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# Techno-Economic Feasibility Analysis of 143kW Solar Mini Grid for Rural Electrification in Gokule Village - A Case Study

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**Abstract:** This paper presents a thorough study conducted in Gokule village, located in the Kavreplanchowk district of Nepal, to address the prevalent electricity problem in the Socio-economically backward Magar community. The village is still not connected to NEA's Grid, giving the locals inadequate energy access. With an average solar radiation level of 4.51 kWh/m$^2$/day and an appropriate temperature range, the area has much solar energy potential, reflecting a reasonable and ecologically straightforward answer to this electricity problem. The research utilized questionnaires to assess the electricity demand and socioeconomic condition, and a simulation was done in PV Syst software to evaluate the technical and financial feasibility of applying a solar mini-grid project in the area. The Metronome database was used for the simulation purpose. Findings exposed a pressing electricity need of 567 kWh/day in the community, which remained unmet. The project cost was $178,933.22, with a levelized electricity (LCOE) cost of $0.012 per kWh. The study also has shown a promising return on investment (ROI) of 119.7% and a payback period of 12.9 years. Based on these findings, a suggested standalone mini-grid system with a capacity of 143 kW was proposed to meet the demand efficiently. The research highlights the technical and economic feasibility of the solar mini-grid project, showcasing its potential to enhance the socioeconomic conditions of the community.

**Keywords:** Assessments, Feasibility, Radiation, Mini-Grid, PV Syst

## 1. Introduction

Solar energy is an important renewable and green source for sustainable development. it is environmentally friendly and offers a vast potential for producing electricity [1]. Expanding the national grid power supply across Nepal's varied geographical conditions and rural areas poses challenges due to economic viability and geographical considerations. As a result, only about 88% of the total population in the country is at present connected to the grid, counting both on-grid and off-grid solutions [2].

Nepal, being located in auspicious latitudes, receives adequate solar radiation. With around 300 sunny days in a year, the average solar radiation is between 3.6 to 6.2 kWh/m$^2$/day. On average, it is 4.7 kWh/m$^2$/day, making solar energy an important renewable alternative for electricity generation. It is estimated that Nepal has a capacity of around 2.13 GW of solar energy [3]. The commercial solar power potential for grid connection is estimated to be 2,100 MW [4]. The country aims to provide electricity to 99% of households by 2030, utilizing renewable energy resources like mini/micro hydro, biomass, and solar. The government and AEPC plan to implement mini-grid projects to meet energy needs [5]. Nepal's renewable energy subsidy policy has played a vital role in better livelihoods, reduced dependence on imported fuels, and promoted rural electrification. Solar Power, with its abundant nature and clean, offers a feasible alternative for meeting energy needs in remote areas [6].

Though the total energy purchased in FY 2021/22 from India was 1,543 GWh compared to 2,806 GWh in FY 2020/21, a reduction of 45.01%, public rural areas are still out of reach with the national grid. National electricity access has been rising in the past few years, with 93% access in 2020/21 and a target to achieve 100% access by 2023, but the target has not been achieved yet [4, 7]. The government also has the objective to grow the economy by 8.5% each year and make the country a middle-income nation by 2030, and it is also projected that electricity used per person will also increase [8]. By 2020, 2030, and 2050, 4,100 MW, 11,500 MW, and 31,000 MW of electrical energy will be needed to electrify all the main sectors. The energy sector's GDP share should be 2.4% or higher to meet the aim [4]. Out of the total electricity production in FY 21/22, 2,033megawatts is from hydroelectricity, 49.73 megawatts from solar plants, 80 megawatts, and 53.4MW megawatt from a thermal plant from others which include renewables as well as co-generation [9].

Solar Mini-grid helps in economic revolutions and productive energy use in off-grid communities. It improves agriculture, rural enterprise, health, education income, and welfare. It suits off-grid areas with challenges like distance and difficult topography [10]. Social science research on solar mini-grids has focused on measuring the socioeconomic impacts of such energy supply. In a survey in the Sunderban Islands, public members said that electricity supplied by solar mini-grids had brought them several advantages, and they would be eager to pay a higher tariff if necessary [11]. Village-scale solar mini-grid systems transform electricity into alternating current (AC) power and deliver it to users via a local grid. A greater variety of appliances can be operated with AC. It fulfills domestic, commercial, and community needs. As skilled operators maintain the system to reduce costs, users are free of major responsibilities. Solar mini-grids also cover commercial enterprises and take demographic and topography aspects into account [11].

Commonly, electrification in rural areas is more expensive than in urban areas because of geographical difficulty, low population density, low consumption, low purchasing power, payment default, and many others. Therefore, rural electrification schemes depend on enormous subsidies to make them financially viable. All these factors have caused slower expansion in rural electrification in many developing countries. Off-grid electrification can substitute for many rural areas [3]. Mini-grids are independent units that can be controlled and managed without producing threats to the main grid. They offer more dependable electricity with speedy identification and maintenance of power interruptions [12]. A study exposes that mini-grids can deliver electricity to households at lower costs than old-style diesel generators. Solar mini-grids offer a clean, cost-effective alternative to old-fashioned energy sources in remote areas [13]. This highlights the need for further research and development to extend solar mini-grids to more isolated societies in Nepal. Several studies have discovered the viability of solar mini-grids in rural villages of Nepal, with findings suggesting that solar mini-grids can provide sustainable electricity to off-grid communities. Renewable energy-based off-grid electrification in Nepal has the potential to be an effective source but different barriers and challenges need to be addressed, such as political instability, lack of suitable policy, and inadequate financing mechanisms and regulatory frameworks [14]. The low level of electricity access in rural Nepal played a vital role in negative social and economic impacts, including inadequate access to education and healthcare services, reduced agricultural production, and limited income-generating opportunities [15].

