Examining The Techno-Economic Viability of Institutional Energy Generation Through Rooftop Solar Photovoltaic - A Case Study

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Abstract

Use of institutional rooftop solar photovoltaics (PV) is considered as a potential alternative to address energy deficit in low middle-income countries. This study aims to conduct techno-economic feasibility assessment of rooftop solar PV taking a sample case of a school in Kathmandu valley. Comprehensive questionnaire survey and field measurement are done to determine load demand and energy usage habits of the institution. PVSyst is used to develop an optimized rooftop solar PV system with a total capacity of 72.6 kW_P. Technical feasibility study is done through performance ratio and loss diagrams, and economic feasibility study is done through determination of payback period. Performance ratio of 85% was achieved, and design losses are within acceptable range. The highest losses are seen in soiling and temperature derating which was below 4%. The designed system has an annual yield of 121.56 MWh, payback period of 6.7 years and return on investment of 211.4% after the payback period. For validation, the simulated results are compared with data logged in a comparable institution with a net metering system. The simulation for this institution was carried out using an identical regime. The payback period of 11.5 years was empirically calculated through the logged generation/usage data whereas the simulation result showed a payback period of 11.8 years, which is in acceptable range. This study shows that institutional rooftop solar PV is both technically and economically viable in Nepal.

Keywords: *Rooftop Solar Photovoltaic, Techno-Economic Feasibility, Institutional Energy Generation, PVSyst*

1. INTRODUCTION

The global installation of Renewable Energy (RE) sources shows an increasing trend, reaching 3372 GW as of 2022 (International Renewable Energy Agency, 2023) comprising of 1256 GW from hydropower, 1053 GW from solar energy, 899 GW from wind energy, 149 GW from bioenergy, 15 GW from geothermal energy and 0.524 GW from marine energy sources. Solar energy has seen an upsurge of 22% (192 GW) followed by wind energy at 9% (75 GW) and hydropower at 2% (21 GW) compared to previous year. With an ambition to decrease fossil fuel consumption, Sustainable Development Goals (SDGs) have set numerous goals to achieve less emission. Among them SDG 7 related to climate and SDG 13 related to clean energy have committed to achieve 50% share of total energy consumption from clean and renewable energy (*Ensuring Access to Affordable, Reliable, Sustainable And Modern Energy For All Environmental Dimension of SDG 7*, n.d.).

In-line with the global target, Nepal has set its own target for net zero emission and 15% share of renewable energy in the total energy consumption through its Nationally Determined Contributions (NDCs). Nepal's energy consumption is primarily dominated by biomass (68%) and fossil fuel (27%), followed by small portion of energy from hydropower and renewables (3.5%) (Water and Energy Commission Secretariat, 2022). In 2022, the total installed capacity of electricity generation projects reached 2.6 GW (*Reports and Publications - Water and Energy Commission Secretariat*, n.d.). Despite having tremendous potential, with an estimated economically feasible capacity of 42000 MW, Nepal has only tapped a fraction of its potential (NEA, 2022). Nevertheless, the country has started to export electricity to India and has been considering the export to Bangladesh during wet season (P. Dhakal et al., n.d.). With majority of hydropower being Run of River (RoR) type, Nepal has been facing energy deficit during dry seasons and has been importing electricity. The deficit and import can be significantly reduced by utilization of other forms of clean and abundant energy such as solar energy.

Nepal lies in the Sun Belt region with more than 300 days of sunshine per year. The country's solar potential is 50,000 TWh/year, which is 100 times larger than its hydro resource and 7,000 times larger than its current electricity consumption [5]. Solar energy, which is not a major source of electrification currently, is easily accessible and is a clean source of energy with less associated greenhouse gas emission and lifetime cost. It can be used for electrification of large institutions and facilities in the form of Photovoltaic (PV) systems. At present, such institutions have been using both on-grid and off-grid solar PV systems. The payback period of such solar PV lies in the range of 6-10 years, and increases the electricity cost savings by a significant amount annually (Solar Payback Period | GreenLancer, n.d.). Roof mounted solar PV systems are highly preferred for such cases due to limited land availability, shadings and rental restrictions. This study aims to conduct techno-economic feasibility study of rooftop solar PV for institution of Nepal with a case study.

