra Municipality
2. Raskot Municipality
3. Tilagufa Municipality
4. Pachaljharana Rural Municipality
5. Sanni Triveni Rural Municipality
6. Narharinath Rural Municipality
7. Shubha Kalika Rural Municipality
8. **Mahabai Rural Municipality**
9. Palata Rural Municipality

Figure 1: Map of Kalikot district

The Karnali Highway connects Kalikot with other parts of the country. The condition of Karnali highway is very poor. It is rough and narrow, and often obstructed during monsoon. The frequency of traffic accidents is high. Khulalu road (38km), Bharta-Sakatiya road (25km) and Manma-Dhaulaga rural road are under construction and will link Kalikot’s DHQ with various VDCs. Various seasonal roads connect Kalikot DHQ with Bajura, Dailekh, Accham and Jumla districts during the dry season. Tractors (during dry season) and mules & goats are the major means of transportation within the district. Landslides are the major hazard in the district.

The district has ample prospects for generating electricity from the Karnali and Tila rivers, but thus far it has only developed micro-hydro power in Mumra, Daha, Malkot, Nanikot and Mugra.

The agriculture land available is 27,213 hectares. The literacy rate (on the basis of read and write) is about 57 % among them 68% and 46 % were male and female respectively and 50.1

% have passed the primary level. Out of total households, 98 % households use fuelwood, 1% household use LPG and 1% household use biogas for cooking purposes. For lighting 11.6% household use electricity, 37 % household use solar, 1 % household use kerosene and 49% household use fuelwood and other measures. 58% of population used piped tap water for drinking and 20.2% have flush toilet.

1.2.1 Local Government Profile

Out of 9 municipalities of Kalikot district, Mahabai rural municipality is one of the RM of the district. The total area occupied by the RM is 322.07 sq km the total population of the rural municipality is 8,323 as of 2011 Nepal census. The rural municipality is divided into 7 wards the headquarters of this newly formed rural municipality is situated at Odanaku, Jajarkot and Jumla district touches on eastern side of the rural municipality while Subhakalika RM lies in western side. Similarly, Tilagupha Municipality is in north of the rural municipality while Dailekh district is in south.

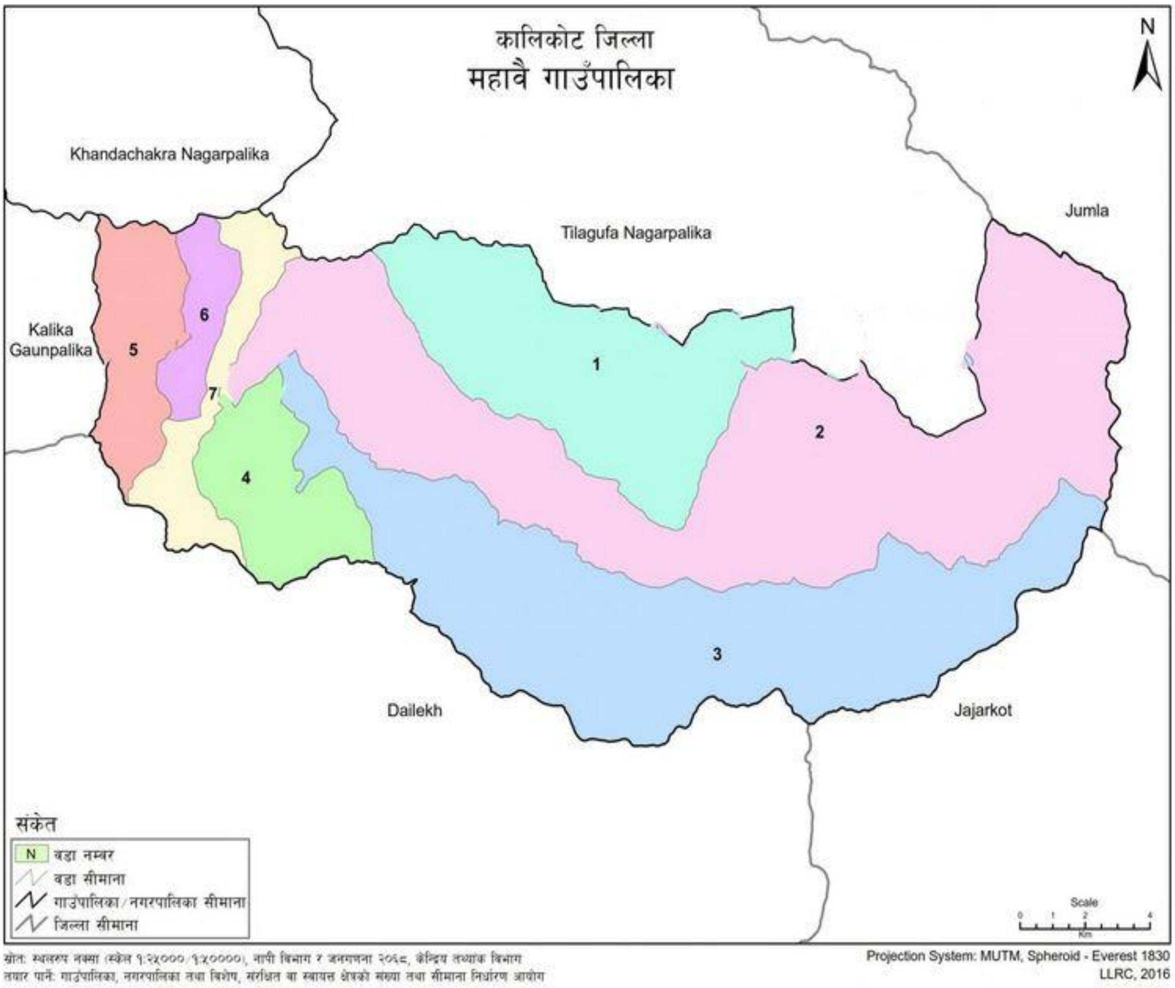


Figure 2: Map of Mahabai Rural Municipality

1.2.2 Project Area Village

The study area is proposed in ward no. 03 of Mahabai Rural Municipality. The study area village resides at 6346 ft elevation from the sea level and 2 km from the Padamghat River. The geographical co-ordinate of proposed location 1 is 29.06652ºN and 81.747434º E with an area of approx. 824. The nearest national grid point at Bhaisekot, Dailekh which is 70 km (aerial distance) distance from the project site. From the implementation of that project altogether 240 household will be benefitted which consist of 1320 population.

1.2.3 Accessibility

There is only one roadway to reach Mahabai RM: Manma to Sherabada and then to Mahabai RM which is approx. 32 km from the Manma (headquarter of Kalikot) to reach. It takes approx. 2 hours of drive by bus from Manma to Sherabada due to aggravated road condition and one hour by walking from Sherabada to Mahabai RM due to only goreto bato called Sherabada-Gairekhada road for transportation but currently Sherabada-Gairekhada road is under construction to make gravel road. The nearest airport is Jumla Airport which is approx. 60 km from the project site.

1.3 Hypothesis

Use of Renewable energy technologies for rural electrification helps in socioeconomic development of community, makes national energy system more independent, diversified, ecologically and environmentally sustainable. It can act as measure for mitigation of climate change.

1.4 Objectives

Main objective

- To analyze role of renewable energy technology in mitigating climate change.

Specific objectives

- To perform demand assessment of the village based on HH survey
- To design Solar PV system and standalone diesel generator system to meet energy demand of village.
- To perform sensitivity analysis so as to investigate effect of changed solar irradiance in system performance and cost for Solar PV system and change in system cost with variation in fuel price for standalone diesel generator system.
- To calculate total GHG and other emissions avoided by implementation of Solar PV system that would have been caused by installation of standalone diesel generator system.
- To help to meet the sustainable goal by implementing the project.

1.5 Rationale of study

This study aims to provide scientific basis for renewable energy based electrification of remote, non-electrified Mahabai Rural Municipality, Kalikot District. The topography of village makes it potential site for Solar Mini grid installation. The study and work regarding installation has already been initiated by AEPC. Use of traditional (biomass) and commercial (LPGs) sources as source of energy, have made effects on health of local peoples with environmental pollution and degradation.

Optimal utilization of locally available renewable resource (solar) to meet primary energy demand of village through Solar PV system is expected to ensure reliable modern energy supply to the village. With access of reliable modern energy there will be growth of productive end use activities such as Grill industry, Saw mills, rice and flour mills, photocopies and printing etc. with pollution free and clean lighting, cooking and heating. Similarly computer based teaching learning environment, information from radio; TVs will make local peoples social, economic and environmental status better.

Household survey was conducted during last week of November, 2021 to explore existing energy consumption pattern of the village. Through survey questionnaires electricity demand of the village for base year 2021 was calculated and projected for next ten years (i.e. up to for the year 2031). Solar Mini grid energy systems and standalone diesel generator system were designed to meet energy demand of year 2031. Finally these two systems were analyzed and compared with reference to cost (capital, OM cost), LCE, NPC, emissions etc.

1.6 Limitations

Main limitations of the study are listed in following points

- The accuracy of the solar irradiance data can't be assured due to the absence of real time observation.
- Some of the system component costs are based on the published cost of equipment in internet due to the unavailability of required supplier in Nepal.
- Season variation of electricity demand wasn't considered. Similarly festive season's higher demand weren't under consideration. These variations are assumed to be covered by random variability (daily and hourly) inputs.

Chapter 2
LITERATURE REVIEW

2.1 Introduction

Electrification is always central for sustainable development which is correlated to economic, social and environmental development. Nepal has committed to achieving the Sustainable Development Goals (SDGs) by 2030. The country stands at a critical juncture at the moment. Nepal is looking forward to graduating from being a member of the Least Developed Country (LDC) category. Nepal has set 17 sustainable goals. Some of them are:

- End poverty in all its forms everywhere
- End hunger, achieve food security and improved nutrition and promote sustainable agriculture
- Ensure healthy lives and promote well-being for all at all age
- Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all
- Ensure access to affordable, reliable, sustainable and modern energy for all
- Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all
- Ensure sustainable consumption and production patterns
- Take urgent action to combat climate change and its impacts
- Conserve and sustainably use the oceans, seas and marine resources for sustainable development
- Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

With the promulgation of a new Constitution in 2015, Nepal has taken significant steps towards decentralising service delivery and working towards inclusive development. It is still too early to comment on the performance of local bodies under its provisions, but the broad range of power and responsibilities enjoyed by the provincial and local governments provides a promising opportunity to make progress towards achieving the SDGs. (UNFPA Nepal,2016) According to the Economic Survey Report, 2019/20 of Nepal (Government of Nepal, June 2020), 90 % (till mid-March) of the total population in Nepal has access to electricity. The majority of the population (about 80%) lives in rural areas, where 95.75% of the urban population and 93.47% of the rural population have access to electricity. Off-grid renewable energy (RE) technologies, such as micro/mini hydro and solar PV provide electricity to 10% of the population, particularly in rural areas (Economic Survey Report, 2019/20). The share of off-grid electrification is likely to grow significantly as electrification reaches geographically isolated and poorer areas where grid extension is not economically attractive.

Off grid rural electrification has been serving the rural communities for more than two decades in Nepal. Most of the off grid rural electrification is located in a remote area where the national grid is not accessible. However, within the few decades, lighting the house with the off grid rural electrification has led to increasing the load demand as people used more electrical utilities. The energy demand of people increased with an increase in economic activities in the later days. Though the connection of multiple end uses seem to be possible and increase the utilization factor, it is somehow impossible to achieve the target due to some constraints left with a single system limitation. Now the time has come to think of increasing the reliability of the systems as well as to increase the possibility of transferring spare power from one area to the other for more productive uses to increase the overall utilization factor of the generated energy and interconnect to the national grid where is possible by promoting the energy mix concept. Similarly, in addition to the isolated micro/mini hydro power plant installation and in response to the technical constraints and limitations of the systems in terms of power out to the huge power demand in the same vicinity and reliability services, solar mini-grid system will remain important for many years so as to achieve energy access to all particularly in the case of remote areas of Nepal. It is also equally important to increase the application of Productive End Use (PEU) for enhancing the economic activities of the rural community.

Making electrification greater less expensive does not clearly require minimizing the total value of additives on the time of creation. Alternatively, the results of system design on existence cycle value and machine performance must be stored in thoughts. A HWSPS aided with a diesel generator is preferred in conditions in which the strength call for isn't always met through the HSWPS system alone. In maximum of the traditional cases; electricity generation changed into accomplished by means of using diesel generators which accounted for the high gas fees and no renewable energy utilization. Nowadays those structures are coupled with a few non-traditional (wind, solar, or micro-hydropower) approach of electricity generation which occupies a prime component and is sort of always the main alternative of rural electrification.

2.1.1 Solar energy and PV

The solar photo-voltaic directly convert photon energy into electricity. These devices use inorganic or organic semiconductor materials that absorb photons with energy greater than their band-gap to promote energy carriers into their conduction band. Electron-hole pairs, or excitons for organic semiconductors, are subsequently separated and charges are collected at the electrodes for electricity generation. Solar PV systems operate in the presence of direct or diffuse solar irradiation. The amount of solar radiation is expressed as annual mean figures in kWh/m^2/year or as kWh/m^2/day. Around 885 million TWh worth of solar radiation reaches the Earth's surface each year (Agency, 2012). The solar resource varies significantly over the day, week and month depending on local meteorological conditions. However, most of the annual variation is related to the Earth's geography. The global horizontal irradiation (GHI) is the total amount of shortwave radiation received from above by a horizontal surface. This is expressed as W/m2 and includes both direct normal irradiance (DNI) and diffuse horizontal irradiance (DHI). Using tilting collectors can increase the irradiance (per unit of surface area) by up to 35%, especially for latitudes lower than 30°S and higher than 30°N. Tracking can also increase the yield, but with considerable additional expense (Agency, 2012)

2.1.2 PV modeling

The photovoltaic module performance is highly affected by the weather, especially the solar irradiation and the PV module temperature. To estimate the PV array output, the solar radiation available on the module surface, the ambient temperature and the manufacture data for the PV module are responsible factors. The calculation method of the PV array output is given by equation (Koutroulis, et. al., 2006):

$$P_{pv}=V_{oc}*I_{sc}*FF$$

Where FF (dimensionless) is a fill factor, dependent on technology of solar modules, which is the ratio between the nominal and the maximum power standard, Voc open circuit voltage, Isc short circuit current (Koutroulis, et. al., 2006).

The short circuit current and open circuit voltage of a solar photovoltaic module are given by Equations below (Koutroulis, et. al., 2006).

$$I_{sc}=[I_{sct}+K_i(T_c-25)]*(G/1000)$$

$$V_{OC}=V_{OCst}-K_V*T_C$$

Iscst (A) is the short circuit current standard, Ki (A/°C) is the short circuit current temperature coefficient, G (W/m²) is the global irradiation incident on the PV module, Vocst (V) is the open circuit voltage standard, Kv (V/°C) is the open circuit voltage temperature coefficient and Tc (°C) is the temperature which can be estimated from the ambient temperature Ta (°C) and the solar radiation. Equation (Koutroulis, et. al., 2006).

$$T_c(t)=T_a+[(NOCT-20)/800]*G$$

Where NOCT (°C) is the nominal operating cell temperature

HOMER models the PV array as a device that produces DC electricity in direct proportion to the global solar radiation incident upon it, independent of its temperature and the voltage to which it is exposed. HOMER calculates the power output of the PV array using the equation

$$P_{pv}=F_{pv}*Y_{pv}*(It/Is)$$

Where, FPV is the PV derating factor, YPV the rated capacity of the PV array (kW), It the global solar radiation (beam plus diffuse) incident on the surface of the PV array (kW/m2), and Is is 1 kW/m2, which is the standard amount of radiation used to rate the capacity of the

PV array. The rated capacity of a PV array is the amount of power it would produce under standard test conditions of 1kW/m2 irradiance and a panel temperature of 25°C (Lambert, et. al., 2013). The derating factor is a scaling factor meant to account for effects of dust on the panel, wire losses, elevated temperature, or anything else that would cause the output of the PV array to deviate from that expected under ideal conditions. HOMER does not account for the fact that the power output of a PV array decreases with increasing panel temperature, but then we can reduce the derating factor to correct for this effect when modeling systems for hot climates.

2.1.3 Diesel generator

Advantage of installing a generator is significant because gensets are readily available in market and they are low-cost and easy to transport and install. A diesel generator is relatively cheaper to install compared to installing similar non-conventional energy sources (wind turbine, PV) for the same power output. The primary concern before installing a generator is to address the availability of fuel in the community will be guaranteed in light of the reliability of transportation, accessibility by road during the rainy seasons, and political uncertainties. Furthermore gensets require expertise for regular engine maintenance and, occasionally, major overhauls. A local source of expertise must be available in or to the community before this option is considered. Without this intervention, the life of the equipment may be short and may lead to frequent and costly replacement of equipment. The principal physical properties of the generator are its maximum and minimum electrical power output, its expected lifetime in operating hours, the type of fuel it consumes, and its fuel curve, which relates the quantity of fuel consumed to the electrical power produced.

In HOMER, a generator can consume any of the fuels listed in the fuel or one of two special fuels: electrolyzed hydrogen from the hydrogen storage tank, or biomass derived from the biomass resource. It is also possible to cofire a generator with a mixture of biomass and another fuel. HOMER assumes the fuel curve is a straight line with a y-intercept and uses the following equation for the generator"s fuel consumption (Lambert, et. al., 2013).

$$F=F_0*Y_{gen}+F_1*P_{gen}$$

Where F_0 is the fuel curve intercept coefficient, F_1 is the fuel curve slope, Ygen the rated capacity of the generator (kW), and Pgen the electrical output of the generator (kW). The units of F depend on the measurement units of the fuel. If the fuel is denominated in liters, the units of F are L/h. If the fuel is denominated in m^3 or kg, the units of F is m^3/h or kg/h, respectively. In the same way, the units of F0 and F1 depend on the measurement units of the fuel. For fuels denominated in liters, the units of F0 and F1 are L/h-kW (Lambert, et. al., 2013).

The fixed cost of energy is the cost per hour of simply running the generator, without producing any electricity. The marginal cost of energy is the additional cost per kWh of producing electricity from that generator. HOMER uses the following equation to calculate the generator"s fixed cost of energy (Lambert, et. al., 2013).

$$C_{gen,fixed}=C_{om,gen}+(C_{rep,gen}/R_{gen})+F_0*Y_{gen}*c_{fuel;eff}$$

where $C_{om,gen}$ is the operation and maintenance cost in dollars per hour, Crep,gen the replacement cost in dollars, R_{gen} the generator lifetime in hours, F_0 the fuel curve intercept coefficient in quantity of fuel per hour per kilowatt, Y_{gen} the capacity of the generator (kW), and $c_{fuel;eff\ the}$ effective price of fuel in dollars per quantity of fuel. The effective price of fuel includes the cost penalties, if any, associated with the emissions of pollutants from the generator.

HOMER calculates the marginal cost of energy of the generator using the following equation (Lambert, et. al., 2013).

$$c_{gen,mar}=F_1*c_{fuel,ef}$$

Where F_1 is the fuel curve slope in quantity of fuel per hour per kWh and $c_{fuel,eff}$ is the effective price of fuel (including the cost of any penalties on emissions)in dollars per quantity of fuel)

2.1.4 Battery

Batteries are a key component in a stand-alone renewable energy system. Lead-acid battery is the type of battery commonly used in stand-alone power systems. Batteries can be classified in two ways: by their application (the way they are used) and their construction (how they are built). The major construction types are flooded (wet), gelled, and AGM (Absorbed Glass Mat). With regard to their applications, the major ones are automotive (starting), marine, and deep-cycle batteries. Deep-cycle batteries are used in renewable energy applications. Deep Cycle batteries are designed to be discharged as low as 80 % and recharged over and over again and therefore have much thicker plates. It is important to note that companies recommend that hybrid system batteries should not be discharged beyond 50% of their capacity (Bekele, 2009). A charge controller regulates the state of load of the battery, controlling the battery not to be overloaded. The complementary resource (such as diesel generator) produces the required energy at times of imminent deep discharge of the battery, at the same time loading the battery. In case of day of autonomy, the system will fully depend on the battery bank. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be

used.
Systems containing a battery bank and one or more generators require a dispatch strategy, which is a set of rules governing how the system charges the battery bank. HOMER can model two different dispatch strategies: load-following and cycle- charging. Under the load-following strategy, renewable power sources charge the battery but the generators do not. Under the cycle-charging strategy, whenever the generators operate, they produce more power than required to serve the load with surplus electricity going to charge the battery bank (Lambert, et. al., 2013). HOMER also uses the simulation results to calculate the battery throughput (the amount of energy that cycled through the battery over the year), which it uses to calculate the lifetime of the battery. The lifetime of the battery affects the total net present cost of the system.

The key physical properties of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and round-trip efficiency. The capacity curve shows the discharge capacity of the battery in ampere-hours versus the discharge current in amperes. Capacity typically decreases with increasing discharge current. The lifetime curve shows the number of discharge–charge cycles the battery can withstand versus the cycle depth. The number of cycles to failure typically decreases with increasing cycle depth. The minimum state of charge is the state of charge below which the battery must not be discharged to avoid permanent damage. A battery cannot be fully charged or discharged all at once; a complete charge requires an infinite amount of time at a charge current that asymptotically approaches zero (Lambert, et. al., 2013). A battery"s ability to charge and discharge depends not only on its current state of charge, but also on its recent charge and discharge history.

2.1.5 Battery modeling

The nominal capacity of the battery is modeled using equation (Ould Bilal B, 2012):

$$\Phi_r=(N_{bt}/N_{bs})*\ \Phi_{bt}$$

Where N_{bt} is the total number of batteries, N_{bs} is the number of batteries in series; φ_{bt} is the nominal capacity (Ah) of one battery.
During the charging process, the available battery capacity at time t can be calculated by equation (Eftichios Koutroulis, 2006):

$$d\Phi=\eta_{bt}*(P_{bt}/U_v)*dt$$

Where φ is the capacity of the storage system at time t given in (Ah), η_{bt} is the battery charging and discharging efficiency. It is difficult to measure separate charging and discharging efficiency, so manufacturers usually specify round-trip efficiency. U (V) is the nominal system operating voltage and P_{bt} is the power received by the battery from source or requested by the demand.

The minimum battery capacity can be given by equation (Bilal, 2012).

$$\Phi_{min}=\Phi_r(1-p_d)$$

Where φ_r is the nominal battery capacity and P_d is the depth of battery discharge.

For estimating the life time of the battery, HOMER simply monitors the amount of energy cycling through it without having to consider the depth of the various charge– discharge cycles.

HOMER uses the sum of the battery wear cost (the cost per kWh of cycling energy through the battery bank) and the battery energy cost (the average cost of the energy stored in the battery bank) to evaluate the marginal costs of energy. HOMER calculates the battery wear cost as (Lambert, et. al., 2013).

$$c_{bw}=C_{rep,batt}/[N_{batt}*Q_{lifetime}*(\eta_{rt})^{1/2}]$$

Where $C_{rep,batt}$ is the replacement cost of the battery bank (dollars), N_{batt} is the number of batteries in the battery bank, $Q_{lifetime}$ is the lifetime throughput of a single battery (kWh), and η_{rt} is the round-trip efficiency.

2.1.6 Converter

A converter is a device that converts electric power from DC to AC in a process called inversion, and/or from AC to DC in a process called rectification. There are DC to DC converters also which are used as switching mode regulators to convert an unregulated DC voltage to a regulated DC output voltage. PV generator and battery sub-systems are connected with DC bus. The electric loads are generally AC loads. A rectifier and an inverter is needed for a system constituting DC and AC bus with power generating units wind turbine, PV and diesel generator. A rectifier is used to transform the surplus AC power from the wind energy generator and diesel electric generator to DC power of constant voltage, when the energy generated by the hybrid energy system exceeds the load demand. A general rule of thumb is to select a converter slightly larger in capacity to the load due to presence of electrical surges likely to happen during the starting of appliances.