As the literature mentioned above showed, rural electrification is a slow process, and solar mini-grid is the best possible solution. The paper is focused on the technical and financial possibility of a solar mini-grid in Gokule village. In this study, firstly, an off-grid PV system is designed based on surveyed demand, and the PV Syst software is used for simulation. The input given to PVsyst includes both primary and secondary data sources.

## 2. Methodology

The site was selected through various means, and a questionnaire was developed to assess the site's load demand, socioeconomic, and geographical condition. The survey data were analyzed in Excel. The components like the battery, panel, inverter, and controller were designed with the help of the peak load obtained. Finally, the data were simulated in PVsyst software to obtain the required technical and economic results.

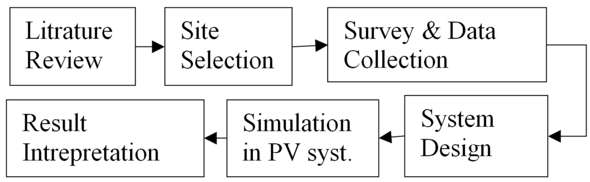


***Figure 1.*** *Methodology used to perform the research.*

### *2.1. Questionnaire Preparation*

Questionnaires were developed based on different published reports. The questionnaires were divided into two parts: one for individual households and the other for focused groups. The first part covers almost all the pieces of information such as occupation status, literacy, current Source of electricity, willingness to support the project, and types of appliances being used, as well as which will be used after they get access to a reliable source of electricity. The second part was focused on information like the number of houses, public institutions in the area, level of need for electricity in the community, land availability for the project, likelihood of natural disaster in the site, and equipment needed for the community.

### *2.2. Socioeconomic Condition*

The study was carried out in Magar Basti of Gokule village. The total number of houses in the community is 43, including a school and a birthing center. There are a total of 219 people in that community. Out of them, members of 5 houses have metalwork, and 4 houses have furniture skills, but they practice the traditional way. 8 youngsters work outside the village, and the rest do miscellaneous professions such as teaching, priests, and businesses. All the other houses depend on agriculture and cattle farming for their livelihood. The community is dependent on a total of 72 acres of land. The average income per family is approximately NPR 13000/month. The total installed PV modules are 1.475kW in the whole community.18 houses have 10W capacity solar panels. People who are engaged in government services and business have 50-155W panels installed.

***Figure 2.*** *Rooftop solar panel installed in typical Nepalese house.*

There is 29kW micro hydropower as a source of electricity, shown in Figure 3. NPR 100 per month is charged as compensation for the electricity consumed. The community entirely depends on firewood for cooking purposes. LPG gas was found only in a house. The electricity is available at night from 6 pm to morning 6 am from micro hydro. Out of 40 responders, 8 have very low satisfaction, 23 have low, 8 were moderately satisfied, 1 was fully satisfied with the current source of electricity, and 58% have shown interest in helping this project. The site survey found that people in the area cannot access electricity during rainy seasons, and micro hydropower is in the vanishing stage as it has an expected efficiency of less than 15%.

Additionally, the standalone systems used in the community have faced issues such as storage inefficiency and a high damage rate. People cannot use electricity for a day during rainy seasons. As a result, most people in the community are unsatisfied with the current electricity system. The people are depending on diesel generator and water mill for grinding crops.

***Figure 3.*** *29kW Microhydro powerplant existing in the village.*

***Figure 4.*** *Water mill used for grinding mainly rice and maize.*

### 2.3. Study Area

The study area is Gokule, located in Mahabharat rural municipality of Nepal, with latitude and longitude of 27.3913$^{\circ}$ N and 85.5607$^{\circ}$E & 1077m from sea level. The community is commonly called Magar Basti. The national grid hasn't reached the community yet. The community is located in a challenging geography and, hence, is underdeveloped.

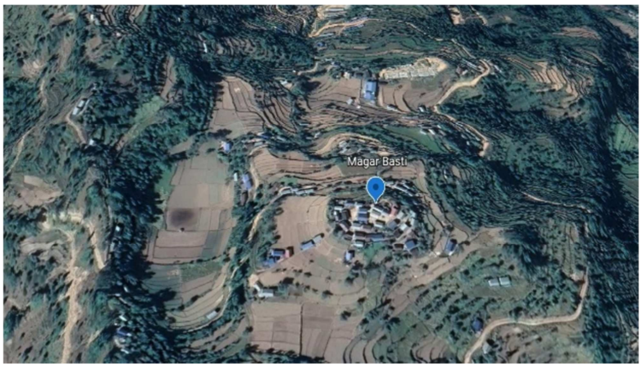


***Figure 5.*** *The setellite view of Magar Basti of Gokule village.*

### 2.4. Simulation Software: PVsyst

The whole thing needed to design a solar system is available from PVsyst. The number of PV modules, battery capacity, inverter size, PV module loss factor, energy computation, hourly profile, P-V curve, maximum power point, and economic analysis are all displayed. PVsyst can also plot the performance ratio, normalized energy profile, loss diagram, etc., according to the selected location. The database of well-known battery and PV module manufacturers is comprehensive on PVsyst. With the help of its extensive geographic database, it can provide accurate information on the solar irradiance and sunshine hours of a particular region of a country [16]. The graphs and diagrams generated by PVsyst were found to be highly informative [16]. A study shows that in comparison of PVsyst with PV Lib & System Advisor Model (SAM), PVsyst was found to be better in overall performance [17]. Sharma et al. also advised using PVsyst because it exhibits only a slight incongruity with real-world data compared to others, whereas the HOMER is mainly used for the hybrid system [18] Source: [19].