2. LITERATURE REVIEW

2.1 Global Context

Globally, there are numerous regions in which rooftop solar PV systems have been installed as major sources of electrification. Various studies have been carried out to evaluate technical and economic viability of the systems. A study conducted for a battery-based hybrid renewable energy system comprising of PV, wind, biogas, syngas and hydrokinetic energy used Analytical Hierarchy Process (AHP) to evaluate the performance of the system in which Levelized Cost of Electricity (LCOE) was \$0.095/kWh. The system required smaller battery storage and space with high prospect of employment and minimum greenhouse gas emissions (Baruah et al., 2021). In a residential building of India with 6 floors and 192 rooms, an off-grid rooftop solar PV has a payback period of less than 10 years with CO_2 reduced by 4490 tonnes (Sharma et al., 2016). For a healthcare institution in the Southeast of England, it was observed that a grid-connected hybrid system can reduce the cost of energy and increase saving compared to a purely grid connected PV system (Kahwash et al., 2021). In a medium scale workshop in Iran, an off-grid hybrid system comprising of wind and PV, wind energy dominated the percentage of energy produced due to the windy climate (Hosseinalizadeh et al., 2016).

In Islamic University of Technology in Bangladesh, a case was carried out for a cost-effective and self-reliant rooftop PV model for a building in which monofacial panels were used. The result was that the savings rose up to \$5810.5 per year and the LCOE was \$0.071/kWh (Mehadi et al., 2021). In a condition monitoring based research on a grid-tied rooftop PV system in a library in Egypt, it was observed that the climate and radiation level of a space greatly affect the performance of a PV system (Besheer et al., 2019). In another research in College of Engineering, Afe Babalola University Ado-Ekiti, Nigeria, it was observed that a grid and solar PV system could adequately meet the load demand and reduce the cost of electricity by 45% and CO_2 emissions by 32.09% (Gbadamosi et al., 2022). Economic feasibility was carried out for a grid-tied PV system in University of New Haven (UNH) Connecticut, which gave a payback period of 10 years at an average and reduced the operating expenses by 8% (Karanam, 2020). This study also recommended the institutions with similar climate and topological regions to use similar systems for electrification.

2.2 Rooftop Solar PV in the Context of Nepal

Nepal has also installed solar PV system in different institutions and public buildings. Table 1 gives a list of such PV systems with details about installation sites, type and remarks. While these systems have demonstrated benefits such as cost savings, reduced carbon emissions, and avoided diesel generator use, they also reveal common challenges. For instance, (Mandal, 2020) found that temperature and irradiance variability significantly impacted PV performance in Kathmandu. The Dasharath Rangashala installation (Kaji Shakya & Nath Shrestha, 2015) showed that even well-designed systems required robust operations and maintenance (O&M) frameworks to sustain performance gains. High upfront cost and unavailability of free roof space were other challenges faced, especially in residential buildings. Although net metering is beneficial, its adoption has been uneven due to limited awareness and policy inconsistencies J. N. Shrestha and D. B. Raut (2020).

Table 1: *Solar PV installation site*

Ref. No	Institution	Location	Type	Remarks
(Mandal, 2020)	Singha Durbar	Kathmandu	Standalone	Effects of irradiance cell, temperature, and wind speed on solar PV power performance
(Thapa et al., 2020)	Chisapani Hariharpurgadhi	Sindhuli	Wind-solar hybrid system	Provided an alternative electrification source, reduced transmission line cost and component size
(Man Bajracharya & Maharjan, n.d.)	Nepal Telecom	Kathmandu	64.3 kW on-grid system	Reduced payback period to 5.2 years, had high LCOE of 17.97/kWh at a discount rate of 12%
(R. Dhakal et al., 2021)	Madan Bhandari Engineering College	Morang	On-grid rooftop PV	Reduced carbon emission significantly, was cost effective
(Kaji Shakya & Nath Shrestha, 2015)	Dasharath Rangashala	Kathmandu	On-grid PV	Reduced Operation & Maintenance (O&M) cost of Diesel Generator and carbon emission had LCOE of NRs. 12.49 per kWh
A. Aryal & N. Bhattarai (2018)	Tribhuvan University Teaching Hospital (TUTH)	Kathmandu	On-grid rooftop PV	Generates 35MWh out of 199 MWh annually off-grid with Specific Yield 1728 kWh/kWp
M. Prajapat, B. RajPahar, & S. R. Shakya (2019)	Residential colony	Kathmandu	On-grid rooftop PV	The net saving of 516$ for without battery and for system with battery is 526$ annually, considering net metering
J. N. Shrestha and D. B. Raut (2020)	Residential buildings	Kathmandu, Pokhara and Biratnagar	On-grid solar PV	Access technical, financial, and market potential in all three cities.