In HOMER, the converter size, which is a decision variable, refers to the inverter capacity, meaning the maximum amount of AC power that the device can produce by inverting DC power. The rectifier capacity is the maximum amount of DC power that the device can produce by rectifying AC power, as a percentage of the inverter capacity. The rectifier capacity is therefore not a separate decision variable in. HOMER assumes that the inverter and rectifier capacities are not surge capacities. In HOMER we can simulate inverter to run in parallel with another AC power source such as a generator or the grid which requires inverter to synchronize to the AC frequency.

2.2 Climate change and its causes

Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing such as modulations of the solar cycles, volcanic eruptions, and persistent anthropogenic changes in the composition of the atmosphere or in land use. Note that the Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as: „a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods." The UNFCCC thus makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes. (IPCC, 2014)
Most climate scientists agree the main cause of the current global warming trend is human expansion of the "greenhouse effect" warming that result when the atmosphere traps heat radiating from Earth toward space. Certain gases in the atmosphere block heat from escaping. Long-lived gases that remain semi-permanently in the atmosphere and do not respond physically or chemically to changes in temperature are described as "forcing" climate change. Gases, such as water vapor, which respond physically or chemically to changes in temperature, are seen as "feedbacks".

(IPCC, 2014) lists gases that contribute to the greenhouse effect as:

- Water vapor: The most abundant greenhouse gas, but importantly, it acts as a feedback to the climate. Water vapor increases as the Earth's atmosphere warms, but so does the possibility of clouds and precipitation, making these some of the most important feedback mechanisms to the greenhouse effect.

- Carbon dioxide (CO_2): A minor but very important component of the atmosphere, carbon dioxide is released through natural processes such as respiration and volcano eruptions and through human activities such as deforestation, land use changes, and burning fossil fuels. Humans have increased atmospheric CO2 concentration by more than a third since the Industrial Revolution began. This is the most important long-lived "forcing" of climate change.

- Methane (CH_4): A hydrocarbon gas produced both through natural sources and human activities, including the decomposition of wastes in landfills, agriculture, and especially rice cultivation, as well as ruminant digestion and manure management associated with domestic livestock. On a molecule-for- molecule basis, methane is a far more active greenhouse gas than carbon dioxide, but also one which is much less abundant in the atmosphere.

- Nitrous oxide (N_2O): A powerful greenhouse gas produced by soil cultivation practices, especially the use of commercial and organic fertilizers, fossil fuel combustion, nitric acid production, and biomass burning.

- Chlorofluorocarbons (CFCs): Synthetic compounds entirely of industrial origin used in a number of applications, but now largely regulated in production and release to the atmosphere by international agreement for their ability to contribute to destruction of the ozone layer. They are also greenhouse gases.

The Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.

2.3 Global warming potential (GWP) and Carbon dioxide equivalent (CO2e)

The global warming potential of a gas refers to the total contribution to global warming resulting from the emission of one unit of that gas relative to one unit of the reference gas, carbon dioxide, which is assigned a value of 1.

For example, if methane has a global warming potential of 21, it means that 1 kg of methane has the same impact on climate change as 21 kg of carbon dioxide and thus 1 kg of methane would count as 21 kg of carbon dioxide equivalent(IPCC, 2014). Detail of GWPs of different GHGs and their CO_2e is documented in Annex 22.

2.4 Response to climate change

In order to prevent dangerous anthropogenic interference with the climate system, actions need to be taken to stabilize greenhouse gas concentrations in the atmosphere. Such actions are referred to as climate change mitigation. More specifically, mitigation involves:

- Reducing GHG emissions, e.g. by making older equipment more energy efficient.
- Preventing new GHG emissions to be released in the atmosphere, e.g. by avoiding the construction of new emission-intensive factories.
- Preserving and enhancing sinks and reservoirs of GHGs, e.g. by protecting natural carbon sinks like forests and oceans, or creating new sinks known as carbon sequestration. (UNFCCC, 2009).

In order to reduce or limit GHG emissions and/or increase carbon sequestration, a variety of mitigation options can be taken. They can be as complex as a low-emission plan for the energy sector or as a simple as improvements to a cook stove design. Mitigation options can vary greatly from one country to the other and need to be adapted to specific national circumstances (referred to as "Nationally Appropriate Mitigation Actions" – NAMAs). Low Carbon and Green Economy: In a nutshell low carbon development implies „using less carbon for growth". The term green economy likewise encompasses the reduction of greenhouse gas emissions, but also covers other environmental issues which are not directly related to climate change (such as protecting human health and the environment from mercury). The green economy concept also puts emphasis on social benefits. (Mulugetta & Urban, 2010). Key Concepts Related to Climate Change Mitigation can be listed as:

- A technology, practice, or policy that reduces or limits emissions of GHGs or increases their sequestration.
- Low carbon development refers to economic development with minimal output of GHG emissions.

Climate change adaptation means anticipating the adverse effects of climate change and taking appropriate action to prevent or minimize the damage they can cause, or taking advantage of opportunities that may arise. It has been shown that well planned, early adaptation action saves money and lives later. Examples of adaptation measures include: using scarce water resources more efficiently; adapting building codes to future climate conditions and extreme weather events; building flood defenses and raising the levels of dykes; developing drought-tolerant crops; choosing tree species and forestry practices less vulnerable to storms and fires; and setting aside land corridors to help species migrate.(European Comission,2017).

2.5 Previous studies and research gaps

Many Researches regarding design and feasibility study of hybrid system have been carried out. They were reviewed thoroughly and summarized in table below

Table 1: Summary of literatures reviewed

S. N	Research topic	Authors	Research theme
1.	Comparative Analysis of Solar-Wind Hybrid System with Diesel Generator System in Powering Remote Telecom Towers of Nepal using HOMER	Shakya S.R.,khadka S.K,shrestha J.N.(2014) IOE graduate conference	This paper presents a techno-economic evaluation of solar-wind hybrid systems to power a remote telecom tower and compares some economic consideration with diesel generator system for the same. As a case study of Nepal Telecom CDMA-BTS (Code Division Multiple Access-Base Transceiver Station) located at Dadakharka, Solukhumbu district Nepal, the model has been optimized using HOMER (Hybrid Optimization Model for Electric Renewable).
2.	Renewable Energy and Other Strategies for Mitigating the Energy Crisis in Nepal	RAMHARI POUDYAL 2021	The study review Nepal's energy scenario from the technical and socio-economic perspective in order to determine the optimal near-term as well as long-term strategies to overcome the energy crisis.
3.	Isolated and Mini-Grid Solar PV Systems: An Alternative Solution for Providing Electricity Access in Remote Areas	Mainali, B., Dhital, et.al	This study presents solar photovoltaic (PV) alternatives for rural electrification, considering off-grid solar PV for individual households and solar mini-grids for electrifying rural communities, and comparing them with the supply option with grid extension and electricity from a diesel generator.

4.	Renewable Techno-economic Analysis of Solar PV/Diesel Hybrid Energy System for Electrification of Television substation- “ACase Study of Nepal Television Substation at Ilam”.	Sharma D.K et al(2014) IOE graduate conference	The paper presented the most feasible configuration of Solar PV system with diesel generator as back up for the electrification of Nepal Television (NTV) substation situated in Ilam (26°58'N, 87°58'E) district in the Eastern development region of Nepal having transmitter power of 5 kW. The attempt was made to model a hybrid electricity generation system for a television substation. This system incorporated a combination of solar PV, battery and diesel generator. HOMER

Many studies had been carried out to evaluate feasibility of rural electrification based on renewable energy resources (mini grid systems), resource assessments, comparative study for different locations and system configurations. It is clearly found that such analysis mainly depends on resource availability condition for the location. Each location has different condition of resource availability and studies are site specific. Similarly based on demography, socioeconomic conditions of location etc. make effect on electricity demand and hence in system configuration designed to meet the demand.

Most of previous studies are based on solar and wind resources data extracted for NASA website and NREL.

This study covers the exploration of demographical aspects, socioeconomic condition, existing energy use pattern, electricity demand of Mahabai village, Kalikot Nepal. Solar irradiance data were downloaded from NREL website and AEPC. Accuracy and reliability of the study was expected to increase with the use of ground level data.

Chapter 3

STUDY METHODOLOGY

3.1 Methodological framework

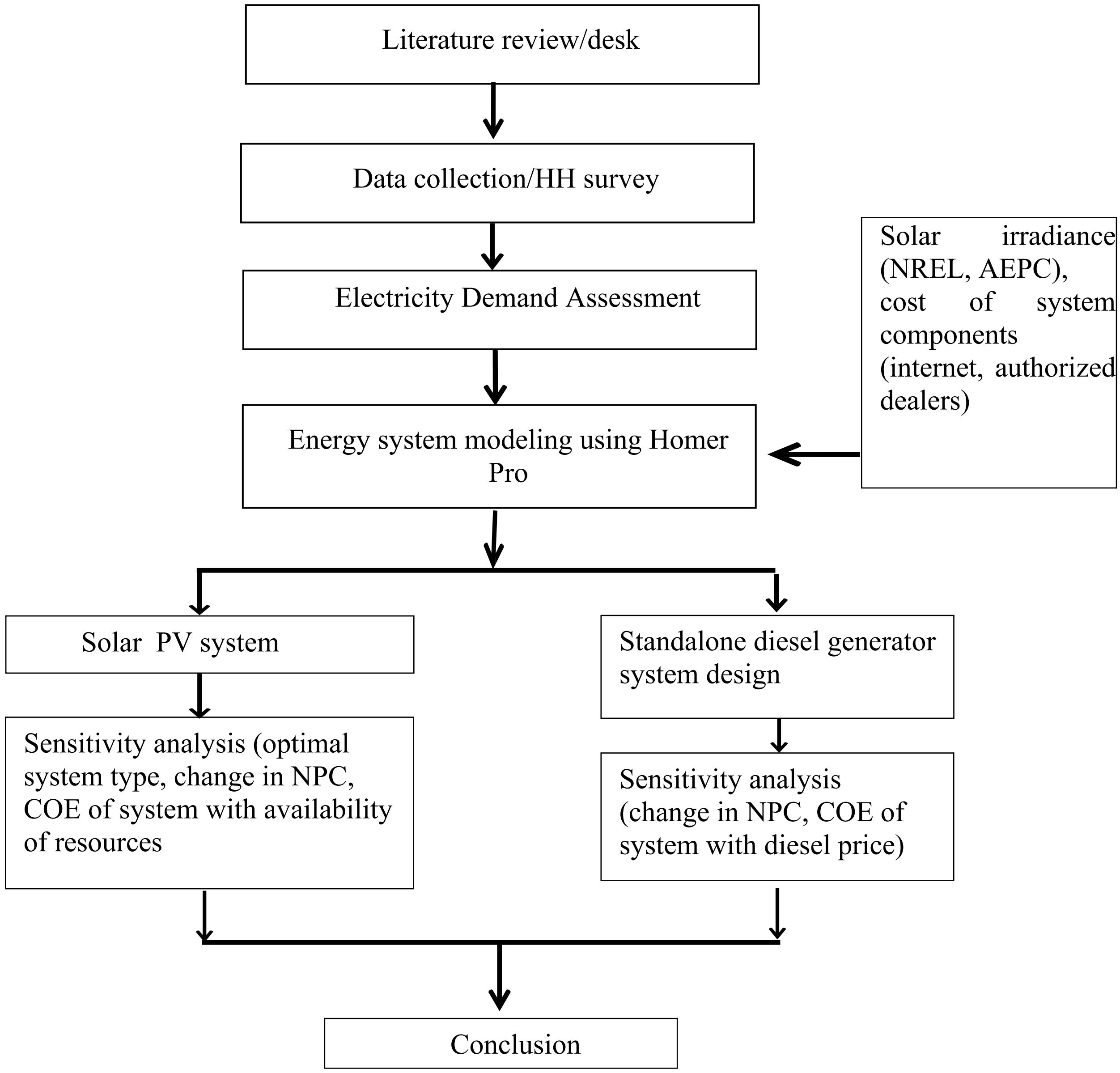


Figure 3: Methodological framework

3.2 Literature review/desk study

It included extensive literature reviews and detail study of the Solar Mini Grid systems along with the parameters associated with it. The components for different possible combination of power system were studied. Parameters for the design solar PV arrays, converters, and batteries for the power system were also studied. Other equipment related to the design of a Solar Mini Grid system was also studied. The selection procedure of the equipment like charge controller, converter, PV was studied. The terminologies associated with the solar were properly understood. Related books, journals and past reports on the study of solar resource data, solar mini grid technology and potential sites local information was reviewed.

Literature review can be summarized in following points:

- ✓ Introduction of solar mini grid power system its suitability and its parameters
- ✓ Solar mini grid system components details for different possible combination of power system.
- ✓ Designing parameters of solar PV module, converters, diesel generators, batteries for the power system.

3.3 Selection of the study area

As we know that Karnali province is least developed in comparision to other province of Nepal. With a view to contribute something , I planned Karnali province for my study area. Among all the district of that province, kalikot district lacks energy for performing different household as well as end use works. The present problem was identified during an interview with the people of Mahabai Rural municipality. The reason behind selecting this area for the study was to explore the demand assessment and to design solar PV system to meet that demand. I was interested to know their traditional and cultural livelihood strategy comparatively with current situation which was influenced by my friends of that area. The people residing of this village has difficulty to run their daily life . With that they are lacking far behind in the field of education, health facility etc. By the same taken, the study area is more convenient place for study since the village is familiar to the researcher.

3.4 Field and site visits

With extensive literature review, consultation with experts, site was identified and was visited on last week of December. With 3 days stay (25th, 26th and 27th November, 2021) in the village questionnaire form was filled up from household survey of 240 HHs for demand assessment. Household survey questionnaires are mentioned in Annex 2.

In order to conduct demand assessment data was collected from individual household on questionnaire basis. As Mahabai rural municipality is potentially feasible site for Solar PV system installation, HOMER pro is chosen as appropriate tool for system design.

To acquire information about future possible grid extension in the village, NEA office in Manma Bazar ,kalikot was visited and found that there is no such extension plan within coming five years. However, the officer mentioned that if the community do manage layout of local grid by themselves, NEA will be forced to energize the grid, according to the existing practice.

3.5 Research tools

For design of mini grid system and comparison of different minigrid systems (different arrangement of components) HOMER pro software is used. Following section contains detail about this tool. For data assimilation, sorting and calculation so as to make final data to feed to HOMER pro, MS Excel 2010 was used.

3.5.1 HOMER pro software

HOMER pro is a computer model developed by the U.S National Renewable Energy Laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models power systems physical behavior and its life-cycle cost, which is the total cost of installing and operating system over its life span. HOMER allows comparing many different designs options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in input (Lambert et. al., 2006). HOMER is hybrid optimization renewable energy model software for both standalone and grid connected micropower systems with the combinations of PV modules, wind turbines, biomass, hydro, reciprocating engines generators, micro turbines, fuel cell batteries and hydrogen storage for thermal and electric load.

a) Inputs

- Energy resources

  It uses two forms of solar resources. First one is Global Horizontal Irradiation (GHI) resource, which is used to calculate flat panel PV array output. Another is Direct Normal Irradiance (DNI), which is used to calculate concentrating PV output. Location on the map can be selected in the home page, the latitude and longitude will appear here. Otherwise, latitude and longitude can be entered manually. Solar resource data can be input via the monthly solar radiation table.

You can enter the monthly data manually, or can be downloaded from the HOMER website.

HOMER pro uses temperature resource as ambient temperature to calculate the PV cell temperature, as described in the article on how HOMER pro calculates the PV cell temperature.

Hydro Resource can be described by adding stream flow data available to the hydro turbine. HOMER uses this data to calculate the output of the hydro turbine in each time step.

Further biomass and fuels can also be added as energy resource.

- Loads

  Primary load is electrical load that the system must meet immediately in order to avoid unmet load. In each time step, HOMER dispatches the power-producing components of the system to serve the total primary load.

  Thermal load is demand for heat energy. The heat may be needed for space heating, hot water heating, or some industrial process.

  Deferrable load is electrical load that must be met within some time period, but the exact timing is not important. Loads are normally classified as deferrable because they have some storage associated with them.

  We will be considering only electric load.

- Economics

  It uses different economics parameters as system fixed capital cost, system fixed operation and maintenance (O&M) cost, annual real interest, project life time, carbon tax and cost of penalty for economic analysis.

- Generator control

  It uses additional operation for the system including battery bank and generator which determines how the generator charges the battery.

- Constraints

  It consists of operating reserve, maximum annual capacity shortage and minimum renewable fraction.

- Decision variable

  It contains the values of each decision variables for the set of possible system configurations.

For many inputs HOMER pro provides default values so that simulation becomes simple and quicker.

b) Outputs

The outputs of results from HOMER are displayed in the form of simulation, optimization and sensitivity analysis.

c) Simulation

HOMER uses energy balance calculation for hourly time-step simulation of its operation for one year duration. It calculates the available renewable energy and compare with the required electrical/thermal loads for each hour. It decides each hour to charge or discharge the batteries. If the system meets the load for the entire year, it estimates the life cycle costs of the systems. The life cycle cost is a convenient to compare the economics of the various system configurations. The outputs of the simulation are broken down into following categories:

- Cost

Its output results are the total net present cost and levelized cost of electricity for the entire project duration. It breaks down the cost into initial capital, annualized replacement, annual operation and maintenance for each component of the system. LCOE is used to quantify and compare the monetary value of electricity produced from various generation technical alternatives irrespective of type, scale of production operation, investment, or life span (Mainali and Silveira, 2013).Levelized cost is the discounted average cost per kWh of useful electrical energy produced by the system over the life of the technology, which can be expressed as

$$LCOE = \frac{Cc + Com + Cr + Cf}{Ei}$$

Life-cycle costs are compared instead of simple capital costs. Such lifetime costs are basically the discounted costs of the project incurred each year and summed over the life span of the project. These costs comprise capital cost (Cc), operation and maintenance cost (Com), replacement cost (Cr), and fuel cost (Cf). The procedures for estimating such costs have been discussed in Mainali and Silveira (2013). The input assumptions highly influence the estimated LCOE. Thus, it is important to have a clear understanding and transparent assumptions for accuracy. We further carry out some sensitivity analysis to reflect the uncertainty associated with the various parameters, namely, capital cost and life span of the energy storage system (in the case of a solar PV system), and rise in fuel price (Diesel generator).

- Electrical

  Its output provides total energy production of each component with excess and shortage of energy.

- Thermal

  Its output provides total annual energy production for each thermal component and total amount of thermal energy that went towards serving the thermal load during the year.

- Generator

  It provides details of generators electrical output, life span, hours of operation, thermal output, annual fuel usage and specific fuel usage.

- Battery

  It gives the overall status of the battery bank with minimum state of charge and maximum state of charge for the whole one year duration.

d) Optimization

HOMER pro displays the list of possible feasible configurations based on the lifecycle cost of the systems. The least life cycle cost is arranged according to top down approach for all the feasible configurations, which provides the optimized results. Thus, optimization modules in HOMER pro provides possible decision variables as size of PV array, number of wind turbines, number of batteries, size of generator, size of electrolyzer, size of hydrogen storage tank, dispatch strategy etc.

e) Sensitivity

HOMER pro can perform sensitivity analysis to see how the results vary with changes in inputs. For example, the values of certain parameters (e.g. PV cell cost) can be changed to determine the impact of cost of energy for the systems. For any input, sensitivity analysis can be performed by assigning more than one values of interest. HOMER repeats the optimization process for all the input values of interest so that the effect of changes can be analyzed in the results.

3.6 Socio-Economic Assessment

3.6.1 Households, Population Caste/Ethnicity

The settlement pattern of Mahabai RM 3 Solar Mini Grid Project area is scattered in some places like Majhgaun, Otkhebada, and dense in some places like in Jamaldhara and Sinkhet. Most of the households belong to Thakuri(58.63%) followed by Kami(14.50%), Brahmin (11.35%), Chhetri(11.26%), Damai (3.98%) and others(0.28%). Talking about the literacy rate, about 59.93% population are able to read and write. (CBS, 2011). The data on the income source is presented in Table 2.

Table 2: Households Income Source

S.N	Income Source	Household Share (%)	Remarks
1	Agricultural production	96	
2	Service/Jobs except remittance	4	
3	Income from remittances	10	
4	Anchor/Business	3	
5	Income from Seasonal Job(from India)	90	People went to India for job about 4-6 month in one year

Source: Field Visit

3.6.2 Energy Interventions

The main source of energy in this projected site is wood. People use fuel wood for cooking and heating and Small Solar Home System (SSHS) mostly used for lighting and to charge batteries in their cell phones. The nearby micro hydro of size 10 kW is located in Rata tole. Of the total HHs, only Rata tole having 40 HHs get the electricity from the micro hydro due to inter-community conflict in their ward. 192 out of 240 households use SSHS for lighting and charging batteries and for cooking 192 HHs uses kerosene and firewood, 40 HHs use LPG and firewood, kerosene and firewood all. Villagers reported the use of around 9 bhari of woods per month per household for cooking and other business purposes, which is available in free of cost from community forest. Almost 98 percent HHs use wood as the main energy source for cooking, as shown in Table 3.

Table 3: Source of energy for cooking

Mahabai RM	**Fuel usually used for Cooking**				
	Wood+ Kerosene	**LPG+ Kerosene+ Wood**	**Cowdung**	**Other**	**Not Stated**
HHs	192	40			4

About 80% of the household has already installed small solar home system (SHS).

3.6.3 Social Conflicts

A number of consultation, focus group discussion and individual interviews were carried out during the survey to identify any adverse impacts experienced by VCs and other groups of the project beneficiaries It was observed that, there were no negative impacts experienced in connection with the solar mini grid and it would not disturb or destroy the existing social structure after the implementation of the mini grid. Besides this, the project will bring them together and uplift socio-economic condition of weak sectors of the community.

3.7 Analysis and Projection of Energy Demand

Mini grid system design utilizing renewable energy resource was carried out using HOMER pro. For this following layout of components is used:

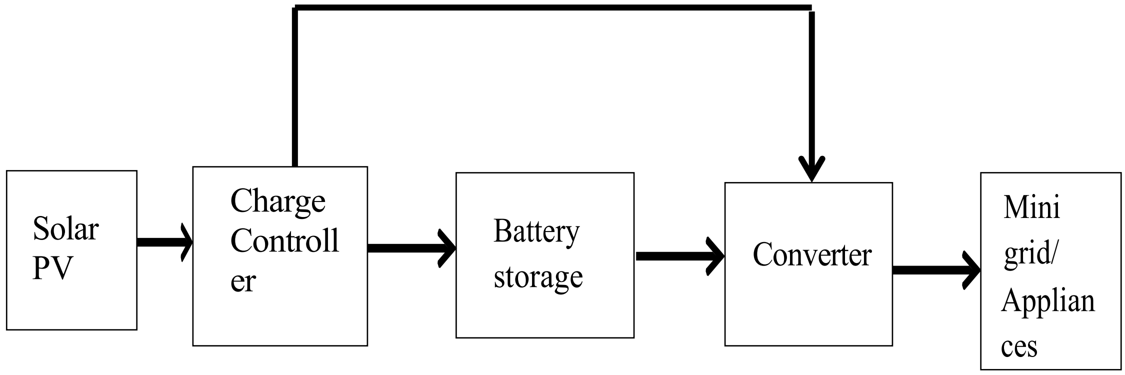


Figure 4: System Layout

A DC bus bar is used instead of AC. The DC bus bar is directly connected to the inverter which is the ultimate supplier to the mini-grid. The charges are collected in the battery bank through the DC bus bar only in case if excess electricity is produced, which the cycle is charging model used by the HOMER pro. Presence of a DC bus bar eliminates the requirement of an AC synchronizer and aids in a feedback system that can be taken easily from the battery banks state of charge.
On the home page of HOMER pro location of Mahabai was set in schematic window as shown in Figure 5.

Discount rate was set as 10%, inflation rate 2%, annual capacity shortage 5% and project lifetime was set 25years for the calculation of net present cost and cost of energy.