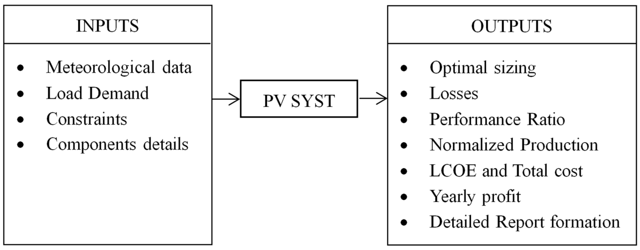


***Figure 6.*** *Inputs given and outputs obtained in PVsyst.*

### *2.5. Load Assessment*

The total load demand per day was 567 kWh per day. The daily electrical demand is calculated by taking the rated electrical Power or standard Power of appliances and the number of usage hours. Total load demand is divided into two types: Current and Future demand. Present demand is the demand that is currently being consumed, while future demand is the demand that will be consumed after the accessibility of reliable electricity. Future demands include the addition of more light bulbs, TV, metalwork machinery, computers in school, and other miscellaneous appliances. The current demand is 93.1015 kWh per day, and the future demand is 473.178 kWh per day. The current energy being used is 28.365625kWh. This analysis does not include the village's current available energy since it comes from unreliable sources. Due to limitations in the PVsyst interface, only up to seven electric appliances could be defined and entered into the system. The load data obtained from the survey were categorized based on comparable hours of use. This categorization helped in understanding the community's energy consumption requirements and patterns. The input given to the PV syst is shown in Table 1.

***Table 1.*** *Surveyed load of Gokule Village.*

| Appliances | Total load (kW) | Total Energy (kWh) |
|---|---|---|
| T.V/PC/Desktops | 4110 | 24087.5 |
| Mobile | 620 | 2420 |
| Light Bulbs | 4005 | 25855 |
| Electric Jugs | 36500 | 71500 |
| Radio | 86 | 567 |
| Furniture Machines | 11000 | 73000 |
| Metal Workshop | 6000 | 50000 |
| Rice cooker/Induction | 10700 | 28800 |
| Electric Heater | 48500 | 217500 |
| Iron | 10000 | 1000 |
| Rice Mills | 10000 | 58000 |
| Emergency Lights | 450 | 1550 |
| Fridge | 500 | 12000 |
| Total | 142471 | 566279.5 |

***Table 2.*** *Categorization of load based on similar hours of appliance use.*

| Appliance Categories | kW | kWh |
|---|---|---|
| TV/PC/Light Bulbs/Radio/Mobiles | 8821 | 52929.5 |
| Electric Jugs / Rice Cookers/induction / Heater/Iron | 105700 | 318800 |
| Furniture/metal workshop/ Rice mills | 27000 | 181000 |
| Emergency Lights | 450 | 1550 |
| Fridge | 500 | 12000 |
| Total | 142471 | 566279.5 |

### *2.6. Daily Load Profile*

The users' estimated appliance usage duration and electricity consumption were used to produce the daily load profile. The load usage from 7 pm to 12 am was minimum with a load of around 2.5 kW, and the load was maximum from 1 pm to 2 pm with a load of 120 kW as most of the furniture machine along with the home appliances will be used at this time.

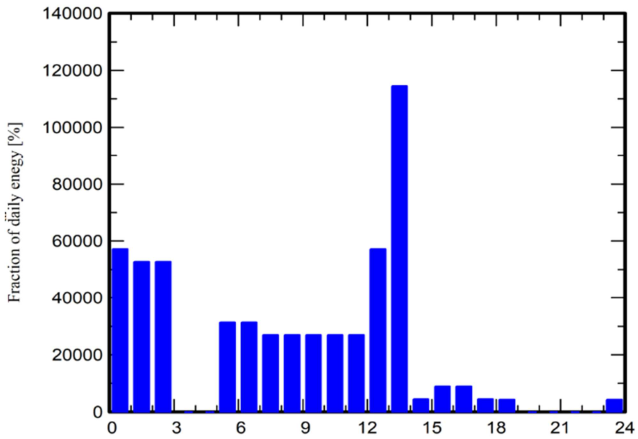


***Figure 7.*** *Daily load profile of the village.*

### *2.7. Meteorological Data*

The table shows this location's average monthly solar radiation, temperature, and wind velocity, which was taken from the metronome database. The site possesses good solar potential with an average daily radiation value of 4.51 kWh/m$^2$/day. The radiation was highest in May at 5.42 kWh/m$^2$/day, while the lowest was received in January at 3.74 kWh/m$^2$/day. With the increase in temperature, the module's efficiency decreases—voltage or efficiency increases when the temperature is between 25°C and 35°C. Voltage remains stable when the temperature is increased, and beyond 44°C, the voltage begins to drop [20]. The site has an average temperature of 20.2°C, so it is the optimum temperature for the PV system to work efficiently. The average wind velocity is 1.5m/s at the site.

***Table 3.*** *Metrological data of the site obtained from pvsyst.*

| Month | Global Horizontal Irradiation (kWh/m$^2$/day) | Temperature (°C) | Wind Velocity (m/s) |
|---|---|---|---|
| January | 3.74 | 9.2 | 1.09 |
| February | 4.18 | 14.1 | 1.50 |
| March | 5.23 | 20.0 | 1.80 |
| April | 4.84 | 24.8 | 1.89 |
| May | 5.42 | 26.4 | 1.79 |
| June | 4.74 | 26.2 | 1.69 |
| July | 4.36 | 24.7 | 1.41 |
| August | 4.91 | 24.6 | 1.41 |
| September | 4.29 | 23.7 | 1.40 |
| October | 4.50 | 21.5 | 1.40 |
| November | 4.09 | 16.3 | 1.11 |
| December | 3.80 | 11.0 | 1.00 |
| Average | 4.51 | 20.2 | 1.5 |

Figure 3 shows the sun path diagram of the site. A Sun path diagram is used to locate the sun's position throughout the year. A sun-path diagram represents the sun's path on a horizontal plane. These diagrams are used for identifying shading phenomena [21]. The Sun path helps to find the proper orientation of panels for maximum output power.