2.3 Techno-Economic Feasibility Studies

A techno-economic feasibility of rooftop solar PV helps to determine whether it is practical and financially viable for installation in a particular location (Sankoh et al., 2022). Solar resource evaluation analyzes solar energy availability using solar radiation maps, and helps to determine size and output of the PV system. Site characteristics such as space, orientation and shading help to determine anticipated outcome from the installed system.

An economic feasibility study helps to determine whether the system is financially viable and is likely to generate a positive return on investment. The study should consider the cost of purchasing and installing the PV system, including the cost of PV panels, inverters, mounting systems, and any other equipment or materials needed. It should also incur costs of O&M including the cost of repairs and replacements, insurance, and any other expenses. The projected energy production of the PV system and its value based on local electricity prices are significant aspects. Government incentives or subsidies, like tax credits or grants, available for solar PV projects, need to be factored in. Understanding the financing options available, such as loans, leases, or power purchase agreements, is crucial. Moreover, assessing the payback period, which indicates the time required for the PV system to cover its costs through savings on electricity expenses, is essential (Gürtürk, 2019).

A technical feasibility study for a PV system is an evaluation of the technical requirements and limitations of the PV system as well as the suitability of the proposed site for the installation of the PV system. It helps to ensure that the PV system is technically viable and that it meets the energy needs of the user (Jamil et al., 2012). There are few factors that should be considered when conducting a technical feasibility study for a PV project including the amount of solar energy available at the proposed site as well as the intensity and duration of the solar radiation, which impact the size and output of the PV system. This can be evaluated using solar resource data, such as solar radiation maps. Additionally, understanding the physical attributes of the site, such as its size, orientation and shading is crucial in determining the system's feasibility. Determining the appropriate system size based on energy needs and available space, evaluating the system's configuration including panel types and inverters, and assessing the existing electrical infrastructure at the site are also vital aspects of a technical feasibility study. Other technical considerations may include the availability of skilled labor for the installation of the PV system, the climate and weather conditions at the site, and any other environmental or regulatory considerations that may impact the PV project. By conducting a technical feasibility study, it is possible to assess the technical requirements and limitations of a PV system and to determine whether the system is likely to be technically viable and meet the energy needs of the user. This can help to ensure that the PV project is successful and that it is likely to achieve its intended goal (Fthenakis et al., 2009).

3 METHODOLOGY

The study methodology comprised of site selection, in-person and yardstick survey, energy consumption determination, on-field measurement, market survey and techno-economic feasibility study in PVSyst 7.2. The simulation results were validated using a real case.

3.1 Site Selection

The criteria for selecting the proposed site were established based on a comprehensive literature review. Factors such as accessibility, user interaction, energy consumption dynamics, and convenience were considered while undertaking the site for study. The chosen site needed to provide access to its load consumption pattern through the submission of monthly electricity bills. Additionally, the site was required to permit the surveying group free access for in-person surveys and group discussions. Coordination from the institute's members or workers during in-person surveys and on-field measurements was deemed essential. Another crucial factor in site selection was the energy consumption dynamics and the high number of users. The energy consumption in the selected site should either be high (to get better outcome from the installed solar PV) or exhibit a similar pattern to other commercial institutions. This approach would enable the study's outcomes and methods to be applied to a broader range of locations. Further parameters for consideration included available rooftop area and the behavior of workers. After a thorough evaluation based on these criteria, Cosmic International Academy located at Balkumari, Kathmandu emerged as the selected site for inspection and the subsequent simulation process. Additional details of the school are provided in Table 2.

Table 2: *Site Characteristics*

Site name	Cosmic International Academy
Location	Balkumari, Lalitpur, Nepal
Latitude (°)	27.675156
Longitude (°)	85.342873
Altitude	1296 m

3.2 In-Person and Yardstick Survey

The survey was performed to provide information for the system’s design. It included a thorough investigation of technological, socioeconomic and psychological aspects. The first step was yardstick survey which helped to determine the site, location, area available and available space for installation. The first survey data established the basis for system design. In person survey which was done through a set of questionnaires. The questionnaire was formed to fulfill the purpose of assessing knowledge and awareness of renewable energy, particularly solar PV, identifying institutional preferences and their willingness to adopt solar energy, evaluate its techno-economic feasibility and identify social challenges and barriers. The final section of the survey, i.e, load estimation, was focused on different types of loads, their usage and energy expenses. This process also included the collection and analysis of the institution’s electricity bill to determine their actual energy consumption and cost.