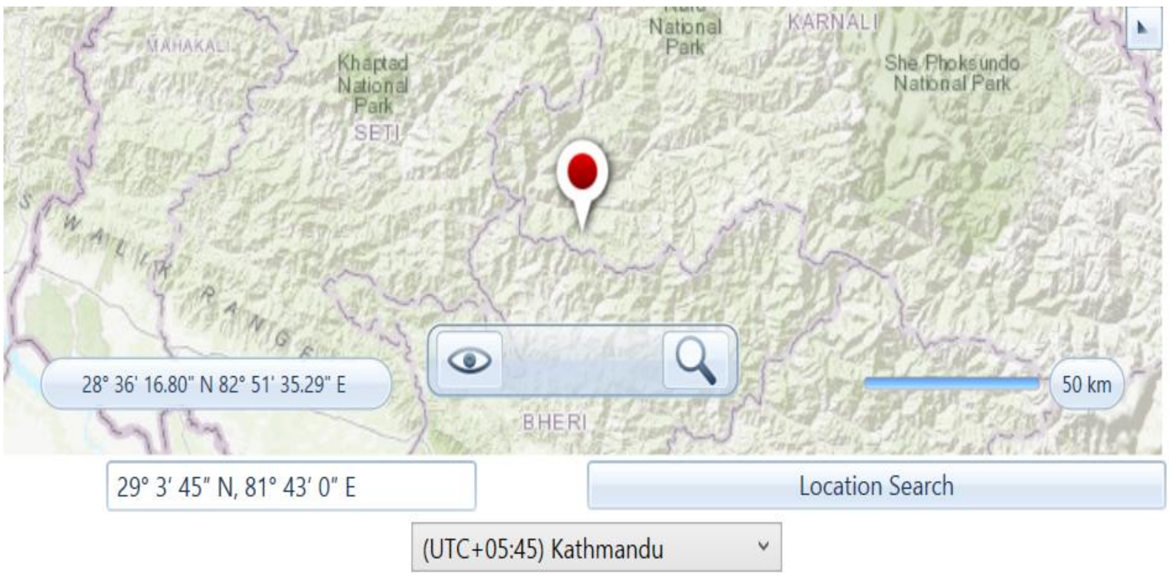


Figure 5: Mahabai in HOMER pro schematic

3.7.1 Energy Demand Assessment

The energy demand survey has been conducted during the field visit. The details of energy demand assessment are presented in Annex 3. The load pattern of the base year 2021 has been calculated separately for households, PEU and community uses.

Productive End Uses (PEU) and Other Public Uses:

In total, there are 240 households and 20 PEU in Mahabai Rural Municipality is made into a five clusters. The details are given in Table 4.

Table 4: List of potential productive end use

S.N	Descriptions	Numbers	Remarks
1	Telecom Tower		
2	Grill Industry	1	
3	Saw Mill	3	
4	Hulling/Milling/Grinding	2	
5	Hotels	12	With retail shop
6	Computer Institute & Electronic Center	1	
7	Photocopy Center	1	
8	Cold Storage		
9	Private Hospital/Clinics		
10	Banks		
	Total PEU Uses	20	

In the base year 2021, the estimated average daily peak power consumption of load is about 30 kW and average daily peak energy demand of load is about 314 kWh/day. The shared ratio of household use, productive end uses and other public uses are about 55 %, 34% and 10 % of the total energy demand. Figure 5 presents the energy demand for the base year 2021, categorized into different used types. Regarding the load pattern, the household loads and community loads will concentrate during the morning and evening time and the productive end uses during the day time.

3.8 Energy Demand Projection

The electricity demand for household use is estimated to increase by 2 % of the base year value every year, while productive end use is also forecasted to increase 3 % each year. The load increases for the next ten years have also been forecasted. Table 5 presents the daily demand of electricity for different end uses in the year of 2026.

Table 5: Demand assessment and forecast

S.N.	Electricity Users	Daily Electricity Consumption (kWh/day), 2021	Daily Electricity Consumption (kWh/day), 2031
1	Household's demand	172.94	210.81
2	Anchor/Business demand	105.20	141.38
3	Public Use	31.49	51.29
4	Power House	4.38	7.13
	Total Power (kW/day)	314.31	410.61

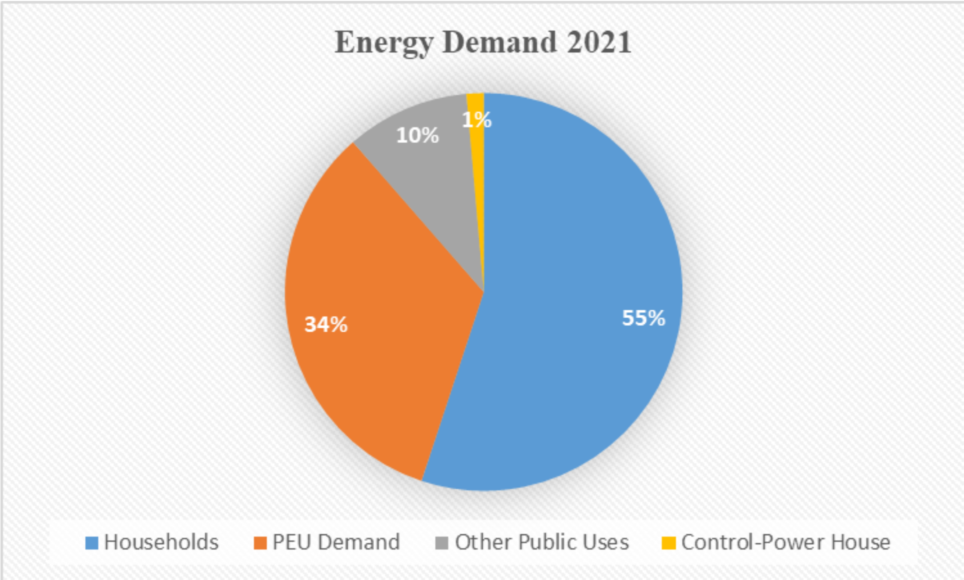


Figure 6: Energy Demand

3.8.1 Load Profile

Figure 7 represents the daily load load profile for Mahabai RM 03.

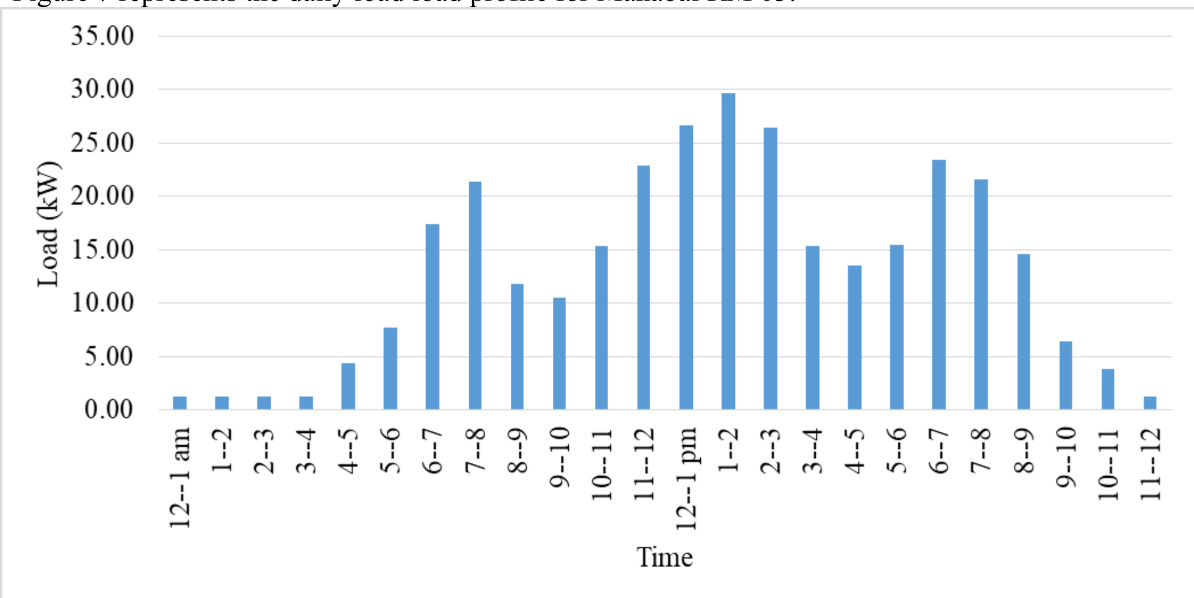


Figure 7: Daily load profile

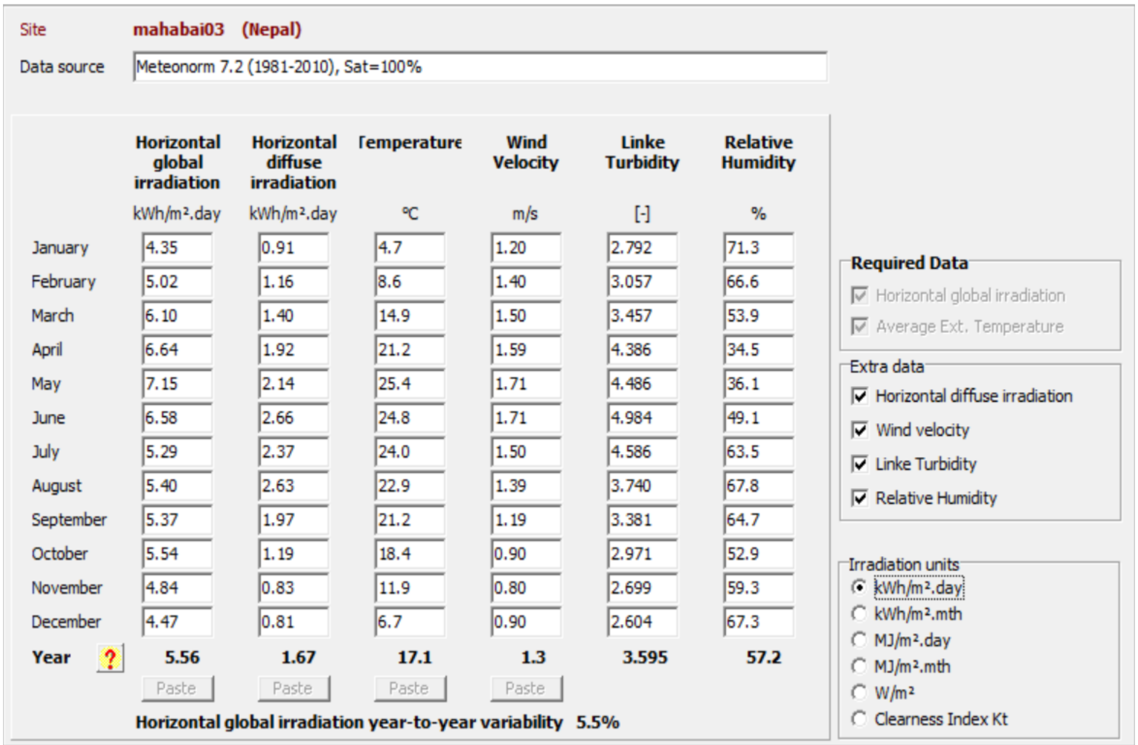
3.9 Renewable energy resources

Abundant solar resource are present in study village for electrification. Energy resources can be added from resources ribbon in HOMER pro. Wind potential in the study area is not good for the design. Wind sites are often in remote locations where there is abundant flow of wind and is not viable in the case of Mahabai Rural Municipality. Equally there is no potential of micro hydro projects because of its topography as well as lack of nearby water resource. Since the sectors related to biomass energy resources like forestry, agriculture and animal husbandry are under different agencies, coordination among these bodies have not been adequate. There is a lack of human resources and other resources in the local bodies for effective management and efficient use of biomass energy. Therefore, for the project area solar energy is found to be most reliable and efficient. The Renewable energies solar is considered for the design and described in following headings. Solar irradiance data are documented in appendix.

3.9.1 Solar energy resources

With about 300 days of sunshine per year in most parts of the country, an average of eight light hours per day and being situated on the ideal 30° North "solar belt", Nepal presents very good conditions for the use of solar power. Solar PV modules installed at an angle of 30° south can intercept a daily average of 4.8 to 6.0 kWh/m2 of solar energy in most locations throughout the country (Chianese et. al., 2009).

Figure 4.5 shows monthly average value of solar irradiance (kWh/m^2) incident on horizontal surface, tilted surface pointing towards equator at an angle equal to latitude using the data obtained from NASA website. The value of irradiance for horizontal surface ranges from 3.73kWh/m^2 in December to 6.122 kWh/m^2 in April with an average of 4.72kWh/m^2 whereas irradiance falling on tilted surface ranges from minimum 4.08 kWh/m^2 in July to maximum 6.86 kWh/m^2 in march with an average of 5.58kWh/m^2. Value of irradiance falling on horizontal surface is taken for solar panel design.


Site mahabai03 (Nepal)
Data source Meteonorm 7.2 (1981-2010), Sat=100%

	Horizontal global irradiation	Horizontal diffuse irradiation	Temperature	Wind Velocity	Linke Turbidity	Relative Humidity
	kWh/m².day	kWh/m².day	°C	m/s	[-]	%
January	4.35	0.91	4.7	1.20	2.792	71.3
February	5.02	1.16	8.6	1.40	3.057	66.6
March	6.10	1.40	14.9	1.50	3.457	53.9
April	6.64	1.92	21.2	1.59	4.386	34.5
May	7.15	2.14	25.4	1.71	4.486	36.1
June	6.58	2.66	24.8	1.71	4.984	49.1
July	5.29	2.37	24.0	1.50	4.586	63.5
August	5.40	2.63	22.9	1.39	3.740	67.8
September	5.37	1.97	21.2	1.19	3.381	64.7
October	5.54	1.19	18.4	0.90	2.971	52.9
November	4.84	0.83	11.9	0.80	2.699	59.3
December	4.47	0.81	6.7	0.90	2.604	67.3
Year	**5.56**	**1.67**	**17.1**	**1.3**	**3.595**	**57.2**

Horizontal global irradiation year-to-year variability 5.5%

Figure 8: Solar energy resources

3.10 System design

Various components such as solar PV, generators, battery, and converter can be added into the system design from components ribbon. For this study PV arrays, battery and converter are added. Detail of steps is explained through following headings.

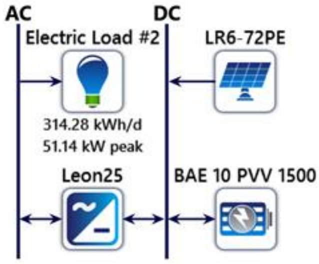


Figure 9: System Design

3.10.1 Solar PV input

Solar PV with flat plate was selected for hybrid system design. The price of PV panel is about $0.56 per watt in Nepalese market with replacement cost $0.4 per watt and $10 per year operation and maintenance cost. The cost includes charge controller also. Charge controller, are needed to regulate the power output to charge the battery and also to prevent the battery energy to flow back when there is no sun. Cost of Solar PV along with all other components is documented in Annex 9. The system was designed for the PV panel to be Non-tracking. A solar tracking system adds up to the additional costs however the output is significantly increased. The temperature effect on the PV panel was considered as per the solar PV module specifications generally available in Nepalese market. The charge controller efficiency has been accounted in the derating factor (80%). The slope is generally taken corresponding to the latitude of the site. For Nepal the value is taken as 30 degrees. Ground reflectance was taken as 15%. Temperature effects on solar PV arrays were also considered. Temperature effect on power was taken -0.38%/°C, nominal cell operating temperature 45°C and efficiency at standard test condition as 19.1%.(cleanhomesenergy@ntc.net). Solar PV inputs for the design are tabulated in table 6 below.

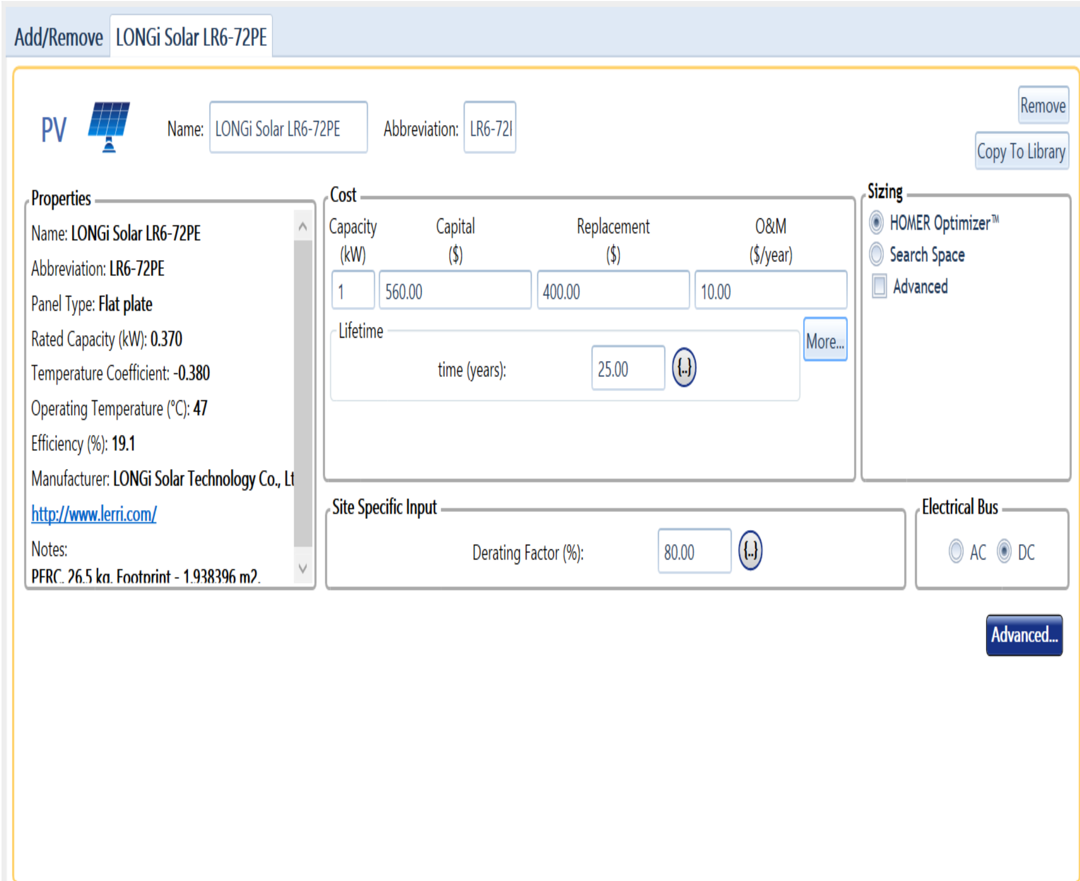


Figure 10: Solar PV input

Table 6: Solar PV inputs

S.N.	Particulars	Value	Units
1.	Name	Solar PV	
2.	Capital cost	0.56	$/kW
3.	Replacement cost	0.4	$/kW
4.	OM cost	10	$/year
5.	Derating factor	80	%
6.	Temperature effects	Considered	
7.	Ground reflectance	15	%
8.	Temperature effects on power	-0.38	%/°C
9.	Nominal cell operating temperature	47	°C
10.	Efficiency at standard test condition	19.1	%

3.10.2 Storage/battery inputs

Batteries are necessary for storage purpose, to store the energy produced. The stored energy can be used when needed. This ensures that you will always have power at your disposal. We bring you the leader in battery manufacturer, Exide and its range of solar batteries to ensure you get the maximum from your solar power system. The Discover 2VRE-7500TF-U battery was selected from the HOMER pro library for the design. It was a compromise between Ah rating and nominal voltage rating. Each battery's nominal voltage was 2V and total maximum amperage rating was 1500Ah. The system voltage is kept 48V, a high bus voltage. Hence the total number of battery in a string is 24. The battery parameters like lifetime throughput, round trip efficiency, and maximum charge current are specified by the manufacturers. The cost of the battery has been taken from online supplier. These are tubular flooded lead acid battery.

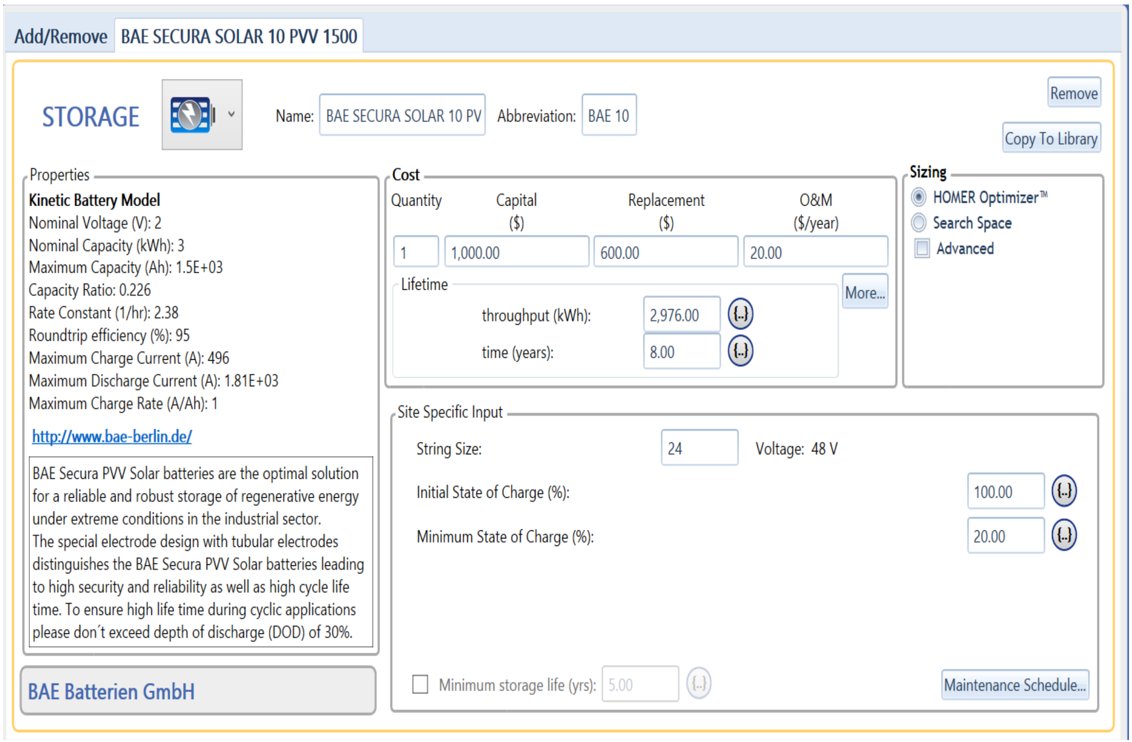


Figure 11: Storage/ Battery inputs

Table 7: Battery inputs

Type	Discover 2VRE-7500TF-U
Lifetime	8 years
Nominal voltage per battery	2V
Nominal capacity	3kWh

Maximum capacity	1500Ah
Capacity ratio	0.226
Rate constant	2.38(1/hr)
Roundtrip efficiency	95%
Maximum charge current	496A
Maximum discharge current	1810A
Maximum charge rate	1A/Ah

Capital cost per battery was taken as $1000, replacement cost $600 and operation maintenance cost $20 per year. Life time was considered as 8 years and throughput as 2976kWh. (cleanhomesenergy@ntc.net.np).

3.10.3 Converter inputs

An instrument to convert direct current (DC) into alternating current (AC), it is a vital part of solar power generation system as all the electricity produced from the PV panels are in the form of DC and needs to be converted into usable form AC. The converter was designed on the basis of cost and capacity. For this, two options were inserted in converter input window. Firstly, 25kW converter with capital cost $700, replacement cost $600 and $10 operation and maintenance cost. Lifetime of converter was taken as 10 years and efficiency of 96%. The capacity of rectifier relative to inverter is taken as 80% and efficiency as 94%. (cleanhomesenergy@ntc.net.np). Converter inputs are tabulated in table 8.