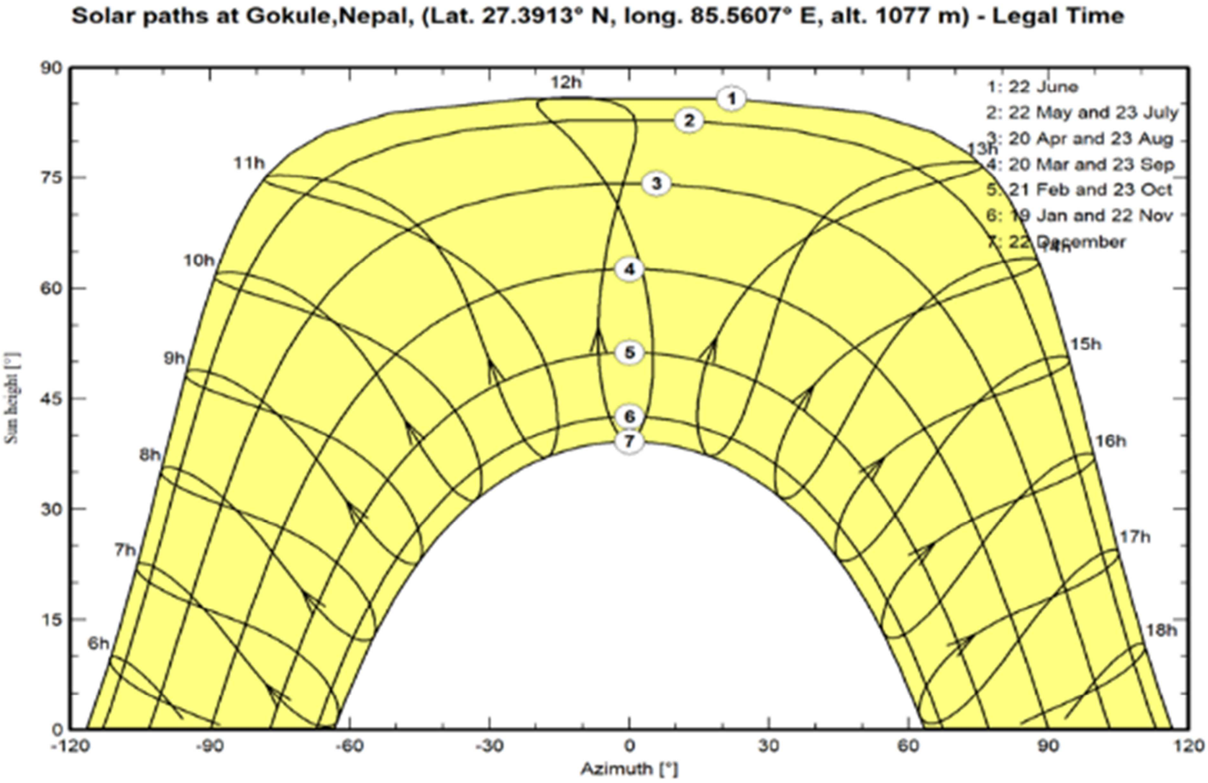


***Figure 8.*** *Sunpath diagram of the study area.*

### *2.8. Technical Component Sizing*

A standalone system is a type of system that is not connected to the national grid and provides electricity directly to homes and businesses [22]. The main components of the grid are PV panels, inverter, controller, battery, and fuse device. The system is controlled by a SCADA system in the control room.

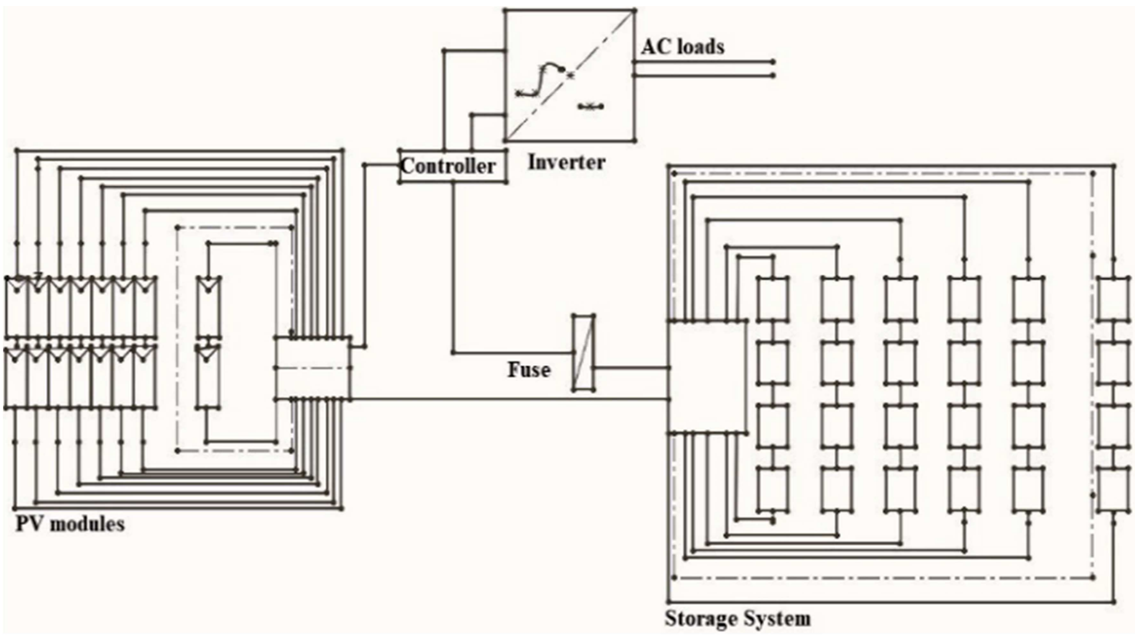


***Figure 9.*** *General cad sketch of the proposed system.*

### *2.8.1. PV Module*

Solar cells are the building block of PV systems. Limited voltage and current values are provided by these cells. These cells are fragile and non-isolated. Solar cells are assembled to form a PV module [23]. The selection of a PV array is an essential parameter to design a system that could meet the total load demand. It is chosen so that the total number of PV panels used in system design is minimal and appropriate. The efficiency of a PV module depends on various factors such as solar irradiance, temperature, voltage, current, and configuration [18]. Figure 5 shows the parameters of the PV module selected.