3.3 Energy Consumption Determination

The determination of the total solar energy required for the electrification of the selected site was done based on electricity bills collected from the school's authorities. Electricity bills serve as the most reliable method for understanding the precise load consumption of any building. The data was collected over 6 months and then the trends were captured to estimate the remaining months by capturing past trends.

a. On-Field Measurement

On-field measurements were conducted to evaluate the available rooftop area of the selected site. There were four buildings, one of which was still under construction. For system simulation, the rooftop area of the building under-construction was excluded from consideration. The total rooftop area of the three existing buildings amounted to approximately 380 square meters. The system design was then modified to fit this available area. To address potential losses, accommodate the placement of bars, reflect the time value of money, market risks and investor expectations, a 10% decrement was applied to the measured area during the design phase, considering the space covered by the stand for the rooftop solar PV. The azimuth angle of the system was taken to be 180 degrees, as the panels were facing purely south, and the tilt angle was taken to be 20 degrees. These values are based on original inclination of the roof itself. It is taken to ensure minimalist design considering structural aspects.

b. Market Survey

A market survey was done to determine the input parameters and their prices during system design and techno-economic analysis. The market survey included figuring out the available brands of the components to be installed and the ones that are conventionally used across the country. With the help of expertise working on solar energy under governmental bodies of Nepal, components were segregated based on numerous parameters and the selected components were used during simulation process of the designed system as shown in table 3. The prices are given in NRs.

Table 3: *Parameters based on market survey*

Component Name/Information	Reason for Selection	Remarks
PV Panel • Trina 660 Wp, TSM-DE21 • 2384×1303×35 mm • Price: 42 per watt	Efficiency up to 21.2%, Higher power generation, Almost same area as others	Required: 110 panels,132 cells
Inverter • Sunways 25 kVA, STT 25KTL-P • Price: 125000 per unit	Reliable and highly efficient (98.6$)	3 inverters which will be changed one time during project lifetime
Supports for Module • Price: 220 per panel	Economic	
Fasteners • Price: 17	Economic	Required:185
Wire • 4 mm^2 DC cable wire • Price: 450 per meter	4 mm^2 dc cable wire is used in 660 Wp of panel	Required: 900 m wire
Combiner Box • Price: 48,000 per unit • Specification: 195W 12V Eco-worthy solar panel,	Can support up to 780 Wp panel at 12V.	Surge arrester embedded
Surge Arrester • Price: 25000	Economical	Required: 3

c. Techno-Economic Feasibility Study

The system design and simulation were executed using PVSyst 7.2 software. The input parameters used in PVSyst 7.2 are given in table 4. Parameters such as altitude, latitude and longitude were provided as input to determine daily irradiance specific to the selected location. Selection of solar panels, inverters, combiner boxes, and other necessary parameters for simulation was done based on a comprehensive market survey. The first segment of the feasibility study focused on technical feasibility, involving a comparison of the output from the simulated system design with an already existing electrification system. Parameters such as price, affordability, and reliability were considered during this comparison. Moreover, specific production, performance ratio and losses associated with the designed system were analyzed to check the technical feasibility of the system. Economic feasibility was carried out using parameters such as LCOE, return on investment (ROI) and payback period.

Table 4: *Input Parameters on PVSyst*

Input Parameter	Source
Schedule	Survey
Total Load	Survey
Site Irradiation	Meteonorm 8.0
Panel Selection	Market Availability
Inverter Selection	Market Availability
Discount Rate	Literature
Consumption Tariff	Market Data and Government Sources

4 RESULTS AND DISCUSSION

4.1 In-Person Survey Results

The main objective of the in-person survey was to determine the familiarity, acceptance, and willingness of the potential users of the PV system. A survey was carried out with 20 respondents (20% of the 100 workers) using a carefully crafted questionnaire.