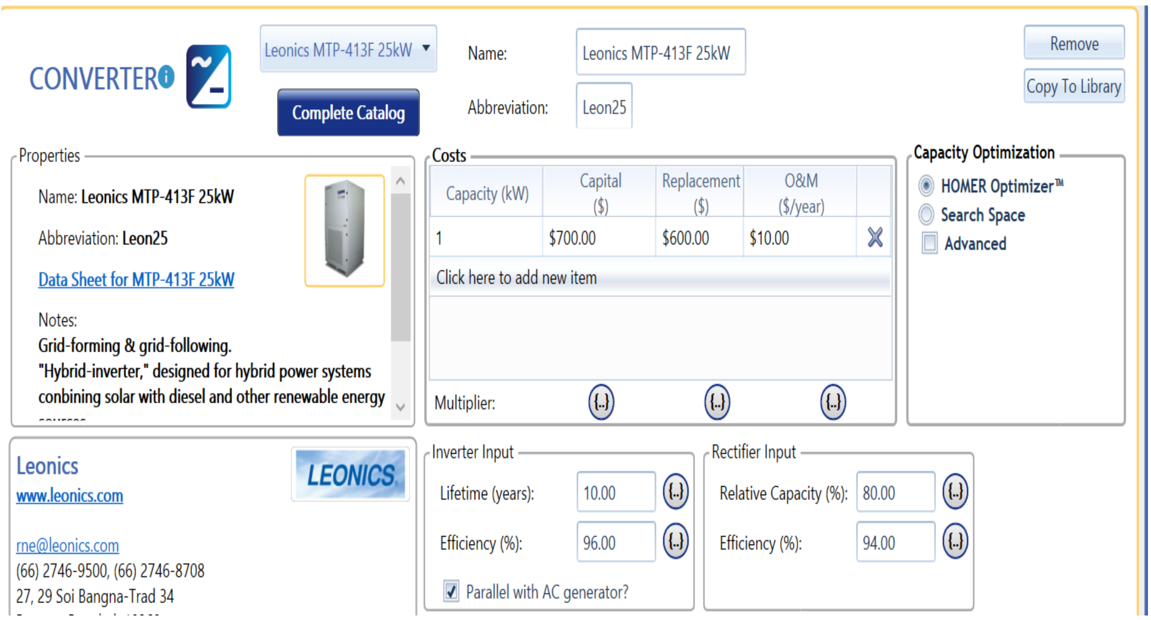


Figure 12: Converter Input

Table 8: Converter inputs

S. N.	Particulars	Value	Units
1.	Capita cost(25kW)	700	$/converter
2.	Replacement cost(25kW)	600	$/converter
4.	Operation & maintenance cost(25kW)	10	$/converter
5.	Lifetime	10	Years
6.	Efficiency	90	%
7.	Rectifier capacity relative to inverter	80	%
8.	Rectifier efficiency	94	%

3.10.1 Load inputs

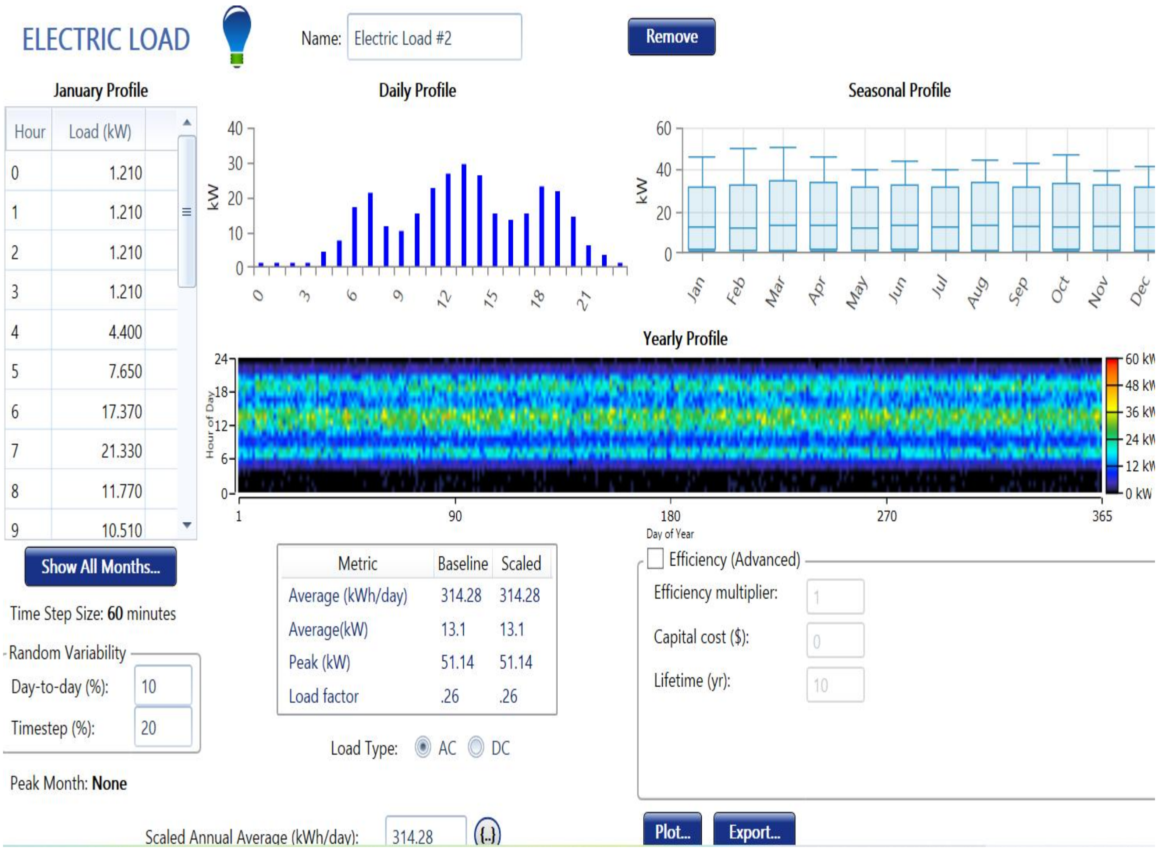


Figure 13: Load Inputs

3.11 Standalone diesel generator system design

The standalone diesel generator system was designed so as to meet electricity demand of the village. The auto size genset is considered for the design as it automatically sizes itself to meet the load it also adjusts fuel curve to match its size. For this design following considerations were made.

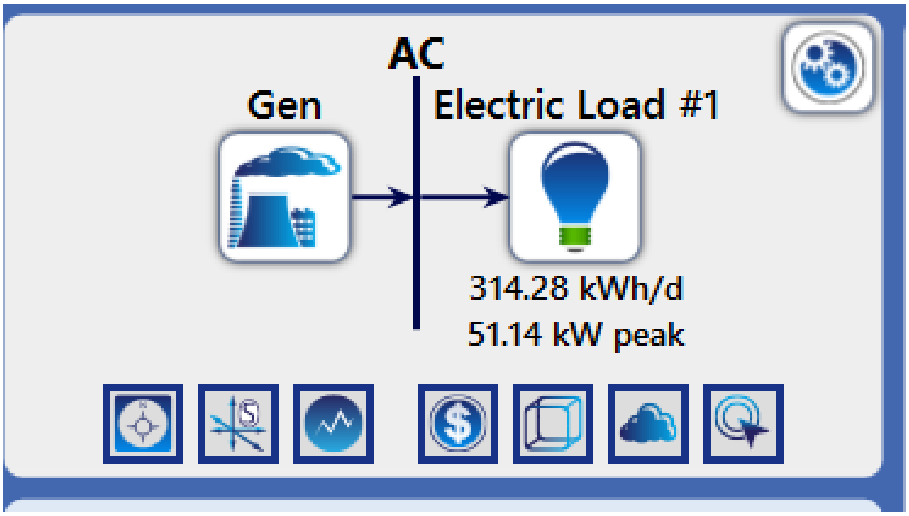


Figure 14: Standalone diesel generator system design

Table 9: Generator system inputs

S.N.	Particulars	Value	Units
1	Fuel used	Diesel	
2	Discount rate	10	%
3	Inflation rate	2	%
4	Annual capacity shortage	5	%
5	Project lifetime	25	Years
6	Fuel curve intercept	2.77	L/Hr
7	Furl curve slope	0.236	L/Hr./kW
8	CO emission	16.5	g/L fuel
9	Unburned hydrocarbons	0.72	g/L fuel
10	Particulates	0.1	g/L fuel
11	Fuel sulphur to PM	2.2	%
12	NO_x	15.5	g/L fuel
13	Lower heating value	43.2	MJ/kg
14	Density	820	Kg/m^3

15	Carbon content	88	%
16	Sulphur content	0.4	%
17	Initial capital cost	500	$/kW
18	Replacement cost	400	$/kW
19	Operation and maintenance cost	0.05	$/hr
20	Minimum load ratio	25	%
21	Heat recovery ratio	0	%
22	Lifetime	25000	Hours
23	Fuel price	1.5	$/L
24	Maintenance and scheduling	Not considered	

Changing prices of diesel may affect the COE and NPC for standalone diesel generator system. Hence sensitivity analysis was conducted for changed condition of fuel price and effect on COE and NPC was analyzed. Figure below shows sensitivity inputs for fuel prices.

Following graph is obtained from time series analysis of historical change in diesel price for Nepal (NOC, 2017). Current price of diesel is $1.5 per liter. Trend line shows increasing diesel price and found to be $1.8 per liter of diesel for year 2024. Hence to perform sensitivity analysis increase in diesel price was assumed. Values were taken as $1.6, $1.65, $1.7, $1.75, and $1.8 per liter.

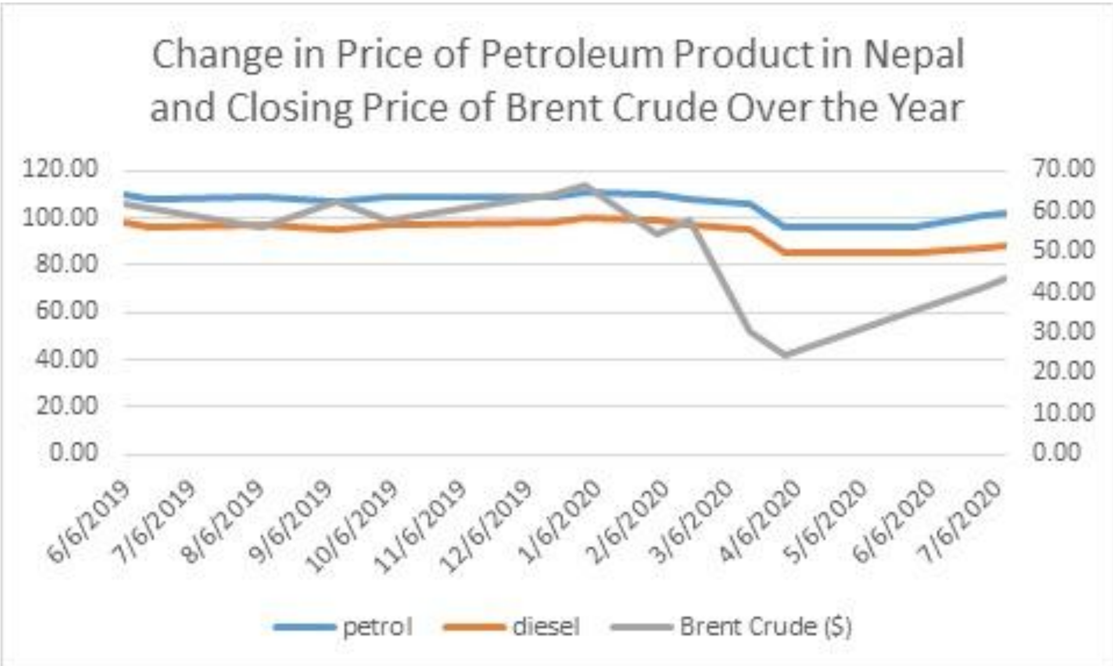


Figure 15: Historical price of diesel in Nepal ($/liter) with trend line

3.12 Technical Assessment and Design

3.12.1 Rational for Technical Design

240 households have been covered for Solar Mini Grid Project. PEU alone accounts for about 34% of the total energy demand which complies with general selection criteria of Mahabai Solar Mini-Grid Projects.

3.12.2 Key PV System Components

The main components off grid interactive solar PV system are PV modules, PV inverters, Battery inverters and Batteries. Other components are array supporting structures, cables & accessories, including PV string junction box, PV string combiner box, PV Combiner Box, AC Distribution Board, circuit breakers, surge protectors, fuses, earthing & protection units etc. The specification of key PV system components is shown in Table 6.

PV Module
PV modules are the key components to convert sunlight into electricity. The 30V-325Wp polycrystalline module has been selected for the technical design and as an example only for the analysis.

Battery
Batteries are the also key components to store the electrical energy generated from PV modules. 2V 2000Ah@C/10 battery has been selected for the technical design and as an example only for analysis.

PV Inverter or Grid Connected Inverter
Grid connected inverter or PV inverter is one of the most important components in grid interactive PV system. The function of grid connected inverter is to convert DC power from PV into AC power and feed electricity to load by passing the battery and excess energy to charge the batteries. 25 kW string inverter has been selected for the technical design and as an example only for the analysis.

Off-grid Inverter or Battery Inverter
The off-grid inverter works as a backup power and it is the back bone of the PV off grid solar systems. 6kW single phase inverter has been selected for the technical design.

A/C Interface Device
The A/C interface device is used on-grid and off-grid applications. It has connections for PV system, battery inverters, load, generator and grid. The required port for the interfacing form PV to DC source should be sufficient for the system.

Chapter 4
RESULTS AND DISCUSSIONS

4.1 Energy consumption pattern

The main source of energy in this subproject site is wood. People use fuel wood for cooking and heating and Small Solar Home System (SSHS) mostly used for lighting and to charge batteries in their cell phones. The nearby micro hydro of size 10 kW is located in Rata tole. Of the total HHs, only Rata tole having 40 HHs get the electricity from the micro hydro due to inter-community conflict in their ward. 192 out of 240 households use SHS for lighting and charging batteries. Villagers reported the use of around 9 bhari of woods per month per household for cooking and other business purposes which approximately equals 309kgs, which is available in free of cost from community forest. Other sources of heating and cooking are kerosene and LPG gas which is brought from Surkhet . Statistically all of 235 HHs use firewood for cooking/heating, 192 HHs uses kerosene and firewood, 40 HHs use LPG and firewood, kerosene and firewood all. Overall 74,160 kg of firewood, 80 liters of kerosene and 15 cylinders of LPG is consumed per month per HH cooking and heating purpose. Almost 98 percent HHs use wood as the main energy source for cooking, as shown in figure 16.

About 80% of the household has already installed small solar home system (SHS) with power rating ranging from 5-75Wp remaining 35 HHs along with HHs having insufficient solar panel use kerosene for lighting. 1 HHs of the community have biogas plant installed in their house both of them are dysfunctional.

During household survey it is found that 87.15% of HH wanted to have television with DTH system. 40% HH wanted to have desktop, 25% HHs wanted to have laptop, 20% wanted to have refrigerators and all HHs wanting to have radio and mobile in base year 2021. With access of reliable modern energy, possible productive end use in the village could be: maize flour mill, cheese factory, chyura mill, photocopy/printing center, furniture etc.

Following table shows consumption pattern of in fuel wood, kerosene and LPG in the village during a month. Energy content of various fuel types are acquired from (WECS, 2010). Total energy consumptions are expressed in thermal units. Heating values of fuel wood, kerosene and LPG were obtained from WECS, 2011.

Source	Consumption(Unit)		Converted		Per month consumption		Heating value(unit)		Total energy(GJ)	Total emission(CO_2)
Firewood	74,160	kg/month	74.16	Tonne	74.160	tonne	16.75	GJ/Tonne	253.026	35.7128 tonnes/month
Kerosene	80	litres/month	0.08	kL	0.08	kL	36.26	GJ/kL	2.90	0.2 tonne/month
LPG	15	cylinders /month	14.2	kg/cylinder	0.213	tonnes	49.24	GJ/tonne	10.48	0.639 tonne/month
Solar	Installed in 192HHs among 240 HHs ,power rating ranging from 5-75kWp									free

Figure 16: Energy Consumption Pattern

4.2 Optimal energy system

4.2.1 Simulation results

HOMER pro simulated various combinations of inputs given to it. The most optimal combination of inputs having least value of COE was given as solution for the system consisting of solar PV which is documented in Annex 1. The system was optimized for scaled annual average solar irradiance 5.29kWh/m^2/day. The simulation result shows that solar PV system of power rating 118 KW, battery 48V(24 batteries per string with 2 strings in parallel) with 40.6kW converter shall suit the system with LCE $0.2370/kWh . The optimal system entails NPC $285774.70 with initial capital cost of $166243.18 and operating cost of $11047.91.

Architecture/ LR6-72PE (kW)	Architecture/ BAE 10 PVV 1500	Architecture/ Leon25 (kW)	Architecture/ Dispatch	Cost/ NPC ($)	Cost/ COE ($)	Cost/Oper	Cost/Initial capital ($)	System/ Ren Frac (%)	LR6-72PE/ Capital Cost ($)	LR6-72PE/ Production	BAE 10 PVV 1500/ Autonom	BAE 10 PVV 1500/ Annual	BAE 10 PVV 1500/ Nominal	BAE 10 PVV 1500/ Usable	Leon25/Inverter Mean Output (kW)
117.5345	72	40.60554	LF	285773.1	0.237023	11047.77	166243.2	100	65819.3	196112.9	13.21078	42127.04	216.2439	172.9951	12.72108
117.5345	72	40.60554	CC	285773.1	0.237023	11047.77	166243.2	100	65819.3	196112.9	13.21078	42127.04	216.2439	172.9951	12.72108
117.4873	72	40.65904	LF	285806	0.237055	11049.79	166254.2	100	65792.89	196034.2	13.21078	42127.71	216.2439	172.9951	12.72083
117.4873	72	40.65904	CC	285806	0.237055	11049.79	166254.2	100	65792.89	196034.2	13.21078	42127.71	216.2439	172.9951	12.72083
119.0483	72	40.09265	LF	286134.2	0.237122	11035.97	166731.9	100	66667.05	198638.8	13.21078	42104.93	216.2439	172.9951	12.73183
119.0483	72	40.09265	CC	286134.2	0.237122	11035.97	166731.9	100	66667.05	198638.8	13.21078	42104.93	216.2439	172.9951	12.73183
117.5904	72	40.99536	LF	286266.8	0.237409	11065.28	166547.4	100	65850.61	196206.2	13.21078	42125.79	216.2439	172.9951	12.72238
117.5904	72	40.99536	CC	286266.8	0.237409	11065.28	166547.4	100	65850.61	196206.2	13.21078	42125.79	216.2439	172.9951	12.72238
118.9467	72	40.49337	LF	286540.7	0.237454	11052.87	166955.5	100	66610.13	198469.2	13.21078	42106.17	216.2439	172.9951	12.73212
118.9467	72	40.49337	CC	286540.7	0.237454	11052.87	166955.5	100	66610.13	198469.2	13.21078	42106.17	216.2439	172.9951	12.73212
119.3376	72	40.39323	LF	286664.9	0.237511	11050.6	167104.3	100	66829.05	199121.5	13.21078	42097.13	216.2439	172.9951	12.73458
119.3376	72	40.39323	CC	286664.9	0.237511	11050.6	167104.3	100	66829.05	199121.5	13.21078	42097.13	216.2439	172.9951	12.73458
118.4025	72	41.12233	LF	286933.9	0.237835	11076.69	167091	100	66305.41	197561.3	13.21078	42113.92	216.2439	172.9951	12.72919
118.4025	72	41.12233	CC	286933.9	0.237835	11076.69	167091	100	66305.41	197561.3	13.21078	42113.92	216.2439	172.9951	12.72919
118.784	72	40.98981	LF	287021.7	0.237855	11073.63	167211.9	100	66519.04	198197.8	13.21078	42108.67	216.2439	172.9951	12.732
118.784	72	40.98981	CC	287021.7	0.237855	11073.63	167211.9	100	66519.04	198197.8	13.21078	42108.67	216.2439	172.9951	12.732
118.625	72	41.25456	LF	287231.4	0.238043	11084.11	167308.2	100	66430	197932.5	13.21078	42110.69	216.2439	172.9951	12.73124
118.625	72	41.25456	CC	287231.4	0.238043	11084.11	167308.2	100	66430	197932.5	13.21078	42110.69	216.2439	172.9951	12.73124
120.2346	72	40.63989	LF	287504.4	0.238085	11065.8	167779.3	100	67331.38	200618.2	13.21078	42073.29	216.2439	172.9951	12.74109
120.2346	72	40.63989	CC	287504.4	0.238085	11065.8	167779.3	100	67331.38	200618.2	13.21078	42073.29	216.2439	172.9951	12.74109
121.6143	72	40.04866	LF	287660.4	0.238074	11047.06	168138.1	100	68103.99	202920.3	13.21078	42040.21	216.2439	172.9951	12.74859
121.6143	72	40.04866	CC	287660.4	0.238074	11047.06	168138.1	100	68103.99	202920.3	13.21078	42040.21	216.2439	172.9951	12.74859
124.0012	72	38.9095	LF	287781.8	0.237982	11008.44	168677.3	100	69440.66	206903	13.21078	41977.57	216.2439	172.9951	12.75889
124.0012	72	38.9095	CC	287781.8	0.237982	11008.44	168677.3	100	69440.66	206903	13.21078	41977.57	216.2439	172.9951	12.75889
120.6479	72	40.81023	LF	287958.5	0.238403	11075.36	168130	100	67562.82	201307.8	13.21078	42062.61	216.2439	172.9951	12.7442
120.6479	72	40.81023	CC	287958.5	0.238403	11075.36	168130	100	67562.82	201307.8	13.21078	42062.61	216.2439	172.9951	12.7442
119.5643	72	41.5548	LF	288168.1	0.238683	11102.64	168044.4	100	66956.02	199499.8	13.21078	42089.63	216.2439	172.9951	12.73851
119.5643	72	41.5548	CC	288168.1	0.238683	11102.64	168044.4	100	66956.02	199499.8	13.21078	42089.63	216.2439	172.9951	12.73851
120.3837	72	41.25818	LF	288321.9	0.238719	11093.64	168295.6	100	67414.89	200867	13.21078	42068.54	216.2439	172.9951	12.74335
120.3837	72	41.25818	CC	288321.9	0.238719	11093.64	168295.6	100	67414.89	200867	13.21078	42068.54	216.2439	172.9951	12.74335
124.7745	72	39.15902	LF	288546.6	0.238512	11022.96	169285	100	69873.71	208193.3	13.21078	41955.94	216.2439	172.9951	12.76435
124.7745	72	39.15902	CC	288546.6	0.238512	11022.96	169285	100	69873.71	208193.3	13.21078	41955.94	216.2439	172.9951	12.76435
127.5957	72	37.83636	LF	288708.1	0.238496	10977.44	169939	100	71453.57	212900.6	13.21078	41877.29	216.2439	172.9951	12.77238
127.5957	72	37.83636	CC	288708.1	0.238496	10977.44	169939	100	71453.57	212900.6	13.21078	41877.29	216.2439	172.9951	12.77238
123.7445	72	40.70338	LF	289732.7	0.239516	11085.97	169789.3	100	69296.94	206474.7	13.21078	41982.5	216.2439	172.9951	12.76312
123.7445	72	40.70338	CC	289732.7	0.239516	11085.97	169789.3	100	69296.94	206474.7	13.21078	41982.5	216.2439	172.9951	12.76312
126.156	72	40.96703	LF	291515.9	0.240722	11108.92	171324.3	100	70647.37	210498.4	13.21078	41917.01	216.2439	172.9951	12.77735
126.156	72	40.96703	CC	291515.9	0.240722	11108.92	171324.3	100	70647.37	210498.4	13.21078	41917.01	216.2439	172.9951	12.77735
128.8744	72	39.63636	LF	291607.3	0.2406	11062.76	171915.1	100	72169.66	215034.2	13.21078	41842.18	216.2439	172.9951	12.78781
128.8744	72	39.63636	CC	291607.3	0.2406	11062.76	171915.1	100	72169.66	215034.2	13.21078	41842.18	216.2439	172.9951	12.78781
124.3439	72	42.24472	LF	291906.4	0.241194	11156.14	171203.9	100	69632.6	207474.9	13.21078	41962.95	216.2439	172.9951	12.7694
124.3439	72	42.24472	CC	291906.4	0.241194	11156.14	171203.9	100	69632.6	207474.9	13.21078	41962.95	216.2439	172.9951	12.7694
123.2457	72	43.82506	LF	293096.5	0.242264	11220.74	171695.1	100	69017.58	205642.4	13.21078	41992.96	216.2439	172.9951	12.76486
123.2457	72	43.82506	CC	293096.5	0.242264	11220.74	171695.1	100	69017.58	205642.4	13.21078	41992.96	216.2439	172.9951	12.76486
129.1363	72	41.11446	LF	293503.4	0.242067	11128.83	173096.5	100	72316.32	215471.2	13.21078	41833.21	216.2439	172.9951	12.79297
129.1363	72	41.11446	CC	293503.4	0.242067	11128.83	173096.5	100	72316.32	215471.2	13.21078	41833.21	216.2439	172.9951	12.79297
132.988	72	42.58214	LF	297574.5	0.245038	11210.79	176280.8	100	74473.3	221898.1	13.21078	41724.52	216.2439	172.9951	12.81316
132.988	72	42.58214	CC	297574.5	0.245038	11210.79	176280.8	100	74473.3	221898.1	13.21078	41724.52	216.2439	172.9951	12.81316
125.8888	72	46.46786	LF	297821.5	0.245844	11349.66	175025.3	100	70497.75	210052.6	13.21078	41920.87	216.2439	172.9951	12.78172
125.8888	72	46.46786	CC	297821.5	0.245844	11349.66	175025.3	100	70497.75	210052.6	13.21078	41920.87	216.2439	172.9951	12.78172
139.3028	72	39.66559	LF	298041.3	0.245031	11115.78	177775.5	100	78009.58	232434.6	13.21078	41574.32	216.2439	172.9951	12.83364
139.3028	72	39.66559	CC	298041.3	0.245031	11115.78	177775.5	100	78009.58	232434.6	13.21078	41574.32	216.2439	172.9951	12.83364
133.0378	72	44.89939	LF	300328.1	0.247258	11312.79	177930.8	100	74501.19	221981.1	13.21078	41720.88	216.2439	172.9951	12.81559
133.0378	72	44.89939	CC	300328.1	0.247258	11312.79	177930.8	100	74501.19	221981.1	13.21078	41720.88	216.2439	172.9951	12.81559
110.9654	96	41.83545	LF	307816.3	0.25379	11127.33	187425.5	100	62140.65	185152.1	17.61437	43442.04	288.3252	230.6602	12.7971
110.9654	96	41.83545	CC	307816.3	0.25379	11127.33	187425.5	100	62140.65	185152.1	17.61437	43442.04	288.3252	230.6602	12.7971
145.3709	72	44.82085	LF	307847.1	0.252479	11374.48	184782.3	100	81407.7	242559.5	13.21078	41424.98	216.2439	172.9951	12.86482
145.3709	72	44.82085	CC	307847.1	0.252479	11374.48	184782.3	100	81407.7	242559.5	13.21078	41424.98	216.2439	172.9951	12.86482
138.0245	72	50.2885	LF	309737.9	0.254542	11575.74	184495.7	100	77293.7	230301.6	13.21078	41595.32	216.2439	172.9951	12.83893
138.0245	72	50.2885	CC	309737.9	0.254542	11575.74	184495.7	100	77293.7	230301.6	13.21078	41595.32	216.2439	172.9951	12.83893
117.6798	96	40.70558	LF	310471.1	0.255169	11098.28	190394.6	100	65900.68	196355.4	17.61437	43203.32	288.3252	230.6602	12.8377
117.6798	96	40.70558	CC	310471.1	0.255169	11098.28	190394.6	100	65900.68	196355.4	17.61437	43203.32	288.3252	230.6602	12.8377
118.9014	96	40.87456	LF	311399.7	0.255779	11109.95	191197	100	66584.8	198393.7	17.61437	43162.18	288.3252	230.6602	12.8454
118.9014	96	40.87456	CC	311399.7	0.255779	11109.95	191197	100	66584.8	198393.7	17.61437	43162.18	288.3252	230.6602	12.8454
122.8241	96	39.41101	LF	312016.6	0.255936	11058.62	192369.2	100	68781.48	204938.9	17.61437	43028.73	288.3252	230.6602	12.86292
122.8241	96	39.41101	CC	312016.6	0.255936	11058.62	192369.2	100	68781.48	204938.9	17.61437	43028.73	288.3252	230.6602	12.86292
113.5758	96	44.45605	LF	312446.8	0.2572	11250.66	190721.7	100	63602.45	189507.7	17.61437	43347.27	288.3252	230.6602	12.81734
113.5758	96	44.45605	CC	312446.8	0.2572	11250.66	190721.7	100	63602.45	189507.7	17.61437	43347.27	288.3252	230.6602	12.81734
117.8693	96	42.69013	LF	312922.7	0.257087	11186.66	191889.9	100	66006.83	196671.7	17.61437	43197.86	288.3252	230.6602	12.84251
117.8693	96	42.69013	CC	312922.7	0.257087	11186.66	191889.9	100	66006.83	196671.7	17.61437	43197.86	288.3252	230.6602	12.84251
124.1997	96	41.84849	LF	315705.6	0.258694	11170.68	194845.8	100	69551.82	207234.2	17.61437	42981.46	288.3252	230.6602	12.87625
124.1997	96	41.84849	CC	315705.6	0.258694	11170.68	194845.8	100	69551.82	207234.2	17.61437	42981.46	288.3252	230.6602	12.87625
105	120	32.08333	LF	316980.7	0.262417	10695.84	201258.3	100	58800	175198.4	22.01796	44451.5	360.4065	288.3252	12.74483
105	120	32.08333	CC	316980.7	0.262417	10695.84	201258.3	100	58800	175198.4	22.01796	44451.5	360.4065	288.3252	12.74483