**PV Array Characteristics**

| | | | |
|---|---|---|---|
| **PV module** | | **Battery** | |
| Manufacturer | Generic | Manufacturer | Exide Classic |
| Model | Mono 300 Wp 60 cells | Model | OPzS Solar 210 |
| (Original PVsyst database) | | Technology | Lead-acid, vented, tubular |
| Unit Nom. Power | 300 Wp | Nb. of units | 183 in parallel x 4 in series |
| Number of PV modules | 468 units | Discharging min. SOC | 20.0 % |
| Nominal (STC) | 140 kWp | Stored energy | 1089.2 kWh |
| Modules | 234 Strings x 2 In series | **Battery Pack Characteristics** | |
| **At operating cond. (50°C)** | | Voltage | 48 V |
| Pmpp | 126 kWp | Nominal Capacity | 28365 Ah (C10) |
| U mpp | 57 V | Temperature | Fixed 20 °C |
| I mpp | 2222 A | | |
| **Controller** | | **Battery Management control** | |
| Universal controller | | Threshold commands as | SOC calculation |
| Technology | MPPT converter | Charging | SOC = 0.92 / 0.75 |
| Temp coeff. | -5.0 mV/°C/Elem. | approx. | 53.8 / 49.5 V |
| **Converter** | | Discharging | SOC = 0.20 / 0.45 |
| Maxi and EURO efficiencies | 97.0 / 95.0 % | approx. | 46.5 / 48.3 V |
| **Total PV power** | | | |
| Nominal (STC) | 140 kWp | | |
| Total | 468 modules | | |
| Module area | 761 m² | | |
| Cell area | 665 m² | | |

***Figure 10.*** *PV array characterstics of the system (Adapted from PV syst).*

$$\text{Theoretical Size of PV array (Watt-Peak)} = \frac{\text{Daily Demand (Wh)}}{\text{Peakshune Shine hours} \times \text{Total Loss Factor}} \text{ [5]}$$

$$= \frac{566279.5}{5.5 \times 0.7} = 147.20kW$$

Whereas the peak load obtained from the survey was 142.471 kW. The peak load obtained from the survey is more reliable. The peak load is considered as 143kW. The deviation from the theoretical is only 4.729 kW in this case. The number of panels required was adjusted on the PVsyst software to get the desired result. The suggested Power by the software was 140kWp.

$$\textit{Theoretical Number of panels} = \frac{\text{Size of PV array (Watt)}}{\text{Power Of single panel(Watt)}} = \frac{143000}{300} = 476$$

$$\textit{Number of panels required in series (Ns)} = \frac{\text{System voltage(48)}}{\text{Voltage of single panel at Pmax(31.50)}} \text{ [24]} = 2 \textit{ Approx.}$$

$$\textit{Number of Panels in Parallel } (N_p) = \frac{\text{Total panels}}{\text{Number in series (Ns)}} = 238 \text{ [24]}$$

### *2.8.2. Battery*

Table 4 shows the battery used its parameters. Batteries are used to store DC electrical energy. The output current is generally converted into AC with the help of an inverter. The AC is then used to power loads when sunlight is absent [23]. The system uses series and parallel configurations to adjust the required voltage. The formula for battery sizing is given as

$$\text{Battery sizing (Ah)} = \frac{\text{Days of autonomy} \times \text{Energy to be Stored(Wh)}}{\text{Battery efficiency of discharge(DOD)} \times \text{Voltage(V)}} \text{ [5]/}$$

$$= \frac{2 \times 566279.5}{0.9 \times 0.8 \times 48} = 32770.80 \text{ Ah}$$

(The suggested value was 27583Ah by PVsyst). Using the suggested value

$$\text{Total number of batteries in parallel (Np)} = \frac{Total\ Battery\ Size}{Capacity\ of\ a\ battery} = 178\ [25]$$

$$\text{Batteries in Series (Ns)} = \frac{System\ voltage}{Voltage\ of\ single\ battery} = 4\ [25]$$

Total number of batteries= Np×Ns=712 [24].

***Table 4.*** *Batteries parameters adapted from PVsyst.*

| Parameters | Values |
|---|---|
| Brand | Exie Classic, Pb open Tub, OPzS Solar 210 |
| Type | Lead-Acid, Vented, Tubular |
| Nominal Voltage (Vnom) | 12V |
| Nominal Capacity (C10, Cnom) | 155Ah |
| Internal Resistance | 16mΩ |
| Columbic efficiency (Without gassing) | 97% |
| Battery Pack Voltage | 48V |
| Stored energy at 80% DOD | 1059 kWh |
| Total stored energy during the battery life | 1167MWh |

### *2.8.3. Solar Charge Controller*

The charge controller, or the photovoltaic controller, ensures that the batteries are not over-charged or over-discharged. This is an important component as over-charging a battery can lead to its destruction, and over-discharging a battery reduces its lifetime drastically. The controller's other function is to prevent the reverse flow of current from the battery to the system. There are two types of charge controllers. The first type is the Pulse width modulation (PWM) controller, and the other is the Maximum Power Point Tracking (MPPT) controller. In this design, the second type is used. MPPT has better efficiency than PWM. It helps to charge Power at any given time [23]. Table 5 shows different parameters of the chosen controller. The solar charge controller can be rated in watts and also in ampere [5].

$$\text{Size of solar Charge Controller (Ampere)} = \frac{\text{PV array capacity (Watt−peak)}}{\text{DC system voltage (volt)}} = 142471/48 = 2968.14\ \text{A}\ [5]$$