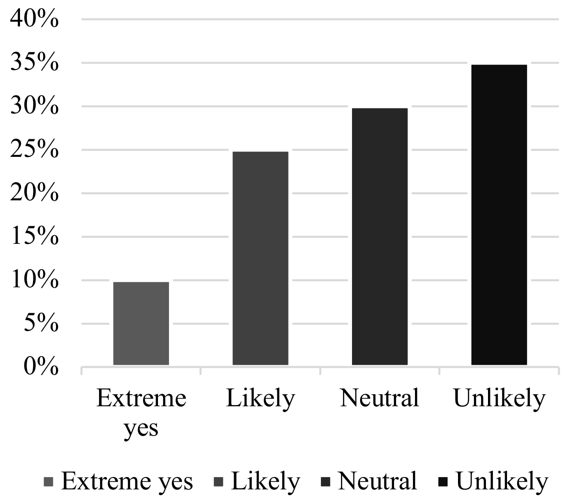

Fig. 1: *Status of RE knowledge.*

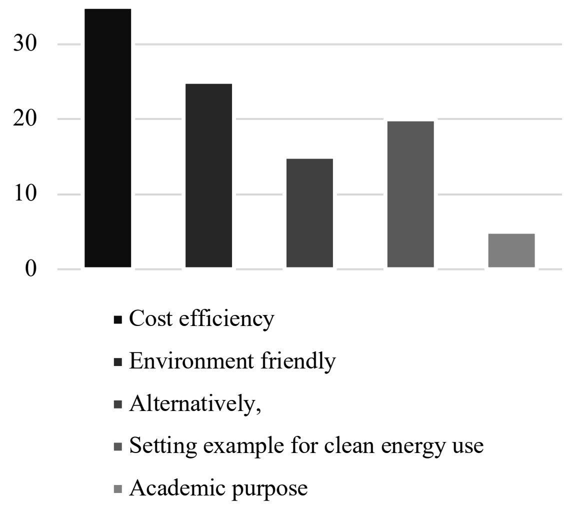

Fig. 2: *Reason for choosing solar PV.*

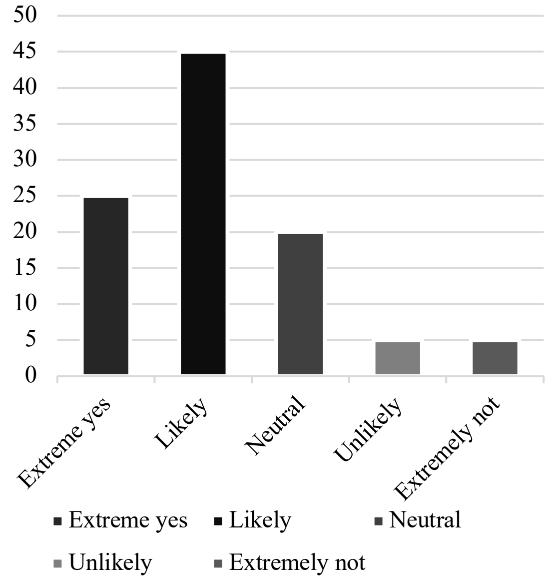

Fig. 3: *Fruitfulness to change.*

Even though 65% of interviewees had relatively less knowledge regarding renewable energy system as shown in figure 1, about 60% of the participants believed the introduction of RE will aid to balance energy demand evenly. The participants were familiar with hydropower but not about other forms of RE such as solar, wind etc. However, if given a proper knowledge about RE technology they are willing to use solar PV as an alternative source of electrification. This is evidenced by the 70% of interviewees who showed their preference solar PV as shown in figure 3. This preference resulted from respondents' perceptions of cost-effectiveness, as 75% thought PV system installation and upkeep to be financially beneficial. The participants indicated a considerable willingness (75%) to switch to solar PV systems, acknowledging that electrification accounted for a sizeable share (20–40%) of their yearly profits. 40% of participants believed that the switching costs would be high (Figure 4). However, 40% of the respondents expressed their concerns about switching costs between the systems, as well as the roof space limitations in urban settings which suggests that despite the strong interest and positive perception of the PV systems, the practical adoption of the PV systems is limited by upfront investment requirements, space availability, and policy limitations regarding installation on rented properties. Addressing these barriers through targeted incentives, design adaptations (e.g., shared/community PV), and regulatory support will be essential for translating willingness into actual installations. The same percentage questioned the effectiveness of solar PV in comparison to hydropower.