Figure 17: Simulation result of Solar PV system

4.2.2 Sensitivity analysis

Figure 18 shows effect of increasing solar irradiance on levelized COE and NPC of hybrid system. It shows increase in solar annual average scaled solar irradiance makes decrement in levelized COE and NPC of the system. As seen in figure LCOE comes to be less than \$0.22/kWh for average solar 7 kwh/m^2 /day.

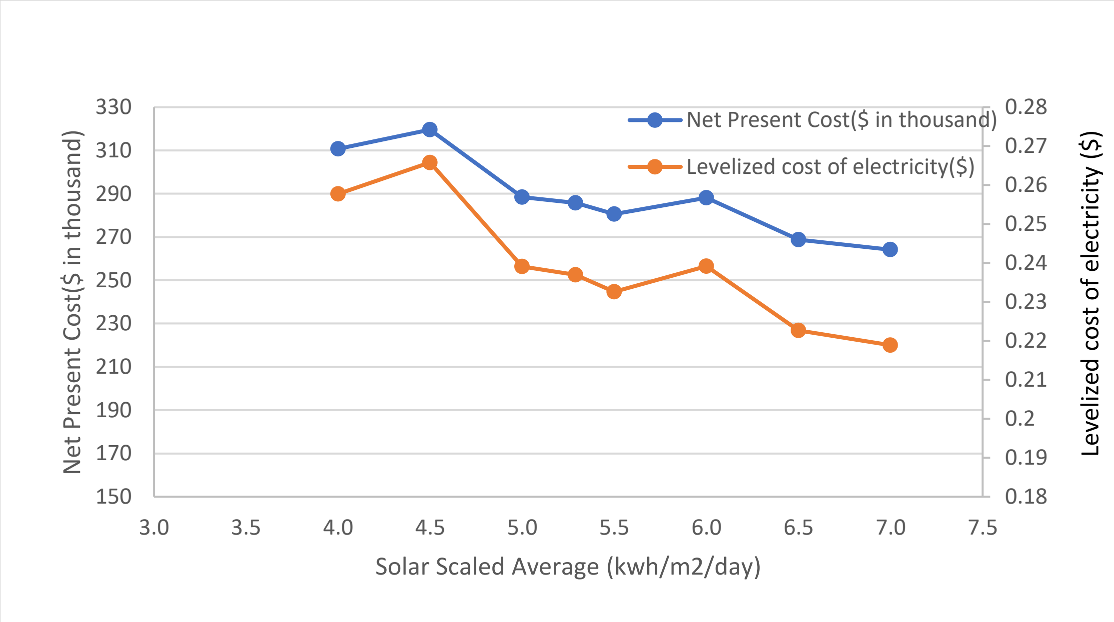


Figure 18: Effect of solar irradiance on LCOE and NPC

Analysis was performed to find PV capacity required for different resource availability condition.

4.2.3 Electrical summary

The solar PV has a mean output of 22.4 kW with a total production of 196,113kWh/year. Capacity factor of PV is 19%. The solar PV has lower amount of production during months July, August and September. Further details of Solar PV and its operation are shown Table 10 and documented in Annex 9.

4.2.4 Solar PV details

The system consists of 118 kW solar PV, 40.6 kW converter and 2 parallel strings of batteries, 24 batteries per string. The total annual electricity production by the system is found to be 196,113kWh. The system produces 5.08% of excess electricity. The system has a capacity shortage of 77,974kWh/yrs. .March, April being sunny months, electricity produce by solar PV is high for these months and model also shows higher amount of solar PV production during October. Highest amount of electricity production was found in the months March, April and October.

Quantity	Value	Units
Rated Capacity	118	kW
Mean Output	22.4	kW
Mean Output	537	kWh/d
Capacity Factor	19.0	%
Total Production	196,113	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	111	kW
PV Penetration	171	%
Hours of Operation	4,376	hrs/yr
Levelized Cost	0.0370	$/kWh

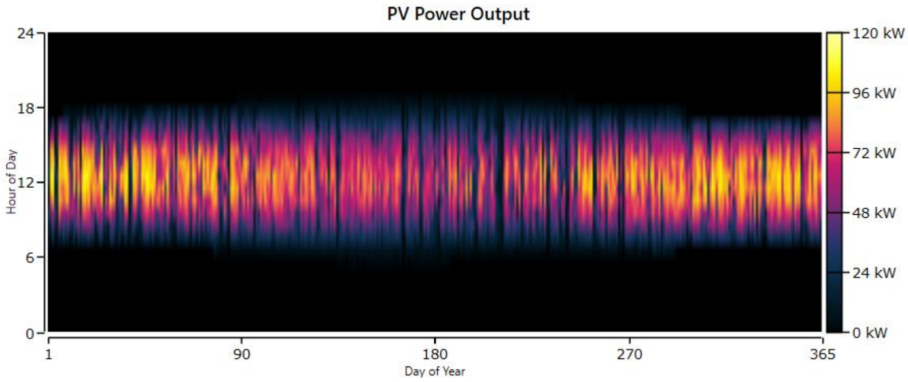


Figure 19: Solar PV output

Table 10: Solar PV details

Particulars	Values	Units
Rated capacity	118	kW
Mean output	22.4	kW
Mean output	537	kWh/day
Capacity factor	19	%
Total production	196113	kWh/year
Minimum output	0	kW
Maximum output	111	kW
PV penetration	171	%
Hours of operation	4376	Hours/year
Levelized cost	0.0370	$/kWh

4.2.5 Battery details

The nominal capacity of the battery bank is 216 kWh with the usable nominal capacity of 173 kWh and with autonomy of 13.2 hour. The total energy into the battery is 43,119 kWh/year while energy out is 41,060 kWh/year with the difference between the two values being the losses in battery. The expected life of the battery is 5.09 years. The battery bank will be at high charge state for most of the months while it will be lesser in the months November and December.

Quantity	Value	Units
Batteries	72.0	qty.
String Size	24.0	batteries
Strings in Parallel	3.00	strings
Bus Voltage	48.0	V

Quantity	Value	Units
Autonomy	13.2	hr
Storage Wear Cost	0.207	$/kWh
Nominal Capacity	216	kWh
Usable Nominal Capacity	173	kWh
Lifetime Throughput	214,272	kWh
Expected Life	5.09	yr

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	43,119	kWh/yr
Energy Out	41,060	kWh/yr
Storage Depletion	99.7	kWh/yr
Losses	2,158	kWh/yr
Annual Throughput	42,127	kWh/yr

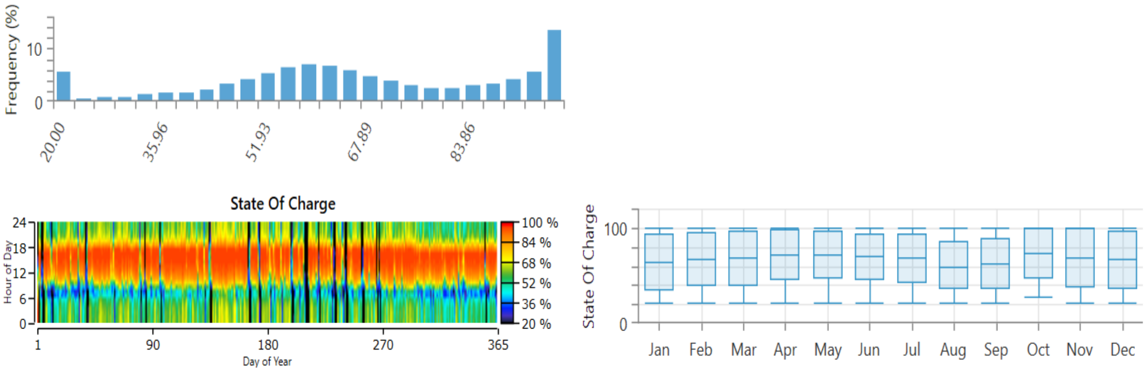


Figure 20: Battery results

Battery details are documented in Annex 10 and summarized in Table 11.

Table 11: Battery Details

S.N.	Particulars	Value	Units
1.	Nominal capacity	216	kWh
2.	Usable nominal capacity	173	kWh
3.	Autonomy	13.2	Hour
4.	Total energy in	43,119	kWh/year
5.	Total energy out	41,060	kWh/year
6.	Annual Throughput	42,127	kWh/year

4.2.6 Converter details

The rectifier has capacity of 32.5 kW. Inverter has mean output of 12.7 kW with maximum output of 40.6 kW. There was a huge loss in the inverter and rectifier that reduced the expected output. This is for the fact that the converter efficiency is taken as 90%. Converter details are summarized in Table 12.

Quantity	Inverter	Rectifier	Units
Capacity	40.6	32.5	kW
Mean Output	12.7	0	kW
Minimum Output	0	0	kW
Maximum Output	40.6	0	kW
Capacity Factor	31.3	0	%

Quantity	Inverter	Rectifier	Units
Hours of Operation	8,700	0	hrs/yr
Energy Out	111,437	0	kWh/yr
Energy In	116,080	0	kWh/yr
Losses	4,643	0	kWh/yr

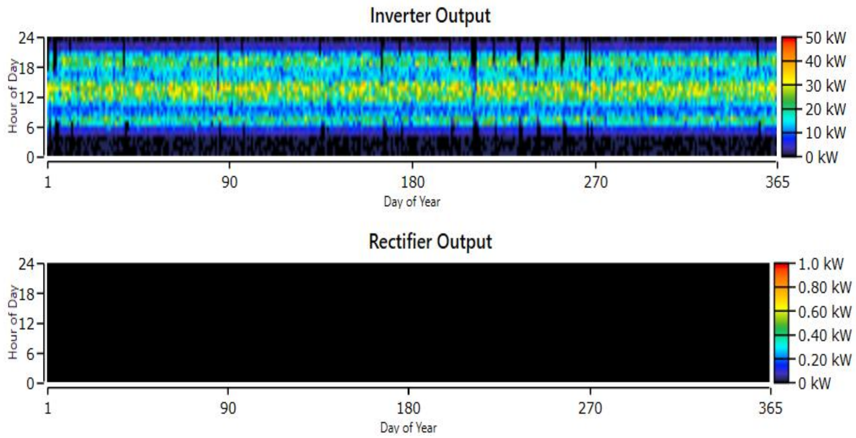


Figure 21: Converter output

Table 12: Converter details

Particulars	Inverter	Rectifier	Units
Capacity	40.6	32.5	kW
Mean output	12.7	0	kW
Minimum output	0	0	kW
Maximum output	40.6	0	kW
Capacity factor	31.3	0	%
Hours of operation	8700	0	Hours/year
Energy in	116080	0	kWh/year
Energy out	111437	0	kWh
Losses	4643	0	kWh/year

4.2.7 Cost summary

Figure 22 and table 13 shows component wise net present cost of the system. Details of capital cost, operation and maintenance cost and salvage value and corresponding cash flows are documented in Annex 7.

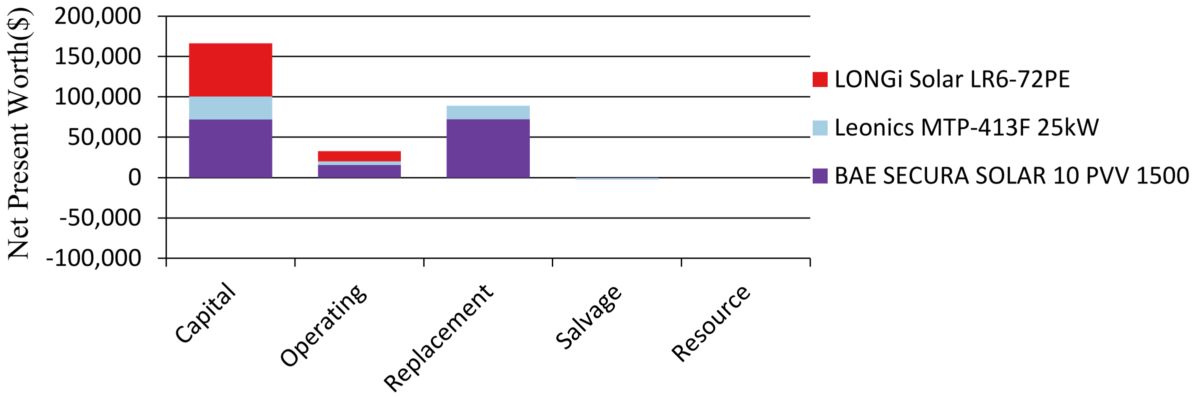


Figure 22: Cost summary

Table 13: Cost summary

Net Present Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Battery	$72,000	$15,580	$72,409	-$555.13	$0.00	$159,433
System converter	$28,424	$4,393	$16,831	-$1,845	$0.00	$47,804
Solar PV	$65,819	$12,716	$0.00	$0.00	$0.00	$78,536
System	$166,243	$32,690	$89,240	-$2,400	$0.00	$285,773

Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Battery	$6,655	$1,440	$6,692	-$51.31	$0.00	$14,736
System converter	$2,627	$406.06	$1,556	-$170.49	$0.00	$4,418
Solar PV	$6,083	$1,175	$0.00	$0.00	$0.00	$7,259
System	$15,365	$3,021	$8,248	-$221.80	$0.00	$26,413

4.3 Standalone diesel generator system results

The simulation showed requirement of 57kW genset to meet the demand of village with levelized COE $1.10/kWh. As exactly 57kW diesel generator isn't available in Nepalese market, 72kVA DG is recommended for the design. Following table lists detail of standalone diesel generator system designed.

Architecture			Cost				System		Gen				
	Gen (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Hours	Production (kWh)	Fuel (L)	O&M Cost ($/yr)	Fuel Cost ($/yr)
	57.0	LF	$1.50M	$1.21	$135,805	$28,500	0	61,009	8,760	155,736	61,009	24,966	103,716
	57.0	CC	$1.50M	$1.21	$135,805	$28,500	0	61,009	8,760	155,736	61,009	24,966	103,716

Figure 23: Standalone diesel generator system results

Table 14: Standalone diesel generator system details

S.N	Particulars	Value	Unit
1.	Power rating	57	kW
2.	Numbers	1	
3.	Levelized COE	1.10	$/kWh
4.	Net present cost	1365184.0	$
5.	Operating cost	123603.60	$
6.	Initial capital	$28,500	$
7.	Hours of operation	8760	Hrs/year
8.	Total production	155736	kWh
9.	Fuel consumed	61,009	L
10.	Excess electricity	41,024	kWh
11.	Average fuel consumed per Day	167	L/day
12.	Average fuel consumed	6.96	L/hr

Fuel consumption pattern, economic cashflows and other details of standalone diesel generator system are documented in figure 24,25 and 26.

Production	kWh/yr	%
Autosize Genset	155,736	100
Total	155,736	100

Consumption	kWh/yr	%
AC Primary Load	114,712	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	114,712	100

Quantity	kWh/yr	%
Excess Electricity	41,024	26.3
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	0	%
Max. Renew. Penetration	0	%

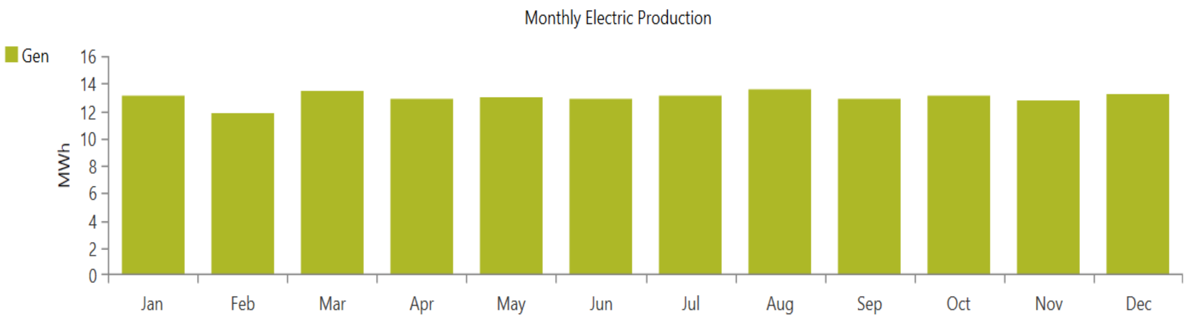


Figure 24: Electrical Summary of standalone diesel generator system

Simulation Results

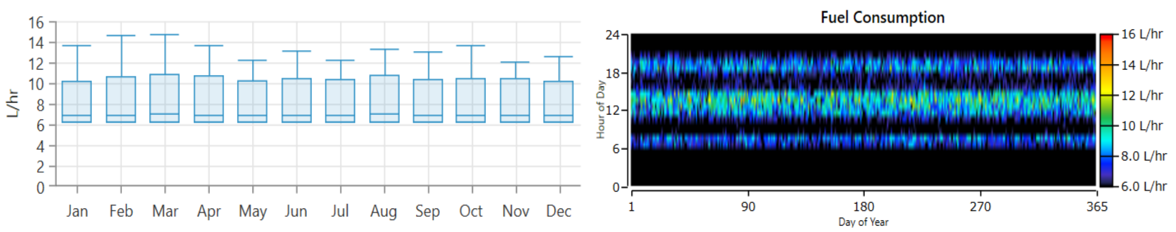
System Architecture:
Autosize Genset (57.0 kW)
HOMER Cycle Charging

Total NPC:	$1,497,830.00
Levelized COE:	$1.21
Operating Cost:	$135,805.40

Cost Summary Cash Flow Compare Economics Electrical Fuel Summary Autosize Genset Emissions

Diesel

Quantity	Value	Units
Total fuel consumed	61,009	L
Avg fuel per day	167	L/day
Avg fuel per hour	6.96	L/hour



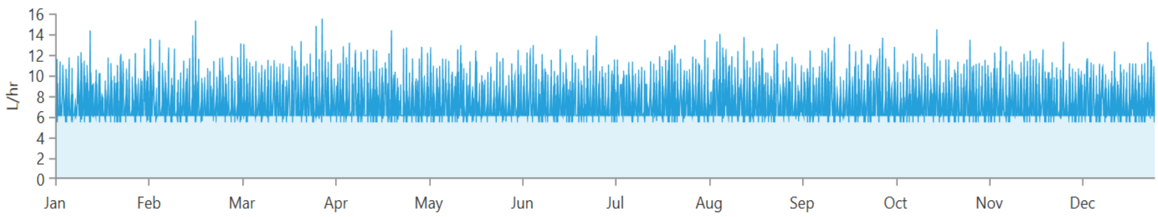


Figure 25: Fuel Summary

Quantity	Value	Units
Hours of Operation	8,760	hrs/yr
Number of Starts	1.00	starts/yr
Operational Life	2.85	yr
Capacity Factor	31.2	%
Fixed Generation Cost	8.47	$/hr
Marginal Generation Cost	0.401	$/kWh

Quantity	Value	Units
Electrical Production	155,736	kWh/yr
Mean Electrical Output	17.8	kW
Minimum Electrical Output	14.3	kW
Maximum Electrical Output	51.1	kW

Quantity	Value	Units
Fuel Consumption	61,009	L
Specific Fuel Consumption	0.392	L/kWh
Fuel Energy Input	600,331	kWh/yr
Mean Electrical Efficiency	25.9	%

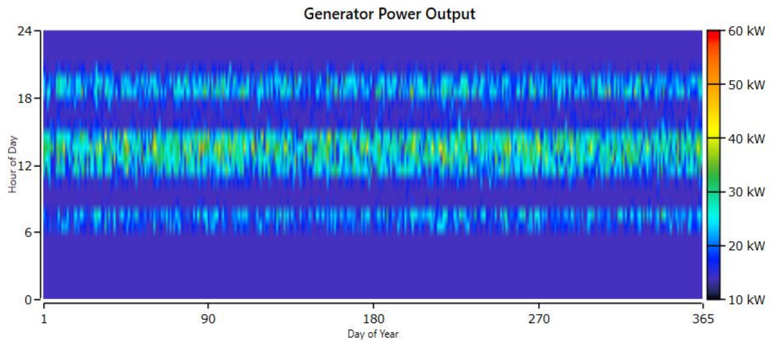


Figure 26: Autosize Genset power output

4.3.1 Emissions associated

Installation of diesel generator system emits various pollutants. Design shows system will bring CO2 emission of 1,59,699kg/year, CO of 1007kg/year, unburned hydrocarbons of 43.9kg/year, particulate matter of 6.10kg/year, Sulphur dioxides of 391kg/year and Nitrogen oxides of 946kg/year.