***Table 5.*** *Different parameters of solar charge controller used.*

| Manufacturer | Generic |
|---|---|
| Model | Universal Controller with MPPT converter |
| Maximum Charging Current according to STC | 3271.2A |
| Maximum Discharging Current according to load | 2384.1A |
| Maximum Backup current | 2384.1A |
| Converter Nominal Power | 114240W |
| Reference Temperature in Celsius. | 20 |
| Nominal O/P Voltage | 48V |
| Nominal Output Current | 2380A |
| Maximum O/P | 124kW |
| System Voltage | 48V |
| Maximum efficiency | 97% |

### *2.8.4. Inverter*

There is no database of inverters for off-grid systems in the PVsyst software. There is a need to estimate the required DC electricity for the proposed load, considering the stand-by losses and inverter efficiency. Battery Inverter efficiency ranges between 0.85 to 0.95, and the Power factor can be taken as 0.8 [5]. Each cluster should have its own battery string fuse box in a multi-cluster system. For example, if there is a storage requirement of 2000Ah and two inverter clusters, 1000Ah will be connected to one cluster, and 1000Ah will be connected to another. Battery strings must be matched in terms of capacity, battery type, cable cross-section, connection type, cable length, and battery fuse box [5]. The equation used for inverter sizing is

$$\text{Inverter Size (Volt-Ampere)} = \frac{\text{System Peak Load (Watt)}}{\text{Battery Inverter efficiency} \times \text{Power factor}}\ [5]$$

$$= \frac{142471}{0.85 \times 0.8} = 209.516\ \text{kVA}$$

### *2.8.5. Accessories*

General Component Sizing for accurate financial estimations.

***Table 6.*** *Sizing of accessories for accurate financial detail calculation.*

| Component | Equations used | Values |
|---|---|---|
| Fuse | Battery fuse sizing=$\frac{\text{Inverter power Rating}}{\text{Inverter efficiency} * \text{nominal battery voltage}}$ [5] | 5.13 kA |
| Cable Size between the Battery and Inverter | Area $(A) = \frac{\text{p x L x I x 2}}{\text{Vd}}$ [26]<br>Where,<br>p=resistivity of wire [For copper p = 1.724 x 10-8 Ω ·m] | $A=1.11mm^2$<br>(d=1.19mm)<br>L=8m |
| Cable Size between Charge Controller and Battery | L = length of wire (in m)<br>A = cross-sectional area of cable.<br>I =the rated current of the regulator (A) | $0.47mm^2$<br>(d=0.77mm)<br>L=5m |
| between PV Array and Charge Controller | $V_d$ =Voltage drops of a module (4% minimum)<br>i.e. $V_d = \frac{4}{100} \times 27 = 1.08$ | $1.15mm^2$<br>(d=1.21mm)<br>L=10m |
| between the Inverter and Load | Area $(A) = \frac{\text{p x L x Iphase x 2}}{\text{Vd}}$ [26] | $30.72mm^2$<br>(d=6.25mm)<br>L=1500m |
| Poles Estimated | - | 12 |

# 3. Result and Discussion

The following simulated results were obtained after the load demands and component specifications were inputted into the PVsyst software.

## *3.1. Technical Analysis*

### *3.1.1. Performance Ratio*

The performance ratio represents the fraction of energy available after deducting energy losses [27]. It gives information about the impact of overall system losses on the rated output. The losses include PV module, tilt angle, dust, shade, and module temperature losses [28]. Figure 6 Shows there is fluctuation in the system's performance throughout the month. The average yearly PR ratio is 72.7% for the PV plant. The highest PR found in January is about 78% due to low module temperature.