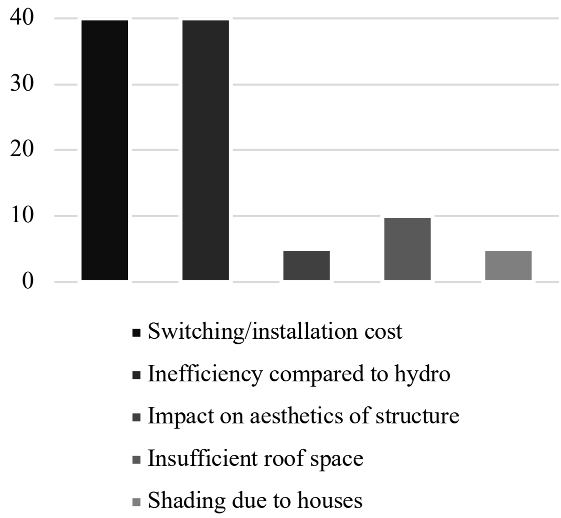

Fig. 4: *Obstructing factors.*

4.2 Technical Feasibility Study

Energy Demand Determination

The simulation of the system yielded an output of 119.5 MWh/year out of which 31.8 MWh/year will be used by the institution for their electrification purposes. The specific production of the plant was calculated to be 1656 KWh/kW$_p$/year which is the amount of energy generated per kilowatt panel in a year. The performance ratio of the plant is 0.85 which is due to the higher margin of the different types of losses considered during the design process. The monthly generation and utilization of the energy from of the plant was analyzed in multiple pasts. Firstly, analysis was the monthly generations for the October to January which was found relatively high compared to other months because of the ambient temperature in the valley being close to the STC temperature. Though June through September are the best radiation months, being rainy season, this reduced energy production. The user consumption for the winter months was the highest because of the use of heating and air conditioning equipment. Due to the higher consumption of energy during the winter seasons it was consistent with the fact that the energy injected to the grid during these seasons is less thus requiring more energy to be evacuated from the grid.

4.3 Loss Analysis

The major losses observed in the systems are Incident Angle Mismatch (IAM) losses, soiling losses, temperature losses, mismatch losses, and ohmic losses. The IAM losses are 2.24%, considering the losses caused by the radiation whose incidence is non-perpendicular to the plane of the module. Due to the highly polluted environment inside the valley and due to the irregularity in the panel cleaning which causes presence of dust and faecal matters on the panels, soiling losses are 3%. Also due to the panels' tilt being low based on the tilt of the roof, due to less clearance beneath the panels disturbing the circulation of cool air, the temperature loss increases up to 3.95%. Light-Induced Degradation (LID) losses are up to 2%. Mismatch losses are caused by varying panels, damaged panels/cells or due to the wiring issues that cause losses up to 2%. Ohmic losses are mainly caused by the resistivity of the wires used and are 1.07%. Inverter losses add up to almost 1.9%. The detailed losses of the plant are represented in the losses diagram in figure 5 and table 5.

Table 5: *Major Loss on PV panel*

Loss type	Loss percentage
IAM losses	2.24
Soiling losses	3.00
Temperature losses	3.95
LID losses	2.00
Mismatch losses	2.00
Ohmic losses	1.07
Inverter losses	1.90

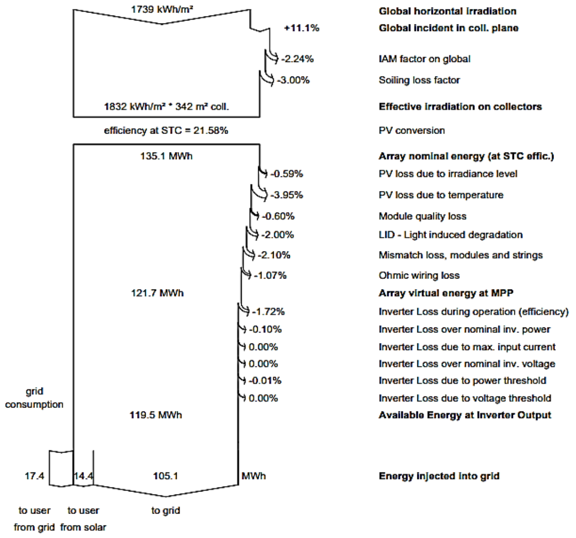

Fig. 5: Loss Diagram.