Table 15: CO2 equivalent emission calculations (greenhouse gas equivalencies calculator)

S. N.	Pollutants	Emission(kg/year)	Carbon equivalent	Tonnes of CO_2e per year
1.	CO_2	1,59,699		175.66
2.	CO	1007	431.54	
3.	Unburned HCs	43.9	28.26	
4.	Particulate matter	6.10		
5.	Sulphur dioxides	391		
6.	Nitrogen oxides	946		
7.	Total			175.66

Hence installation of standalone diesel generator system will cause greenhouse gas emission of 175.66 tonnes of CO_2e per year, with other pollutants as particulate matter 6.10 kg/year, Sulphur dioxides 391 kg/year and Nitrogen oxides 946kg/year.

4.3.2 Sensitivity analysis

Figure 27 shows there is increase in COE and NPC for increased prices of fuel and the relation is almost linear.

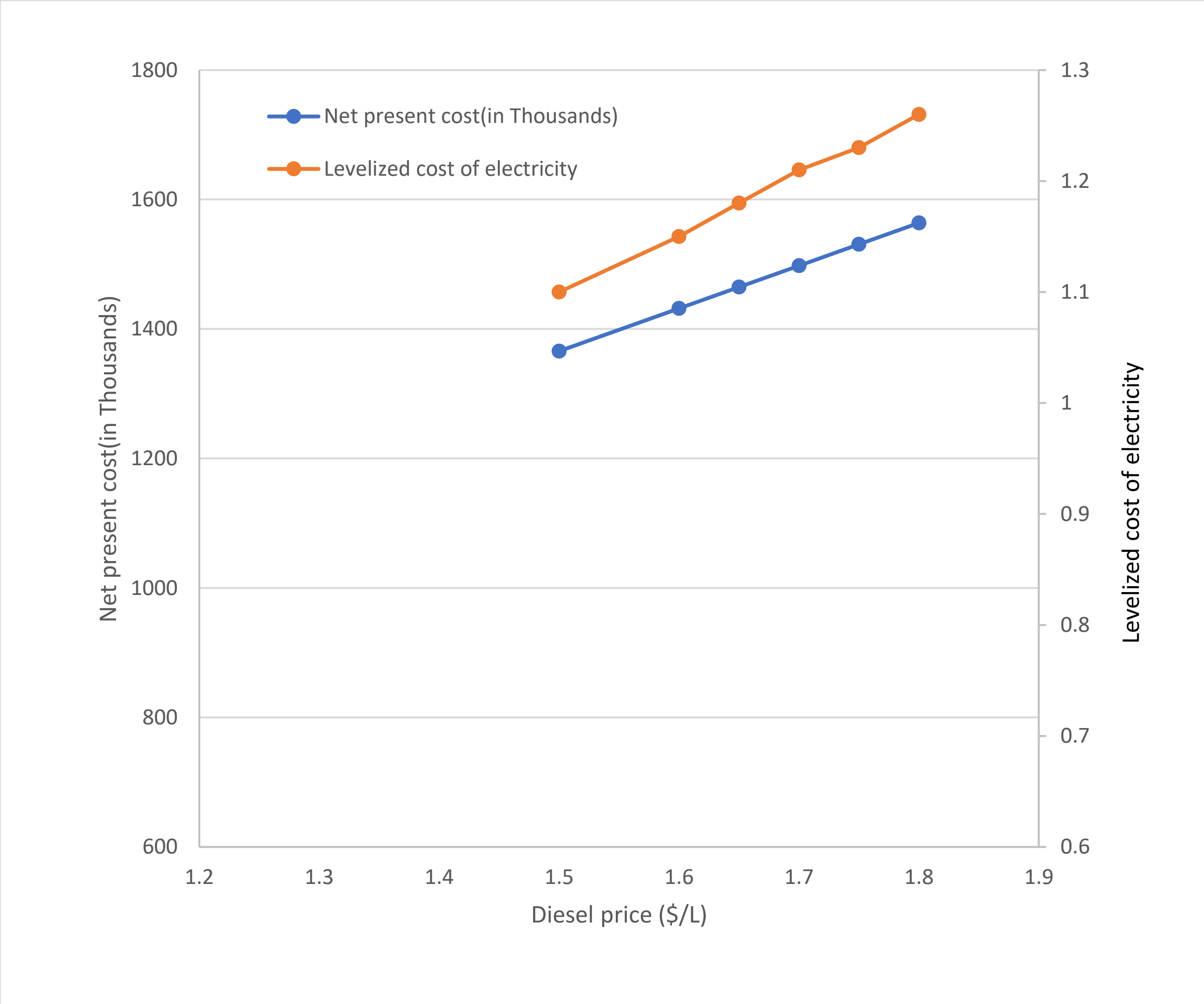


Figure 27: Effect of increase in diesel price in LCE and NPC

4.4 Comparison between Mini Grid system and standalone generator system

Following tabulated parameters (Table 16) shows comparison between two options under consideration for electrification of Mahabai village.

Table 16: Comparison between Solar mini grid system and standalone generator system

Particulars	Standalone generator system	Mini Grid system
Resources used	Diesel	Solar
Price of resource	\$1.5/L	Free
LCE	\$1.10/kWh	\$0.2370/kWh
NPC	\$ 13,65,184	\$2,85,774.70
Initial capital cost	\$28,500	\$1,66,243.18
Operating cost	\$123,603.60	\$11047.91
Emissions	CO_2,CO,PM,NO_x,SO_2, unburned HCs	No emission

The comparison shows despite having high initial capital cost, mini grid system has lower levelized COE and NPC. Further there are no any emissions associated with it. Whereas standalone diesel generator system produces CO_2, CO, PM, NO_x, SO_2, unburned Hydrocarbons which have environmental effect from local to global effects. Similarly emissions also affect physical health of local people and biodiversity. Use of Solar PV system than system including generator helps to avoid emission of CO_2 which is major greenhouse gas contributing significantly to changing climate. Hence rural electrification based on renewable energy resource helps to mitigate climate change.

Fuel source for standalone generator system being diesel, its availability, transportation, increasing prices may be drivers for reliability of such system.

Chapter 5
CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

Following conclusions were drawn from this study:

- People use fuel wood for cooking and heating and Small Solar Home System (SSHS) mostly used for lighting and to charge batteries in their cell phones in the village. 235 HHs among 240 HHs used wood for cooking, only one HH uses LPG for cooking whereas 4 HHs did not stated. The nearby micro hydro of size 10 kW is located in Rata tole. Of the total HHs, only Rata tole having 40 HHs get the electricity from the micro hydro due to inter-community conflict in their ward. 192 out of 240 households use SSHS for lighting and charging batteries. Villagers reported the use of around 9 bhari of woods per month per household for cooking and other business purposes, which is available in free of cost from community forest.

  The electricity demand of village for average daily peak power consumption of load is about 30 kW and average daily peak energy demand of load is about 314 kWh/day for the base year 2021. Energy system design is based on projected demand of year 2021.
- A Solar mini grid system (118kW) is proposed and well suited to meet demand of village. A standalone diesel generator system consisting of generator of 57kW (72kVA DG available in market) can meet the electricity demand of the village because NEA has no plan for coming 5 years to connect grid to that area.
- Despite having high initial capital cost, Solar Mini grid system assure lower NPC and levelized COE compared to standalone diesel generator system with no emissions.
- It is found that there were unsustainable ways of energy used and not proper for that area. By implementing the system design, it would reduce the high expenses of using SSHS , also the modern energy used results to meet the sustainable goals of the country.
- It also helps to increase the socio-economic status of that area like tourism , small scaled industries etc. and also helps to meet the municipality goals in the field of development.
- Implementation of Solar mini grid system instead of standalone diesel generator system would avoid greenhouse gas emission of 175.66 tonnes of CO_2e per year, with other pollutants as particulate matter 6.10 kg/year, Sulphur dioxides 391kg/year and Nitrogen oxides 946kg/year. Use of renewable energy resource for rural electrification aids in mitigation of climate change.

5.2 Recommendations

Following points are recommended to conduct further research and to implement this project:

- Real time/proper measurement of data will help in selection of accurate combination of Solar PV system.
- The simulation and sensitivity analysis was carried out in 1 month trial version of the software due to the financial restrictions. Fully licensed software may give a more accurate analysis of simulation and sensitivity analysis.
- Confirming the results obtained by use of other similar software will also give a better idea about the system needed.
- Performance of Solar mini grid system depends on changing climatic parameters. Effect of climate change on designed system will give clear insight on how system will behave under changing climate.

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ANNEX 1: OPTIMIZATION RESULTS

Architecture/ LR6-72PE (kW)	Architecture/ BAE 10 PVV 1500	Architecture/ Leon25 (kW)	Architecture/ Dispatch	Cost/ NPC ($)	Cost/ COE ($)	Cost/Oper	Cost/Initial capital ($)	System/ Ren Frac (%)	LR6-72PE/ Capital Cost ($)	LR6-72PE/ Production	BAE 10 PVV 1500/ Autonom	BAE 10 PVV 1500/ Annual	BAE 10 PVV 1500/ Nominal	BAE 10 PVV 1500/ Usable	Leon25/Inverter Mean Output (kW)
117.5345	72	40.60554	LF	285773.1	0.237023	11047.77	166243.2	100	65819.3	196112.9	13.21078	42127.04	216.2439	172.9951	12.72108
117.5345	72	40.60554	CC	285773.1	0.237023	11047.77	166243.2	100	65819.3	196112.9	13.21078	42127.04	216.2439	172.9951	12.72108
117.4873	72	40.65904	LF	285806	0.237055	11049.79	166254.2	100	65792.89	196034.2	13.21078	42127.71	216.2439	172.9951	12.72083
117.4873	72	40.65904	CC	285806	0.237055	11049.79	166254.2	100	65792.89	196034.2	13.21078	42127.71	216.2439	172.9951	12.72083
119.0483	72	40.09265	LF	286134.2	0.237122	11035.97	166731.9	100	66667.05	198638.8	13.21078	42104.93	216.2439	172.9951	12.73183
119.0483	72	40.09265	CC	286134.2	0.237122	11035.97	166731.9	100	66667.05	198638.8	13.21078	42104.93	216.2439	172.9951	12.73183
117.5904	72	40.99536	LF	286266.8	0.237409	11065.28	166547.4	100	65850.61	196206.2	13.21078	42125.79	216.2439	172.9951	12.72238
117.5904	72	40.99536	CC	286266.8	0.237409	11065.28	166547.4	100	65850.61	196206.2	13.21078	42125.79	216.2439	172.9951	12.72238
118.9467	72	40.49337	LF	286540.7	0.237454	11052.87	166955.5	100	66610.13	198469.2	13.21078	42106.17	216.2439	172.9951	12.73212
118.9467	72	40.49337	CC	286540.7	0.237454	11052.87	166955.5	100	66610.13	198469.2	13.21078	42106.17	216.2439	172.9951	12.73212
119.3376	72	40.39323	LF	286664.9	0.237511	11050.6	167104.3	100	66829.05	199121.5	13.21078	42097.13	216.2439	172.9951	12.73458
119.3376	72	40.39323	CC	286664.9	0.237511	11050.6	167104.3	100	66829.05	199121.5	13.21078	42097.13	216.2439	172.9951	12.73458
118.4025	72	41.12233	LF	286933.9	0.237835	11076.69	167091	100	66305.41	197561.3	13.21078	42113.92	216.2439	172.9951	12.72919
118.4025	72	41.12233	CC	286933.9	0.237835	11076.69	167091	100	66305.41	197561.3	13.21078	42113.92	216.2439	172.9951	12.72919
118.784	72	40.98981	LF	287021.7	0.237855	11073.63	167211.9	100	66519.04	198197.8	13.21078	42108.67	216.2439	172.9951	12.732
118.784	72	40.98981	CC	287021.7	0.237855	11073.63	167211.9	100	66519.04	198197.8	13.21078	42108.67	216.2439	172.9951	12.732
118.625	72	41.25456	LF	287231.4	0.238043	11084.11	167308.2	100	66430	197932.5	13.21078	42110.69	216.2439	172.9951	12.73124
118.625	72	41.25456	CC	287231.4	0.238043	11084.11	167308.2	100	66430	197932.5	13.21078	42110.69	216.2439	172.9951	12.73124
120.2346	72	40.63989	LF	287504.4	0.238085	11065.8	167779.3	100	67331.38	200618.2	13.21078	42073.29	216.2439	172.9951	12.74109
120.2346	72	40.63989	CC	287504.4	0.238085	11065.8	167779.3	100	67331.38	200618.2	13.21078	42073.29	216.2439	172.9951	12.74109
121.6143	72	40.04866	LF	287660.4	0.238074	11047.06	168138.1	100	68103.99	202920.3	13.21078	42040.21	216.2439	172.9951	12.74859
121.6143	72	40.04866	CC	287660.4	0.238074	11047.06	168138.1	100	68103.99	202920.3	13.21078	42040.21	216.2439	172.9951	12.74859
124.0012	72	38.9095	LF	287781.8	0.237982	11008.44	168677.3	100	69440.66	206903	13.21078	41977.57	216.2439	172.9951	12.75889
124.0012	72	38.9095	CC	287781.8	0.237982	11008.44	168677.3	100	69440.66	206903	13.21078	41977.57	216.2439	172.9951	12.75889
120.6479	72	40.81023	LF	287958.5	0.238403	11075.36	168130	100	67562.82	201307.8	13.21078	42062.61	216.2439	172.9951	12.7442
120.6479	72	40.81023	CC	287958.5	0.238403	11075.36	168130	100	67562.82	201307.8	13.21078	42062.61	216.2439	172.9951	12.7442
119.5643	72	41.5548	LF	288168.1	0.238683	11102.64	168044.4	100	66956.02	199499.8	13.21078	42089.63	216.2439	172.9951	12.73851
119.5643	72	41.5548	CC	288168.1	0.238683	11102.64	168044.4	100	66956.02	199499.8	13.21078	42089.63	216.2439	172.9951	12.73851
120.3837	72	41.25818	LF	288321.9	0.238719	11093.64	168295.6	100	67414.89	200867	13.21078	42068.54	216.2439	172.9951	12.74335
120.3837	72	41.25818	CC	288321.9	0.238719	11093.64	168295.6	100	67414.89	200867	13.21078	42068.54	216.2439	172.9951	12.74335
124.7745	72	39.15902	LF	288546.6	0.238512	11022.96	169285	100	69873.71	208193.3	13.21078	41955.94	216.2439	172.9951	12.76435
124.7745	72	39.15902	CC	288546.6	0.238512	11022.96	169285	100	69873.71	208193.3	13.21078	41955.94	216.2439	172.9951	12.76435
127.5957	72	37.83636	LF	288708.1	0.238496	10977.44	169939	100	71453.57	212900.6	13.21078	41877.29	216.2439	172.9951	12.77238
127.5957	72	37.83636	CC	288708.1	0.238496	10977.44	169939	100	71453.57	212900.6	13.21078	41877.29	216.2439	172.9951	12.77238
123.7445	72	40.70338	LF	289732.7	0.239516	11085.97	169789.3	100	69296.94	206474.7	13.21078	41982.5	216.2439	172.9951	12.76312
123.7445	72	40.70338	CC	289732.7	0.239516	11085.97	169789.3	100	69296.94	206474.7	13.21078	41982.5	216.2439	172.9951	12.76312
126.156	72	40.96703	LF	291515.9	0.240722	11108.92	171324.3	100	70647.37	210498.4	13.21078	41917.01	216.2439	172.9951	12.77735
126.156	72	40.96703	CC	291515.9	0.240722	11108.92	171324.3	100	70647.37	210498.4	13.21078	41917.01	216.2439	172.9951	12.77735
128.8744	72	39.63636	LF	291607.3	0.2406	11062.76	171915.1	100	72169.66	215034.2	13.21078	41842.18	216.2439	172.9951	12.78781
128.8744	72	39.63636	CC	291607.3	0.2406	11062.76	171915.1	100	72169.66	215034.2	13.21078	41842.18	216.2439	172.9951	12.78781
124.3439	72	42.24472	LF	291906.4	0.241194	11156.14	171203.9	100	69632.6	207474.9	13.21078	41962.95	216.2439	172.9951	12.7694
124.3439	72	42.24472	CC	291906.4	0.241194	11156.14	171203.9	100	69632.6	207474.9	13.21078	41962.95	216.2439	172.9951	12.7694
123.2457	72	43.82506	LF	293096.5	0.242264	11220.74	171695.1	100	69017.58	205642.4	13.21078	41992.96	216.2439	172.9951	12.76486
123.2457	72	43.82506	CC	293096.5	0.242264	11220.74	171695.1	100	69017.58	205642.4	13.21078	41992.96	216.2439	172.9951	12.76486
129.1363	72	41.11446	LF	293503.4	0.242067	11128.83	173096.5	100	72316.32	215471.2	13.21078	41833.21	216.2439	172.9951	12.79297
129.1363	72	41.11446	CC	293503.4	0.242067	11128.83	173096.5	100	72316.32	215471.2	13.21078	41833.21	216.2439	172.9951	12.79297
132.988	72	42.58214	LF	297574.5	0.245038	11210.79	176280.8	100	74473.3	221898.1	13.21078	41724.52	216.2439	172.9951	12.81316
132.988	72	42.58214	CC	297574.5	0.245038	11210.79	176280.8	100	74473.3	221898.1	13.21078	41724.52	216.2439	172.9951	12.81316
125.8888	72	46.46786	LF	297821.5	0.245844	11349.66	175025.3	100	70497.75	210052.6	13.21078	41920.87	216.2439	172.9951	12.78172
125.8888	72	46.46786	CC	297821.5	0.245844	11349.66	175025.3	100	70497.75	210052.6	13.21078	41920.87	216.2439	172.9951	12.78172
139.3028	72	39.66559	LF	298041.3	0.245031	11115.78	177775.5	100	78009.58	232434.6	13.21078	41574.32	216.2439	172.9951	12.83364
139.3028	72	39.66559	CC	298041.3	0.245031	11115.78	177775.5	100	78009.58	232434.6	13.21078	41574.32	216.2439	172.9951	12.83364
133.0378	72	44.89939	LF	300328.1	0.247258	11312.79	177930.8	100	74501.19	221981.1	13.21078	41720.88	216.2439	172.9951	12.81559
133.0378	72	44.89939	CC	300328.1	0.247258	11312.79	177930.8	100	74501.19	221981.1	13.21078	41720.88	216.2439	172.9951	12.81559
110.9654	96	41.83545	LF	307816.3	0.25379	11127.33	187425.5	100	62140.65	185152.1	17.61437	43442.04	288.3252	230.6602	12.7971
110.9654	96	41.83545	CC	307816.3	0.25379	11127.33	187425.5	100	62140.65	185152.1	17.61437	43442.04	288.3252	230.6602	12.7971
145.3709	72	44.82085	LF	307847.1	0.252479	11374.48	184782.3	100	81407.7	242559.5	13.21078	41424.98	216.2439	172.9951	12.86482
145.3709	72	44.82085	CC	307847.1	0.252479	11374.48	184782.3	100	81407.7	242559.5	13.21078	41424.98	216.2439	172.9951	12.86482
138.0245	72	50.2885	LF	309737.9	0.254542	11575.74	184495.7	100	77293.7	230301.6	13.21078	41595.32	216.2439	172.9951	12.83893
138.0245	72	50.2885	CC	309737.9	0.254542	11575.74	184495.7	100	77293.7	230301.6	13.21078	41595.32	216.2439	172.9951	12.83893
117.6798	96	40.70558	LF	310471.1	0.255169	11098.28	190394.6	100	65900.68	196355.4	17.61437	43203.32	288.3252	230.6602	12.8377
117.6798	96	40.70558	CC	310471.1	0.255169	11098.28	190394.6	100	65900.68	196355.4	17.61437	43203.32	288.3252	230.6602	12.8377
118.9014	96	40.87456	LF	311399.7	0.255779	11109.95	191197	100	66584.8	198393.7	17.61437	43162.18	288.3252	230.6602	12.8454
118.9014	96	40.87456	CC	311399.7	0.255779	11109.95	191197	100	66584.8	198393.7	17.61437	43162.18	288.3252	230.6602	12.8454
122.8241	96	39.41101	LF	312016.6	0.255936	11058.62	192369.2	100	68781.48	204938.9	17.61437	43028.73	288.3252	230.6602	12.86292
122.8241	96	39.41101	CC	312016.6	0.255936	11058.62	192369.2	100	68781.48	204938.9	17.61437	43028.73	288.3252	230.6602	12.86292
113.5758	96	44.45605	LF	312446.8	0.2572	11250.66	190721.7	100	63602.45	189507.7	17.61437	43347.27	288.3252	230.6602	12.81734
113.5758	96	44.45605	CC	312446.8	0.2572	11250.66	190721.7	100	63602.45	189507.7	17.61437	43347.27	288.3252	230.6602	12.81734
117.8693	96	42.69013	LF	312922.7	0.257087	11186.66	191889.9	100	66006.83	196671.7	17.61437	43197.86	288.3252	230.6602	12.84251
117.8693	96	42.69013	CC	312922.7	0.257087	11186.66	191889.9	100	66006.83	196671.7	17.61437	43197.86	288.3252	230.6602	12.84251
124.1997	96	41.84849	LF	315705.6	0.258694	11170.68	194845.8	100	69551.82	207234.2	17.61437	42981.46	288.3252	230.6602	12.87625
124.1997	96	41.84849	CC	315705.6	0.258694	11170.68	194845.8	100	69551.82	207234.2	17.61437	42981.46	288.3252	230.6602	12.87625
105	120	32.08333	LF	316980.7	0.262417	10695.84	201258.3	100	58800	175198.4	22.01796	44451.5	360.4065	288.3252	12.74483
105	120	32.08333	CC	316980.7	0.262417	10695.84	201258.3	100	58800	175198.4	22.01796	44451.5	360.4065	288.3252	12.74483

ANNEX 2: HOUSEHOLD SURVEY QUESTIONNAIRES

Project location: Latitude /Longitude:
Altitude (ASL):

House No.