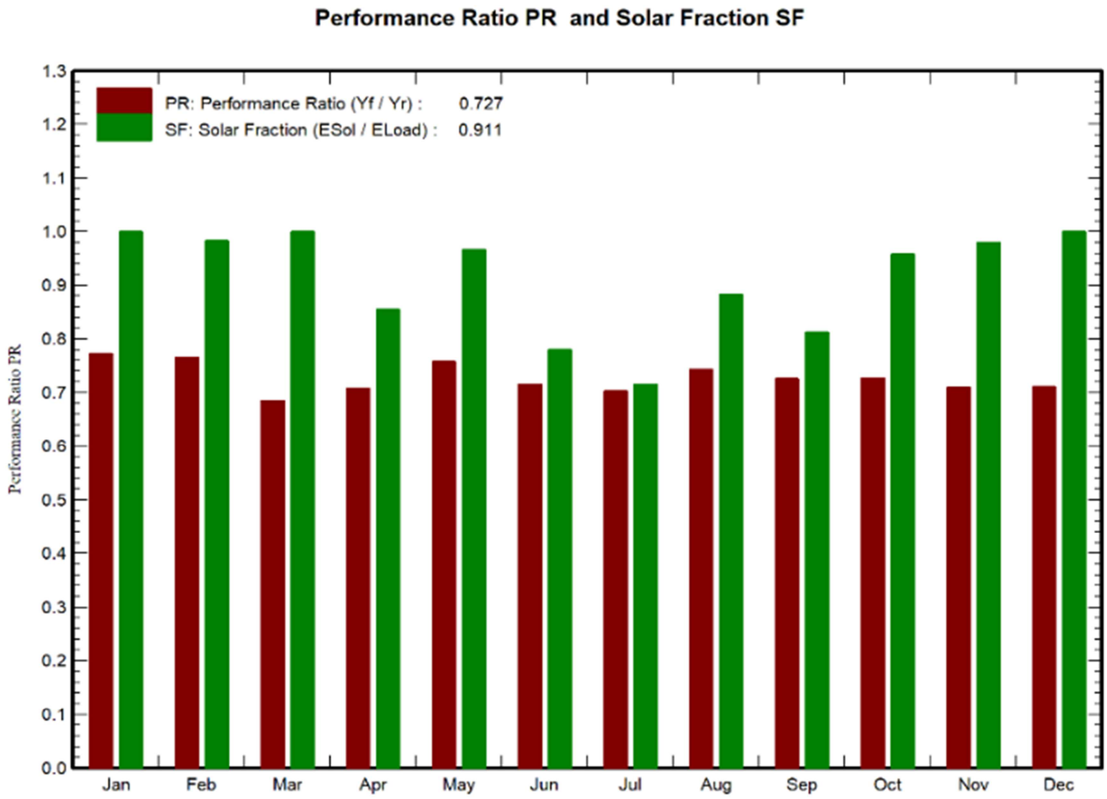


***Figure 11.*** *Graph showing performance monthly performence ratio.*

### *3.1.2. Normalised Production*

The actual energy output of the system is affected by external factors. These external factors include weather conditions, temperature changes, and shading effects. The displayed data provides information on monthly energy yields and corresponding losses per kilowatt hour (kWh) [29]. The highest generated energy production is about 4 kWh/kWp/day. Conversely, the lowest production would happen in July, with a value of 2.84 kWh/kWp/day.

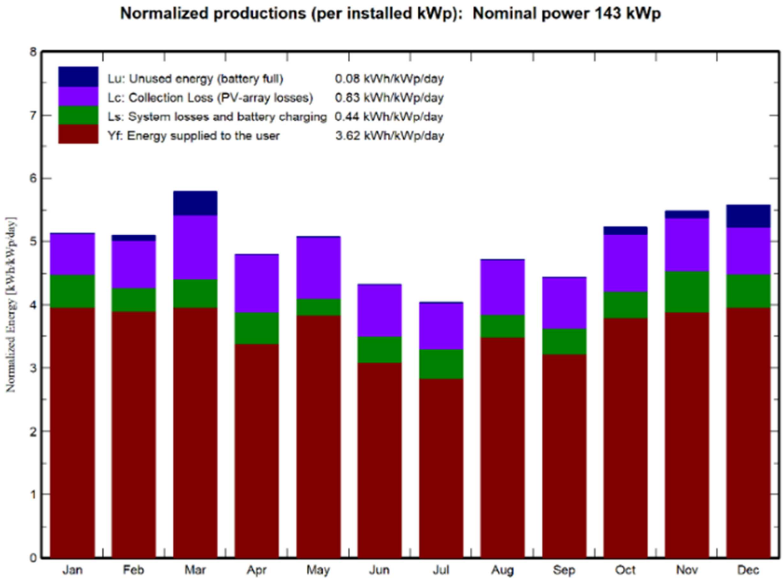


***Figure 12.*** *Normalized energy production.*

### *3.1.3. Arrow Loss Diagram*

The arrow loss diagram is used to examine different losses that will occur during the installation of a PV plant [8]. The Global irradiance on the horizontal plane is 1649 kWh/m$^2$. The effective irradiation on the collector is 1724kWh/m$^2$, while the Nominal array energy at STC efficiency is 246317 kWh, and the effective array output energy is 211644kWh. These various kinds of losses are 6.32% due to temperature, 2.10% due to mismatch, 2.45% loss due to ohmic wiring, and 2.03% due to unused energy. Available energy at the converter output and battery storage is 202325kWh; the loss is 4.42% during this process. The energy finally injected to the user annually is 188501kWh, and the 8.86% of energy which is missing is 18331.9kWh. The detailed losses are shown in figure.