4.4 Economic Analysis

In the economic model, a standard inflation rate of 7.5% was applied to maintenance costs. In order to present a conservative baseline analysis, no government subsidies were included. The discount rate used was zero for validation (see Section 4.4), and was considered inflation-neutral for the main project LCOE/ROI analysis. Key performance indicators like LCOE, payback period, and ROI during a 25-year project lifetime were employed in the economic study of the solar PV system to ensure financial sustainability. The total cost of installation of the system was NRs. 48.8 lakhs out of which NRs. 38 lakhs worth are the depreciable assets. The installation costs included the cost of panels, inverters, wiring and accessories as well as the transportation costs. The maintenance costs were NRs. 40,000 per year at an average throughout the plant lifecycle. The maintenance costs could go up to NRs. 1.08 lakhs. Subsidies were disregarded for the primary analysis. The Feed-in Tariff (FIT) was considered NRs. 5.9 per kWh and the consumption tariff was NRs. 11 per kWh. Based on the above-mentioned data, the economic analysis was carried out. The payback period of the project was estimated to be 6.7 years and the LCOE was NRs. 2.54 per kWh by selling 105 MWh worth of energy to the grid per year. The ROI of the project was 211.4% which is an attractive figure for investors. This thorough economic analysis highlights the project's stability financially and its potential to be a profitable venture in the field of renewable energy.

Table 5: Summary of economic evaluation

Project Lifetime	25 years
Feed in Tariff	NRs. 5.9 kWh
Maintenance Cost	NRs. 40,000 per year
Energy Sold to Grid	105 MWh per year
Levelized Cost of Electricity (LCOE)	NRs. 2.54 per kWh
Payback Period	6.7 years
Net Present Value (NPV)	NRs. 48.8 lakhs
Return on Investment (ROI)	211.4%

A simple sensitivity analysis was performed to examine how variations in FIT would affect key financial indicators (Table 6). Results show that increasing FIT significantly improves ROI and reduces payback period, making PV investment more attractive.

***Table 6:** Econometrics values for different FIT*

FIT (NRs/kWh)	LCOE (NRs/kWh)	Payback Period (yrs.)	ROI (%)
5.9	2.543	6.7	211.4
7.3	2.543	5.6	274.4
10.25	2.543	4.1	422.3

4.5 Validation

The 2018 installation of a rooftop solar PV system at Kopila Valley School in Surkhet provided a real-world case study to confirm the simulated data. The characteristics of the validated site is shown in table 7. The necessary data such as total cost of installation, yearly revenue, total generation and consumption of the institute, and the specifications of all parameters were collected through Key Informative Interview (KII) provided by a reputed solar energy company of Nepal (confidential). Using this data, an empirical analysis was conducted using the Net Present Value (NPV) method, which is a simple yet effective method to evaluate the payback period and status of the project. IRENA recommends a 10% discount rate for Solar PV projects in developing countries. Moreover, several studies of Solar PV system across South Asia for small commercial PV systems have used similar 10% discount rate (Brijesh Mainali & Semida Silveria, Md Alam Hossain Mondal & A.K.M. Sadrul Islam). However, while calculating the payback period in this study, the discount rate was set to 0, as the validation was done on the basis of saving, which balances out the inflation. The NPV of NRs. 2,200,000 was obtained, and the payback period was found to be 11.5 years. The institute itself consumed 90-95% of the power generated by the plant. To ensure a fair comparison, the same factors used in the simulation, such as FIT, soil losses, IAM losses and wiring losses, were kept similar. Using the conforming parameters, simulation was done using PVsyst 7.2 which produced almost similar payback period of 11.8 years for Kopila Valley as empirical result. The discrepancy in payback period of Kopila Valley School for simulated and empirical outcome was only 2.54%, as illustrated in Figure 6. Based on this result, it can be concluded that the deviation between the simulated and actual values during real-life implementation of the selected site will be between 2-3%. This finding highlights the accuracy of the simulation method used in this study, demonstrating that the results obtained can be reliably applied to real-life scenarios. It also indicates that the simulated values are consistent with empirical data, providing further support for the validity of the simulation results.

***Table** 7: Site Characteristics*

Site name	Cosmic International Academy
Location	Surkhet, Nepal
Latitude (°)	28.60 °N
Longitude (°)	81.62 °E
Altitude	699 m