Household owner:

Family members: Male: Female:

Non-residing/out: Ethnicity: No. of rooms in house:

- Existing energy consumption (per month):

Purpose/source	Fuel wood	LPG	Kerosene	Solar	Biogas	Others
Cooking						
Lighting						
Productive end use						
Others						

- Electricity demand: HH demand:

Appliances		Number	Daily Operating Hours	Weekly operating days	Power rating
Lights	CFL				
	Filament				
Mobile					
Radio					
TV/VCR/DVD					
Refrigerators					
Computer	Desktop				
	Laptop				
Kitchen appliances					
Others					

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Productive end use demand:

Components		Number	Operating hours	Weekly operating days	Power rating
Motor					
Lights	CFL				
	Filament				
Computer	Desktop				
	Laptop				
Others					

School/college demand:

Components		Number	Operating hours per day	Weekly operating days	Power rating
Lights	CFL				
	Filament				
Computer	Desktop				
	Laptop				
Others					

Public Uses:

Components	Number	Operating hours per day	Weekly operating days	Power rating
Street Lights				
Others				

Power House Uses:

Components		Number	Operating hours per day	Weekly operating days	Power rating
Lights	CFL				
	Filament				
Control units					

ANNEX 3: DEMAND ASSESSMENT DETAILS

S.N	Type of Electricity Users	Quantity	Watt / Unit	Total Watts	Hours Use/ day	Utilization factor	Total Units	Total Load (kW)	Total (kWh/ day)
1	**Household**								
1.1	LED Lights	6	5	30	6	0.95	240	7.2	47.196
1.2	Radio	1	5	5	5	0.8	240	1.2	5.52
1.3	Mobile Charging	2	5	10	2	1	240	2.4	5.52
1.4	Television	0.4	40	16	4	0.9	240	3.84	15.8976
1.5	DTH Receiver	0.4	40	16	4	0.9	240	3.84	15.8976
1.6	Fan	0.1	40	4	5	0.8	240	0.96	4.416
1.7	Refrigerator	0.2	90	18	12	0.9	240	4.32	53.6544
1.8	Rice Cooker	0.25	400	100	1	0.9	240	24	24.84
							Total	47.76	172.9416
2	**Business Power Demand**								
2.1	Grill Industry	1	4300	4300	3	0.9	1	4.3	13.3515
2.2	Saw Mill	3	2400	7200	3.5	0.9	1	7.2	26.082
2.3	Haulling/Milling	2	2000	4000	4	0.9	1	4	16.56
2.4	Hotels+Kirana	12	500	6000	7	0.95	1	6	45.885
2.5	Computer Institute	1	300	300	4	0.9	1	0.3	1.242
2.6	Photocopy Centre	1	1000	1000	2	0.9	1	1	2.07
							Total	22.8	105.1905
3	**School**								
3.1	LED lights	5	5	25	7	1	1	0.025	0.20125
3.2	Computers	4	120	480	3	0.9	1	0.48	1.4904
3.3	Mobile Charger	3	5	15	2	1	1	0.015	0.0345
3.4	Router	1	12	12	24	1	1	0.012	0.3312
3.5	Printer	2	500	1000	1	0.85	1	1	0.9775
3.6	Projectors	2	300	600	2	0.8	1	0.6	1.104
3.7	Electric Kettle	1	1000	1000	2	0.9	1	1	2.07
							Total	3.132	6.20885
4	**Health Post**								
4.1	LED Lights	6	7	42	12	1	1	0.042	0.5796
4.2	Refirgerator	1	100	100	24	0.95	1	0.1	2.622
4.3	Heater	1	1000	1000	3	0.8	1	1	2.76
4.4	Mobile Charger	2	2	4	4	1	1	0.004	0.0184
4.5	Nebulizer	2	75	150	1	0.8	1	0.15	0.138
4.6	Sterilizing Machine	1	3000	3000	1.5	0.95	1	3	4.91625
4.7	Infant radiant warmer	3	500	1500	3	0.85	1	1.5	4.39875
4.8	Suction Pump	1	100	100	0.5	1	1	0.1	0.0575
4.9	Exhaust Fan	1	70	70	3	1	1	0.07	0.2415
							Total	5.966	15.732
5	**Community Power Demand**								
5.1	Ward office	1	500	500	7	1	1	0.5	4.025
5.2	Street Lights	1	15	15	8	1	40	0.6	5.52
							Total	1.1	9.545

6	**Power House**								
6.1	LED Lamp	5	7	35	6	1	1	0.035	0.2415
6.2	Control System	1	150	150	24	1	1	0.15	4.14
							Total	0.185	4.3815
			Total	32797			Sum Total	160.601	314.31

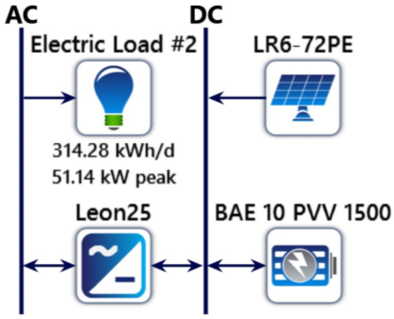
ANNEX 4: PEAK LOAD CALCULATION DETAILS

Time	Load (kW)	LED Lights	Radio	Mob ile	Tele vision	DTH	Fan	Lap top	Refri gerat or	Ricecc	Grill	Saw mill	Hau ling	Hotels	Com p uter	Photo copy	Schoc	Healt h post	Ward office	Street Lights	LED Lam	Contr ol syste
12--1 am	1.21								0.3								0.01	0.142		0.6		0.1
1--2	1.21								0.3								0.01	0.142		0.6		0.1
2--3	1.21								0.3								0.01	0.142		0.6		0.1
3--4	1.21								0.3								0.01	0.142		0.6		0.1
4--5	4.40	2.5	0.5						0.3								0.01	0.142		0.6	0.04	0.1
5--6	7.65	6	0.5	0.2					0.3								0.01	0.142			0.04	0.1
6--7	17.37	5	0.5	0.5	2.5	2.5			0.3	3							0.01	2.1			0.04	0.1
7--8	21.33	2.5	0.5	0.7	2.7	2.7			2	7							0.01	2.1				0.1
8--9	11.77		0.5	0.5	1.5	1.5			4	2							0.01	1.1				0.1
9--10	10.51			0.5					4					3	0.3		0.01	2.1				0.1
10--11	15.34								4			1.5	2	4	0.3	0.1	0.01	2.1	0.5			0.1
11--12	22.92						0.5		4		1	2.5	2.5	4	0.3	0.2	3.13	3.1	0.5			0.1
12--1 pm	26.70		0.5	0.1	0.2	0.2	0.5		4		2	5	2.5	4	0.3	0.3	3.13	2.1	0.5			0.1
1--2	29.62			0.1	0.4	0.4	0.5		4		4	7	4	4	0.3	0.8	0.01	2.1	0.5			0.1
2--3	26.49			0.1	0.4	0.4	0.5		4		2.5	5	3	4	0.3	0.2	3.13	1.1	0.5			0.1
3--4	15.34						0.5		4		2	1	1	4	0.3	0.1	0.01	1.1	0.5			0.1
4--5	13.54		0.25				0.5		4		1	1	1	4	0.3	0.1	0.01	0.1	0.5		0.04	0.1
5--6	15.48	2	0.5		0.5	0.5	0.5		4		1	1		4			0.01	0.1	0.5		0.04	0.1
6--7	23.40	6.5	0.5	0.7	2.5	2.5	0.3		1	4				4			0.01	0.142			0.04	0.1
7--8	21.62	6.5	0.5	0.7	2.5	2.5			1	6							0.01	0.142		0.6	0.04	0.1
8--9	14.55	6.5	0.5	0.7	2	2			0.3	1							0.01	0.142		0.6		0.1
9--10	6.36	3.5			0.7	0.7			0.3								0.01	0.142		0.6		0.1
10--11	3.84	2.5							0.3								0.01	0.142		0.6		0.1
11--12	1.21								0.3								0.01	0.142		0.6		0.1
Total	314.31	43.50	5.25	4.80	15.90	15.90	3.80	0.00	47.30	23.00	13.50	24.00	16.00	39.00	2.40	1.80	9.65	20.90	4.00	6.00	0.25	2.40

ANNEX 5: System Architecture

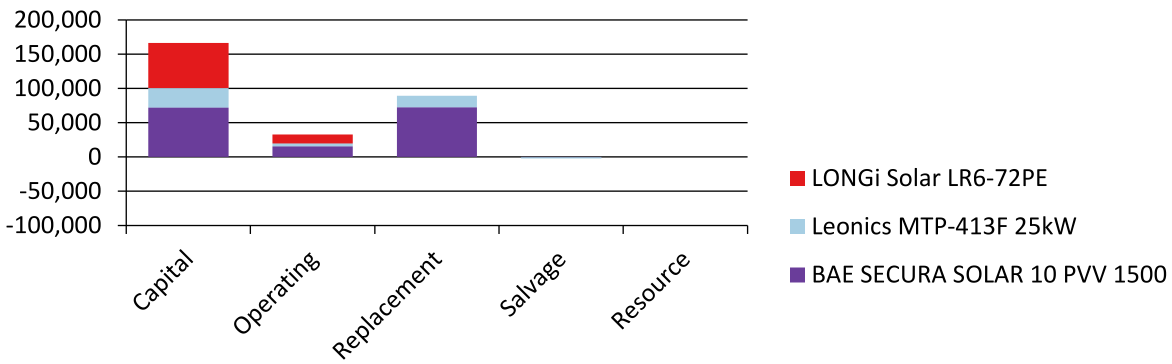
Component	Name	Size	Unit
PV	LONGi Solar LR6-72PE	118	kW
Storage	BAE SECURA SOLAR 10 PVV 1500	3	Strings
System converter	Leonics MTP-413F 25kW	40.6	kW
Dispatch strategy	HOMER Cycle Charging		

Schematic



AC
DC
Electric Load #2
LR6-72PE
314.28 kWh/d
51.14 kW peak
Leon25
BAE 10 PVV 1500

ANNEX 6: Cost Summary



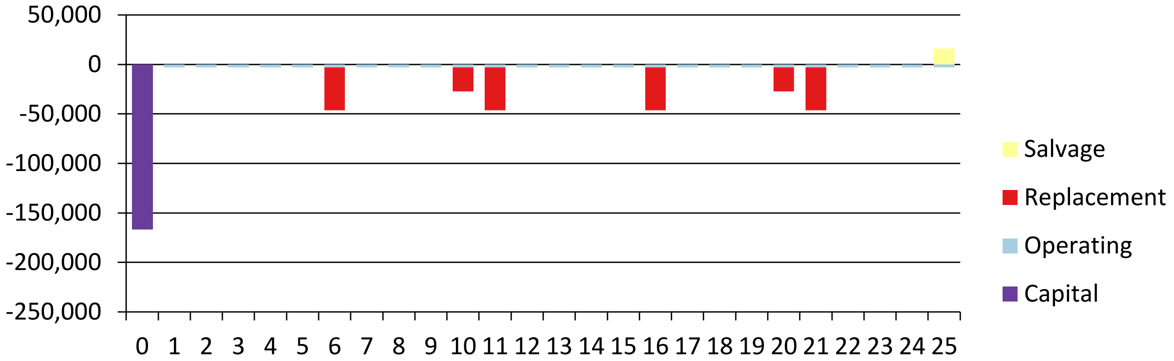
Net Present Costs

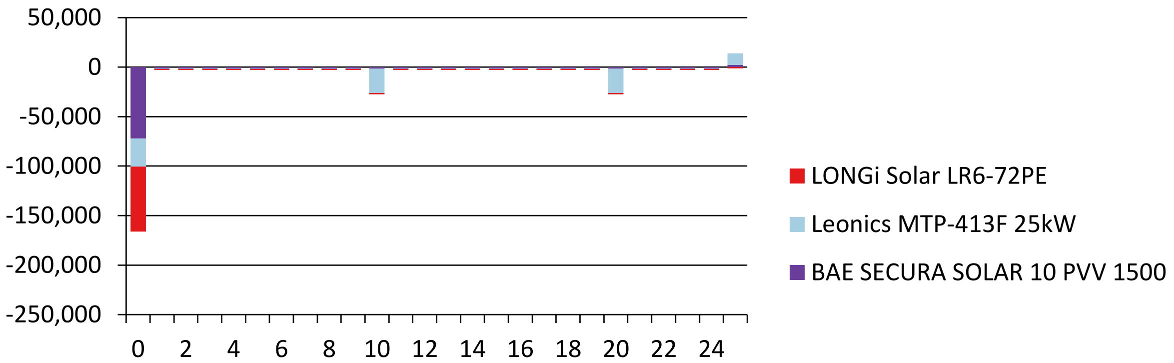
Name	Capital	Operating	Replacement	Salvage	Resource	Total
BAE SECURA SOLAR 10 PVV 1500	$72,000	$15,580	$72,409	-$555.13	$0.00	$159,433
Leonics MTP-413F 25kW	$28,424	$4,393	$16,831	-$1,845	$0.00	$47,804
LONGi Solar LR6-72PE	$65,819	$12,716	$0.00	$0.00	$0.00	$78,536
System	$166,243	$32,690	$89,240	-$2,400	$0.00	$285,773

Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
BAE SECURA SOLAR 10 PVV 1500	$6,655	$1,440	$6,692	-$51.31	$0.00	$14,736
Leonics MTP-413F 25kW	$2,627	$406.06	$1,556	-$170.49	$0.00	$4,418
LONGi Solar LR6-72PE	$6,083	$1,175	$0.00	$0.00	$0.00	$7,259
System	$15,365	$3,021	$8,248	-$221.80	$0.00	$26,413

ANNEX 7: Cash Flow





ANNEX 8: Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	77,974	kWh/yr
Unmet Electric Load	3,276	kWh/yr
Capacity Shortage	5,827	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
LONGi Solar LR6-72PE	196,113	100
Total	196,113	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	111,437	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	111,437	100

ANNEX 9: PV LONGi Solar LR6-72PE

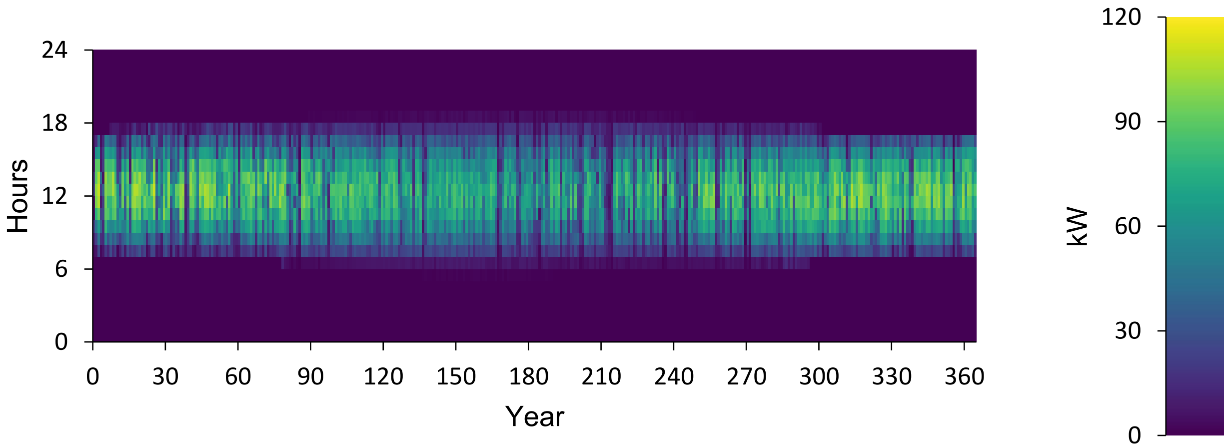
LONGi Solar LR6-72PE Electrical Summary

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	111	kW
PV Penetration	171	%
Hours of Operation	4,376	hrs/yr
Levelized Cost	0.0370	$/kWh

LONGi Solar LR6-72PE Statistics

Quantity	Value	Units
Rated Capacity	118	kW
Mean Output	22.4	kW
Mean Output	537	kWh/d
Capacity Factor	19.0	%
Total Production	196,113	kWh/yr

LONGi Solar LR6-72PE Output (kW)



ANNEX 10: BAE SECURA SOLAR 10 PVV 1500(Storage)

BAE SECURA SOLAR 10 PVV 1500 Properties

Quantity	Value	Units
Batteries	72.0	qty.
String Size	24.0	batteries
Strings in Parallel	3.00	strings
Bus Voltage	48.0	V

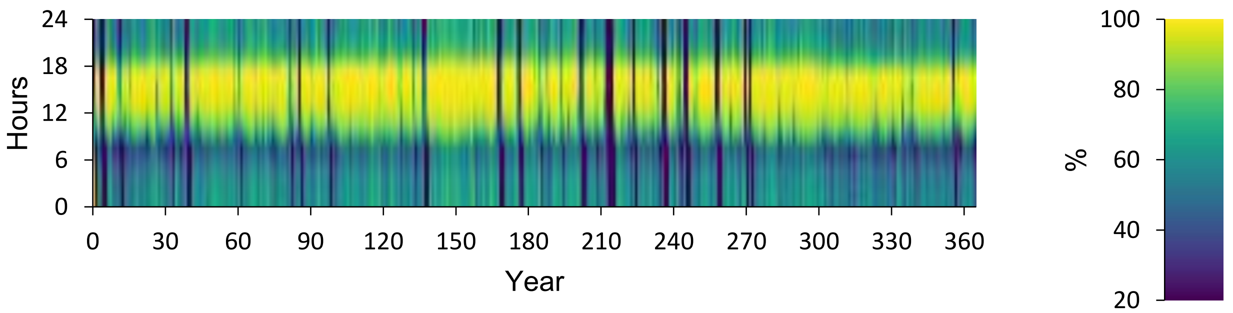
BAE SECURA SOLAR 10 PVV 1500 Result Data

Quantity	Value	Units
Average Energy Cost	0	$/kWh
Energy In	43,119	kWh/yr
Energy Out	41,060	kWh/yr
Storage Depletion	99.7	kWh/yr
Losses	2,158	kWh/yr
Annual Throughput	42,127	kWh/yr

BAE SECURA SOLAR 10 PVV 1500 Statistics

Quantity	Value	Units
Autonomy	13.2	hr
Storage Wear Cost	0.207	$/kWh
Nominal Capacity	216	kWh
Usable Nominal Capacity	173	kWh
Lifetime Throughput	214,272	kWh
Expected Life	5.09	yr

BAE SECURA SOLAR 10 PVV 1500 State of Charge (%)



ANNEX 11: Leonics MTP-413F 25kW(Converter)

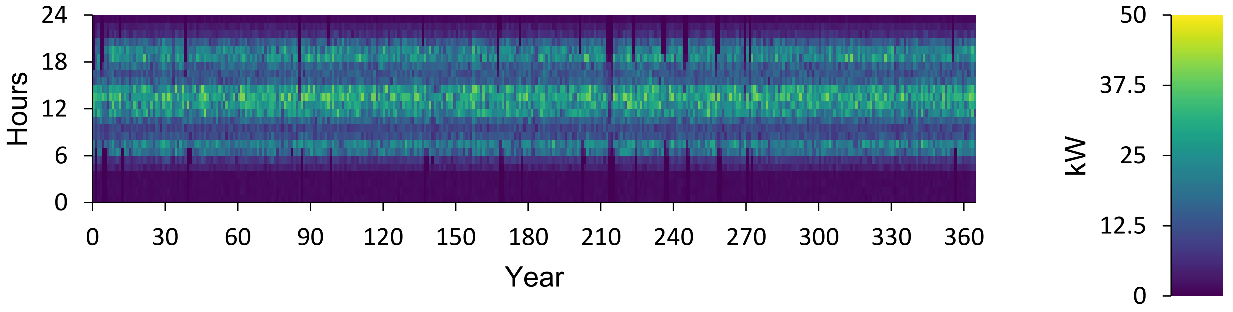
Leonics MTP-413F 25kW Electrical Summary

Quantity	Value	Units
Hours of Operation	8,700	hrs/yr
Energy Out	111,437	kWh/yr
Energy In	116,080	kWh/yr
Losses	4,643	kWh/yr

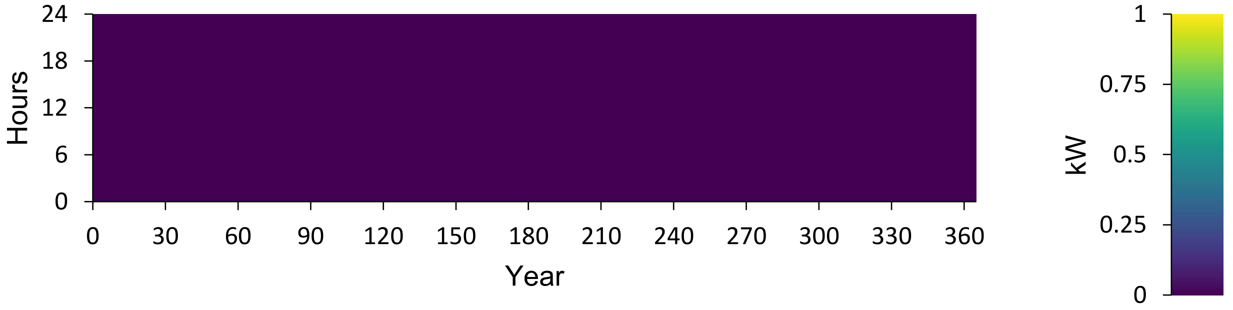
Leonics MTP-413F 25kW Statistics

Quantity	Value	Units
Capacity	40.6	kW
Mean Output	12.7	kW
Minimum Output	0	kW
Maximum Output	40.6	kW
Capacity Factor	31.3	%

Leonics MTP-413F 25kW Inverter Output (kW)



Leonics MTP-413F 25kW Rectifier Output (kW)



ANNEX 12: Compare Economics

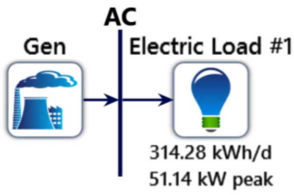
IRR (%):**N/A**
Discounted payback (yr):**N/A**
Simple payback (yr):**N/A**

	Base System	Proposed System
Net Present Cost	$285,773	$285,773
CAPEX	$166,243	$166,243
OPEX	$11,048	$11,048
LCOE (per kWh)	$0.237	$0.237
CO2 Emitted (kg/yr)	0	0
Fuel Consumption (L/yr)	0	0

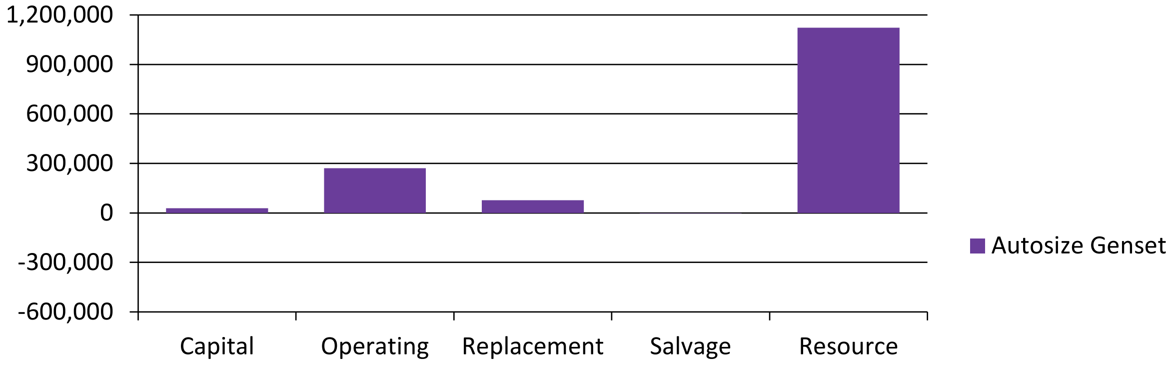
ANNEX 13: System Architecture

Component	Name	Size	Unit
Generator	Autosize Genset	57.0	kW
Dispatch strategy	HOMER Load Following		