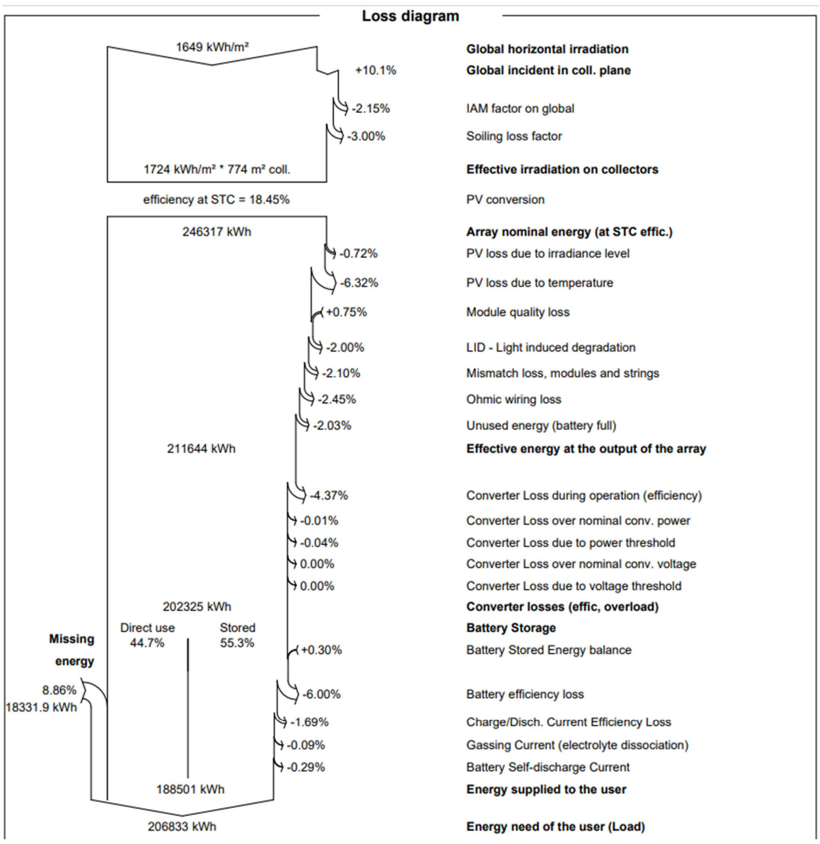


***Figure 13.*** *Arrow loss diagram containing detail losses.*

### *3.2. Economic Analysis*

Economic analysis also includes indirect costs and benefits caused by the project but incurred or enjoyed; the economic analysis of the Photovoltaic project is done to assess its profitability over its lifetime. It includes indirect costs and benefits associated [30]. A comprehensive evaluation of component costs is achieved by closely considering recent market trends. The total installation cost for the project has been accurately estimated at $178933.22, encompassing all essential equipment and materials. An annual operating cost of $ 2,361.04 has been accounted for, covering maintenance, monitoring, and other ongoing requirements. The projected lifetime of the PV plant spans 25 years, during which significant output is estimated. With a payback period of 12.9 years, the initial investment is projected to be recovered within this timeframe, allowing the project to generate profits for the remaining 12.1 years of operation. This substantial period of profitability showcases the long-term financial sustainability of the PV plant. A critical aspect of financial analysis involves determining the levelized cost of electricity (LCOE), which represents the average cost per unit of electricity generated over the project's entire lifespan. Remarkably, the LCOE for this project is calculated to be $ 0.012 per kilowatt-hour (kWh). Moreover, the Return on Investment (ROI) serves as the key metric for calculating the profitability of a project. In this case, the ROI stands at an impressive 119.7%, highlighting the substantial returns expected from the investment made in the PV plant. This compelling figure underscores the financial appeal and potential long-term gains associated with the project.

According to the RE subsidy policy of the Government of Nepal 2073BS, the region where the national grid hasn't been reached yet is given 60% of the project's total cost for installing a solar mini grid [6]. The Power Purchase Agreement (PPA) was signed by the Nepal Electricity Authority (NEA) and a solar power project at a fixed flat fee of $0.056 per unit [24]. By comparing the LCOE to the agreed-upon Power Purchase Agreement (PPA) price set by the Nepal Electricity Authority (NEA) at $0.056 per unit [31], it becomes evident that the project offers an economically viable and cost-effective solution. This favorable LCOE ensures competitiveness in pricing and positions the PV plant as an attractive investment opportunity. By conducting a meticulous financial analysis that incorporates installation costs, operational expenses, LCOE, ROI, and cumulative profit, it becomes evident that the implementation of the PV plant is both economically viable and financially rewarding. These findings provide invaluable insights to stakeholders, policymakers, and investors, showcasing the positive impact and sustainable profitability achieved through renewable energy solutions, particularly in regions where national grid access is limited.

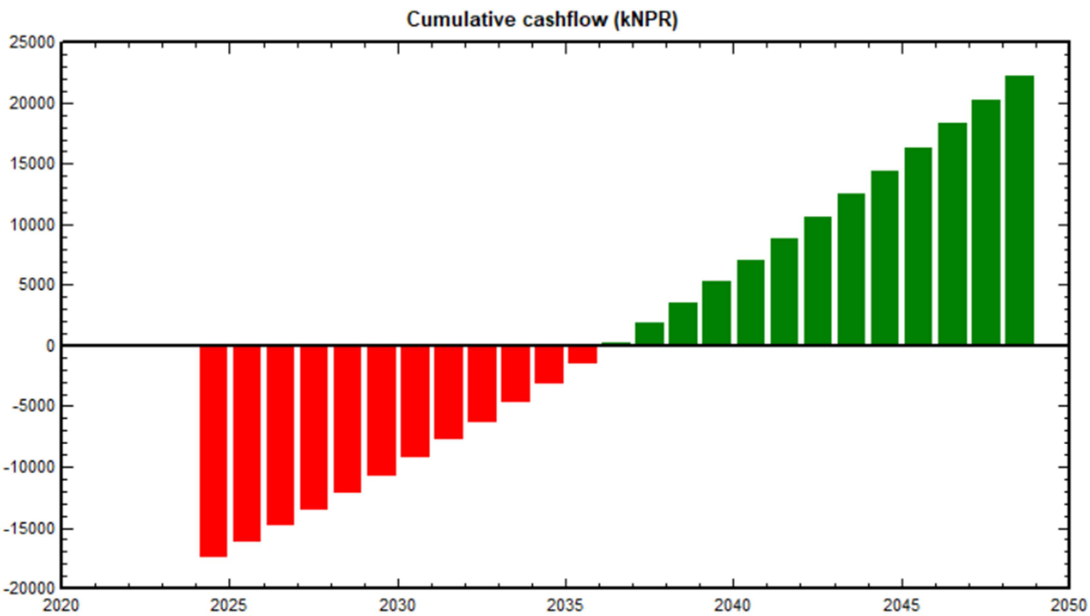


***Figure 14.*** *Cumulative cash flow within total projectlife time.*

## 4. Conclusion

The research study conducted a technical and economic feasibility analysis of a solar mini-grid in the Magar community of GOKULE village to address the ongoing electricity issue. The community's daily electricity demand was estimated to be approximately 567 kWh/day, highlighting the significant gap between their needs and the available supply. The absence of national grid coverage in the area compounded the challenges faced by the community in accessing electricity. However, the study discovered a potential solution by leveraging the area's favorable conditions for solar power generation. With an optimal radiation level of 4.51 kWh/m$^2$/day, installing solar photovoltaic (PV) systems emerged as a viable option. The research further examined the project's financial aspects and estimated the total cost to be $178,933.22, with an impressive levelized cost of electricity (LCOE) of $0.012 per kWh. The study also highlighted the strong economic viability of the project, with a promising return on investment (ROI) of 119.7% over its lifetime and a payback period of 12.9 years, making the project cost-effective.

Area being remote and underdeveloped, characterized by inadequate infrastructure, the research recommended a standalone mini-grid system as the most suitable solution. This standalone system, with a proposed capacity of 143 kW, could effectively meet the community's electricity demand with the capacity to provide 188501kWh energy annually to the user. The PV system components were completely optimized in the PV Syst based on local weather conditions, irradiation, temperature, and wind velocity. Notably, the availability of electricity would unlock new opportunities for community members, enabling them to utilize machinery effectively and engage in productive activities. By addressing the electricity deficit, the project has the potential to significantly improve the socioeconomic conditions of the community, offering new prospects for growth and development. The research would help in the village's electrification and also help prevent the emission of pollutants [32]. The work can be conducted.

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