Schematic



ANNEX 14: Cost Summary



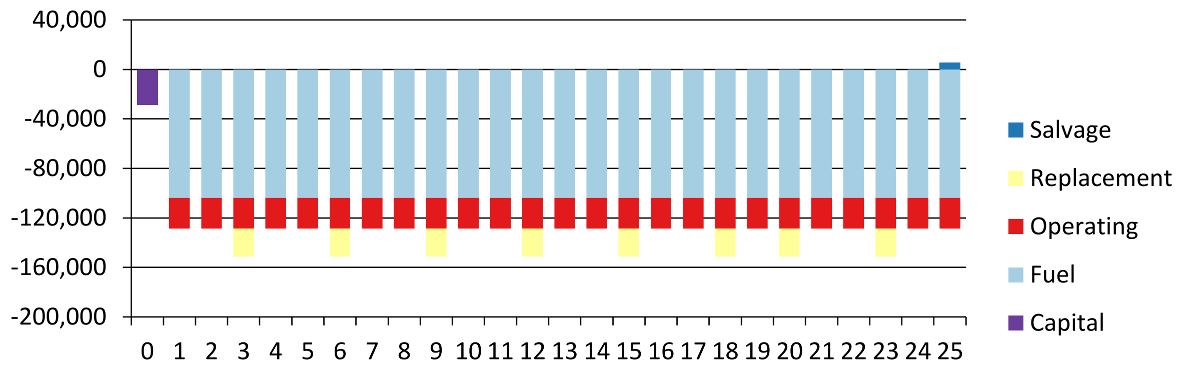
Net Present Costs

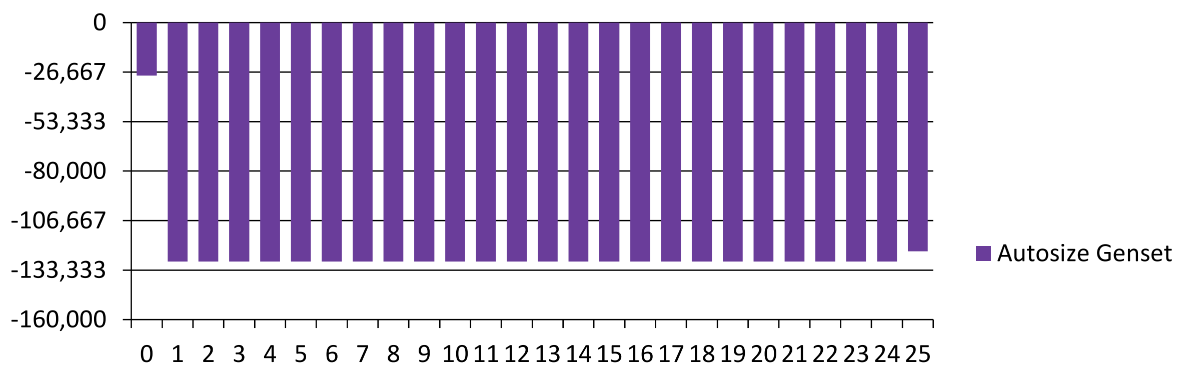
Name	Capital	Operating	Replacement	Salvage	Resource	Total
Autosize Genset	$28,500	$270,117	$77,903	-$828.58	$1.12M	$1.50M
System	$28,500	$270,117	$77,903	-$828.58	$1.12M	$1.50M

Annualized Costs

Name	Capital	Operating	Replacement	Salvage	Resource	Total
Autosize Genset	$2,634	$24,966	$7,200	-$76.58	$103,716	$138,440
System	$2,634	$24,966	$7,200	-$76.58	$103,716	$138,440

ANNEX 15: Cash Flow





ANNEX 16: Electrical Summary

Excess and Unmet

Quantity	Value	Units
Excess Electricity	41,024	kWh/yr
Unmet Electric Load	0	kWh/yr
Capacity Shortage	0	kWh/yr

Production Summary

Component	Production (kWh/yr)	Percent
Autosize Genset	155,736	100
Total	155,736	100

Consumption Summary

Component	Consumption (kWh/yr)	Percent
AC Primary Load	114,712	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	114,712	100

ANNEX 17: Autosize Genset (Diesel Generator)

Autosize Genset Electrical Summary

Quantity	Value	Units
Electrical Production	155,736	kWh/yr
Mean Electrical Output	17.8	kW
Minimum Electrical Output	14.3	kW
Maximum Electrical Output	51.1	kW

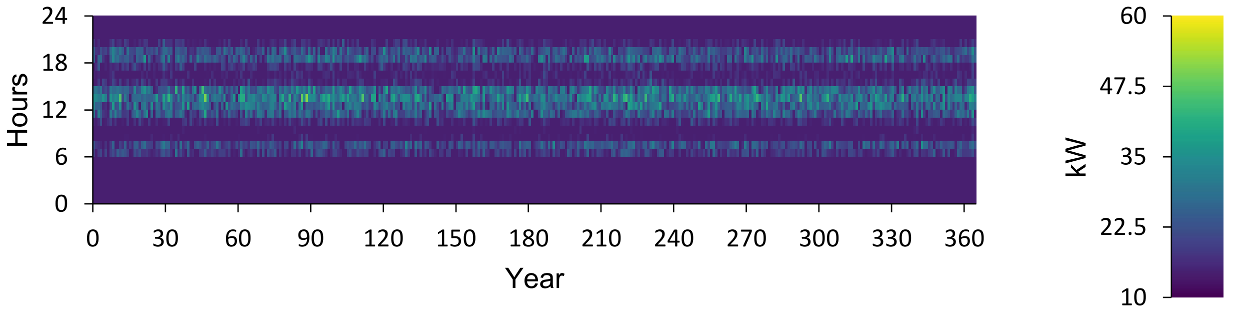
Autosize Genset Fuel Summary

Quantity	Value	Units
Fuel Consumption	61,009	L
Specific Fuel Consumption	0.392	L/kWh
Fuel Energy Input	600,331	kWh/yr
Mean Electrical Efficiency	25.9	%

Autosize Genset Statistics

Quantity	Value	Units
Hours of Operation	8,760	hrs/yr
Number of Starts	1.00	starts/yr
Operational Life	2.85	Yr
Capacity Factor	31.2	%
Fixed Generation Cost	8.47	$/hr
Marginal Generation Cost	0.401	$/kWh

Autosize Genset Output (kW)

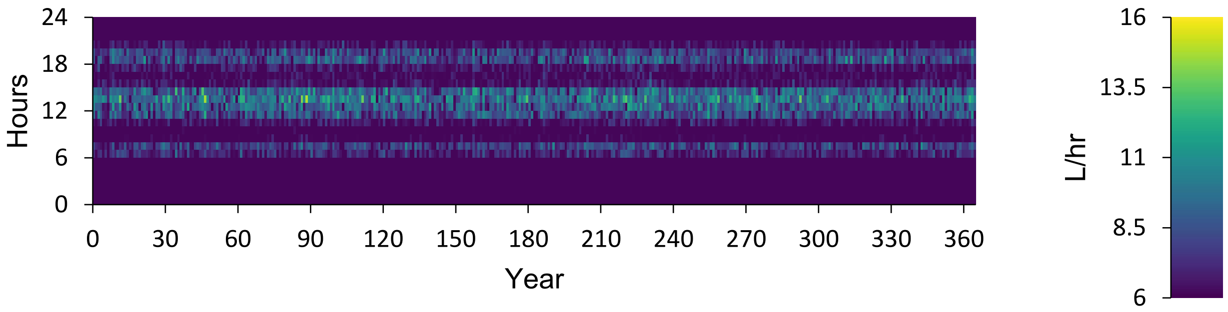


ANNEX 18: Fuel Summary

Diesel Consumption Statistics

Quantity	Value	Units
Total fuel consumed	61,009	L
Avg fuel per day	167	L/day
Avg fuel per hour	6.96	L/hour

Diesel Consumption (L/hr)



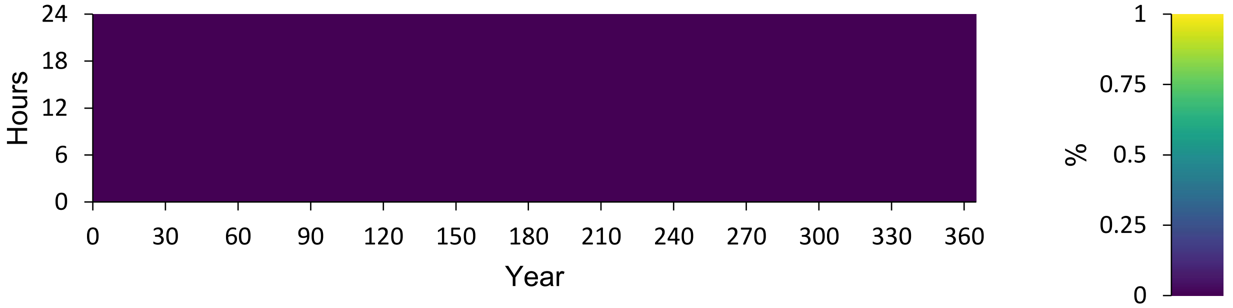
Emissions

Pollutant	Quantity	Unit
Carbon Dioxide	159,699	kg/yr
Carbon Monoxide	1,007	kg/yr
Unburned Hydrocarbons	43.9	kg/yr
Particulate Matter	6.10	kg/yr
Sulfur Dioxide	391	kg/yr
Nitrogen Oxides	946	kg/yr

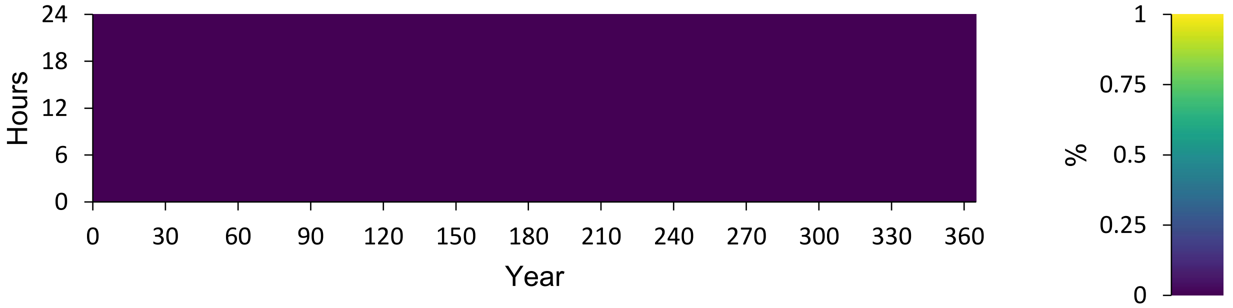
ANNEX 19: Renewable Summary

Capacity-based metrics	Value	Unit
Nominal renewable capacity divided by total nominal capacity	0	%
Usable renewable capacity divided by total capacity	0	%
Energy-based metrics	Value	Unit
Total renewable production divided by load	0	%
Total renewable production divided by generation	0	%
One minus total nonrenewable production divided by load	-35.8	%
Peak values	Value	Unit
Renewable output divided by load (HOMER standard)	0	%
Renewable output divided by total generation	0	%
One minus nonrenewable output divided by total load	0	%

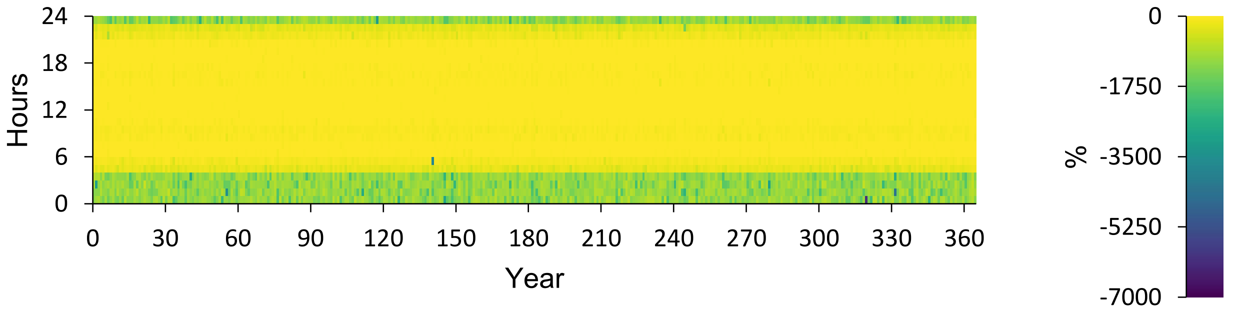
Instantaneous Renewable Output Percentage of Total Generation



Instantaneous Renewable Output Percentage of Total Load



100% Minus Instantaneous Nonrenewable Output as Percentage of Total Load

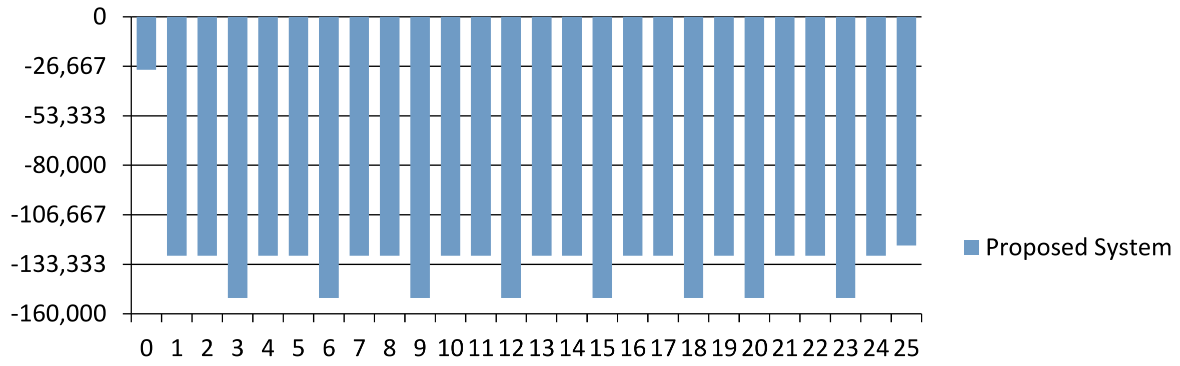


ANNEX 20: Compare Economics

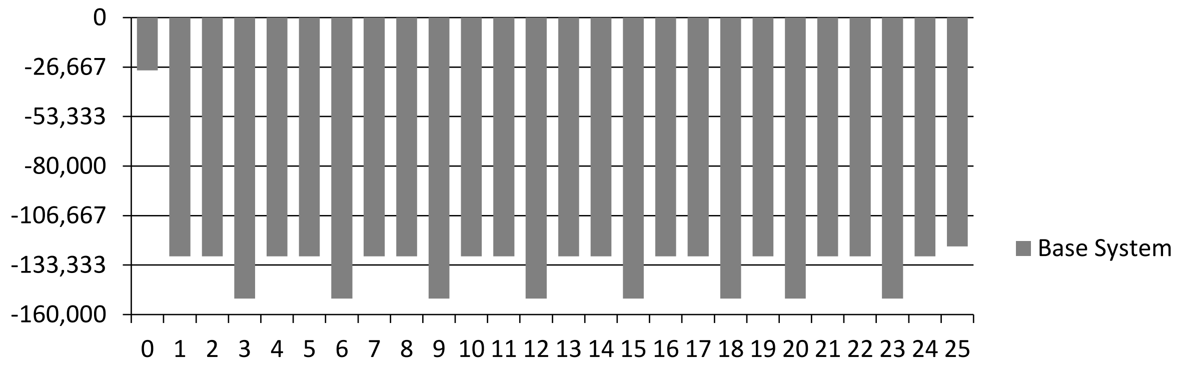
IRR (%):**N/A**
Discounted payback (yr):**N/A**
Simple payback (yr):**N/A**

	Base System	Proposed System
Net Present Cost	$1.50M	$1.50M
CAPEX	$28,500	$28,500
OPEX	$135,805	$135,805
LCOE (per kWh)	$1.21	$1.21
CO2 Emitted (kg/yr)	159,699	159,699
Fuel Consumption (L/yr)	61,009	61,009

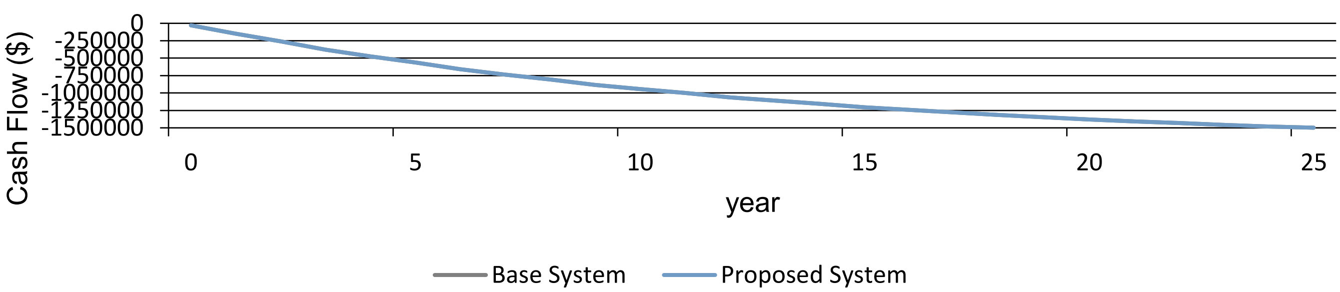
Proposed Annual Nominal Cash Flows



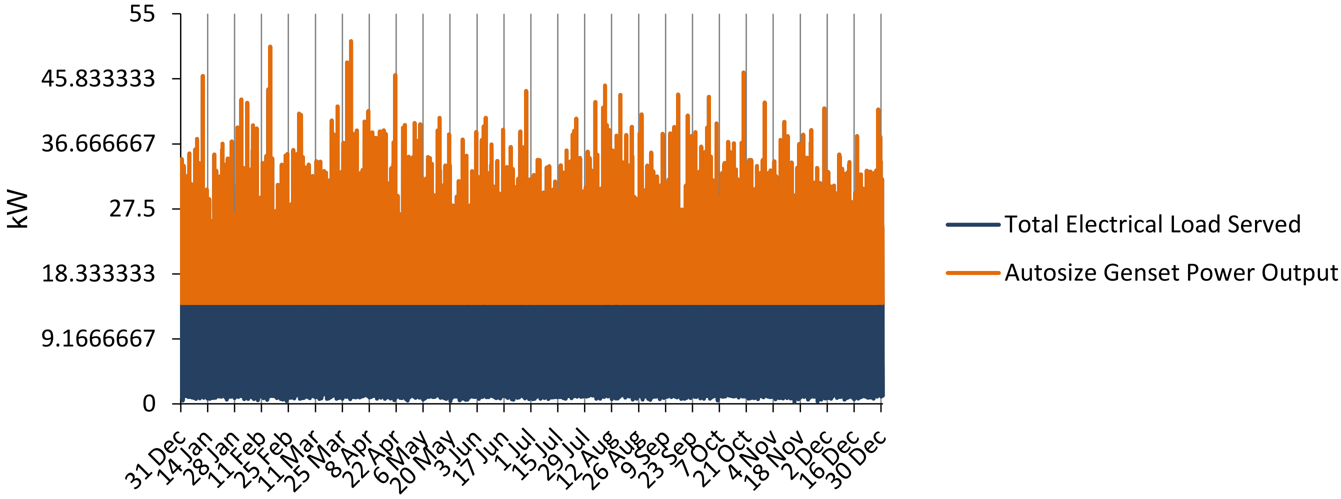
Base System Annual Nominal Cash Flows



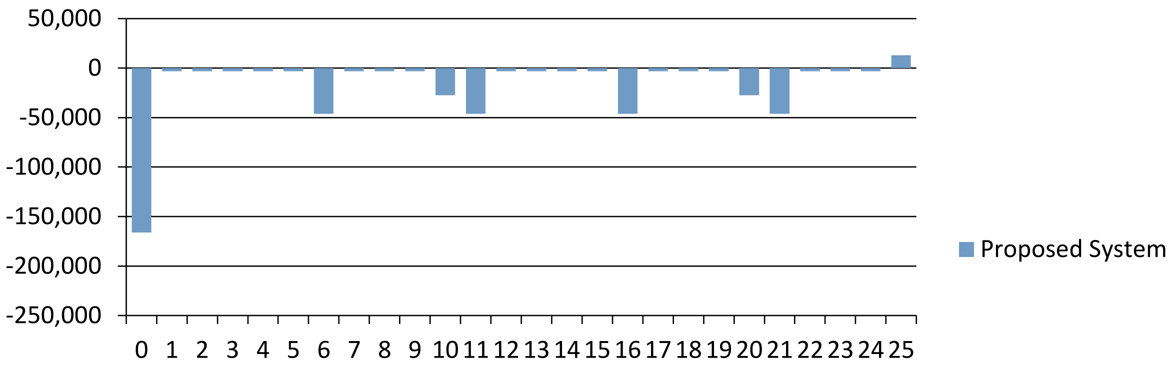
Cumulative Discounted Cash Flows



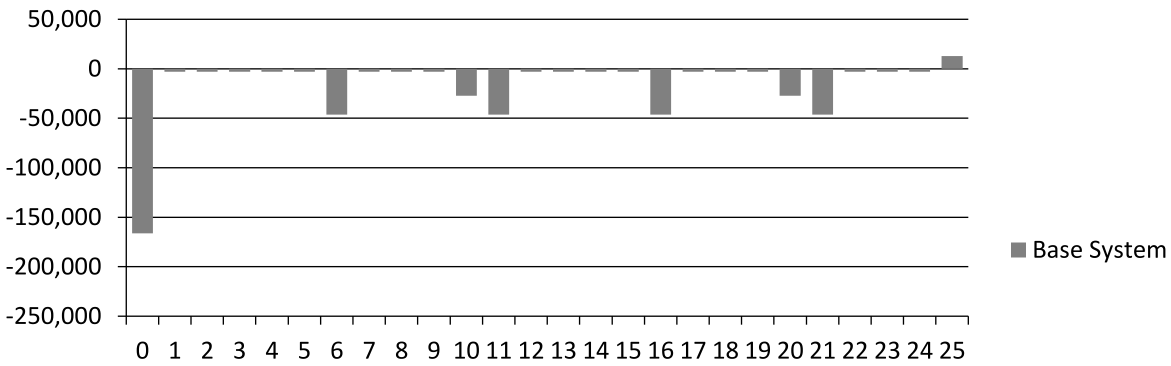
ANNEX 21: Time series charts:



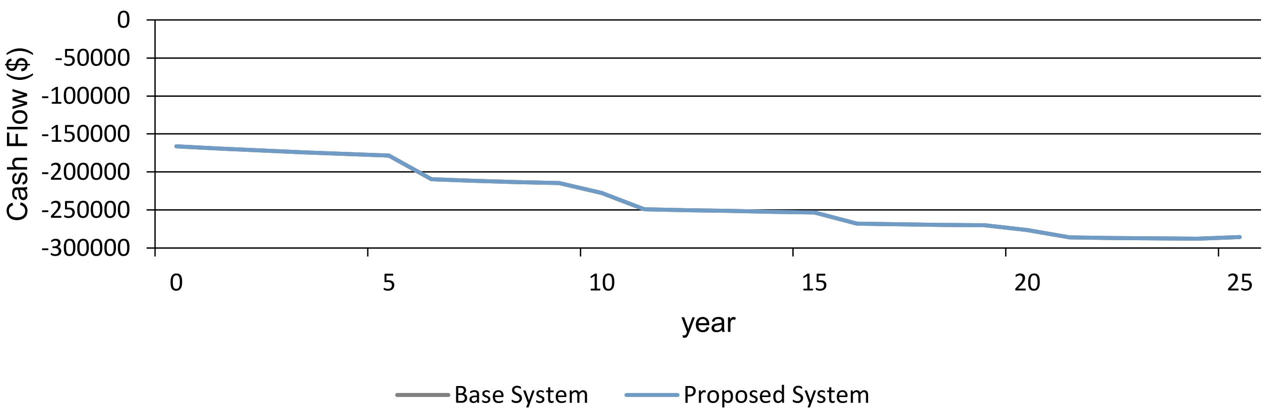
Proposed Annual Nominal Cash Flows



Base System Annual Nominal Cash Flows



Cumulative Discounted Cash Flows



ANNEX 22: GLOBAL WARMING POTENTIAL OF GREENHOUSE GASES

Greenhouse Gases	GWP
CO2	1
Methane	21
nitrous oxide(N2O)	296
Fluorocarbons	120-12000
Chlorofluorocarbons	5700-11900
Sulpherhexafluoride	22200