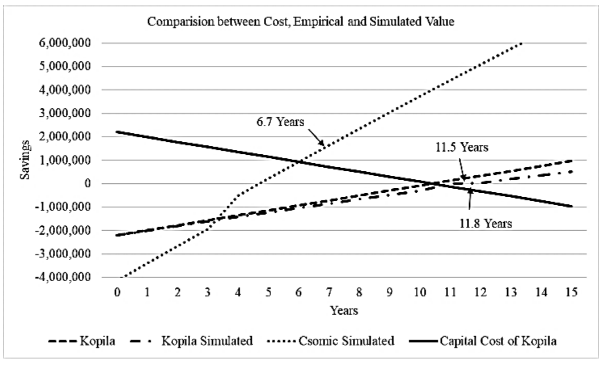

***Fig. 6:** Comparison between simulated and empirical solution.*

5 RECOMMENDATIONS

Solar PV systems have been installed in Nepal below its available potential. Different residencies, facilities, institutions and organizations have opted to go for the electricity provided by the hydropower-based grid. With the least effective examples of solar PV systems installed, the system lacks recognition thus resulting in the low number of installations despite being an effective source of energy. For this, the energy policies and trends need to be modified to establish solar PV systems as effective energy means. This section includes some of the recommendations which were carried out on the basis of survey data, economic analysis and socio-economic factors obstructing the establishment of solar PV system. The recommendations for the establishment of PV system have been categorized into four types: regulation intervention, market-based incentives, and information schemes.

5.1 Regulation Intervention

There are very limited number of regulations in Nepal set by the authorities. Due to lack of regulation, there is an unsuitable environment for the investment and installation of solar PV systems. Very less tariff rate, limited energy shares, land and housing standards are some of the regulatory mishaps in the PV adaptation trend. Adjustment of FIT rates is one of the major incentives that can be provided by the government to the PV system owners. Increasing the tariff rates will help to create an economically attractive environment for the investors and users as the increased rate of FIT provides better econometrics as shown in table 6. Additionally, the government can encourage the widespread adoption of PV in urban areas, as 75% of surveyed people were willing to install solar PV, by providing increased subsidies for the installation of the PV system in rooftop areas, which would help in addressing the lack of space in urban scenarios. Additionally, as evidenced by the validation study done on Kopila Valley School, the outcomes are replicable in real-world scenarios. Incentives such as tax rebates, priority grid access, and accelerated depreciation can encourage compliance with installing solar PV.

5.2 Market Based Incentives

Market based incentives include creating a favorable environment for the adoption of PV systems by creative an economic market environment. The following policies can be taken into account for this purpose. Research and development activities should be initiated and funded by the government — entirely or partially — by collaborating with universities and institutions. This will enable the researchers to figure out the problems in the solar PV systems in the context of Nepal. Similarly, attractive subsidies along with some operation and maintenance incentives will attract more consumers as 40% people out for 20 have pointed out the switching cost as the major obstructing factors while installing solar PV. Additionally, training programs for installers and users on proper panel cleaning and maintenance can help reduce soiling, temperature, and wiring-related losses, thereby improving long-term system performance.

5.3 Information Schemes

From the survey it was observed that a majority of people were unaware about the availability and trend of the renewable energy sector in our country. The survey questions had to be tailored to first familiarize the participants with the renewable energy, PV system, and then further technical and socio-economic questions. As it was seen, the participants were willing to install and pay for the solar PV systems once given knowledge about them. So, to do so for the majority of the projected users, education campaigns can play a vital role. By including solar PV systems, their techno-economic information in the academic curricula from the grassroots level, the upcoming generation can be educated about the availability and advantages of a sustainable energy system. Workshops, door-to-door campaigns, webinars along with site demonstrations can be conducted with the collaboration between the local and foreign universities. PV companies where the experts and intellectuals of the respective field can broaden the scope of information to the technical manpower or those pursuing their careers in the field of solar PV systems. Further, Green Building Programs can be introduced in the civil sector in which the facilities that can be environmentally sustainable and resource friendly. In the field of solar PV, as observed in countries like Germany and Australia, modern facilities can be designed with frames of windows, doors, and beams made of PV materials that act as PV panels. This helps to reduce space, increase aesthetics and improve structural integrity while contributing to environmental sustainability.

6 CONCLUSIONS

Following survey results and available roof space at Cosmic International Academy, the system design produced a grid-connected solar PV system with no battery backup which had a total capacity of 72.6 kW_p with 110 PV panels each of 660 W_p and inverter capacity of 75 kW with 3 units, one for each building. The total system yield was expected to be 121.56 MWh throughout the year under ideal operating conditions with the maximum generations in the dry summer months of March to May. The results show that the system will suffice for the energy demands and the additional energy can be injected to the grid. Around 31 MWh of energy will be available for consumption and the rest can be injected to the grid which leads to the cost of electricity being NRs. 2.54 per unit and the payback period will be 6.7 years. Beyond the payback period, the plant will help to achieve a ROI of 211.4%. Validation against the operational PV system at Kopila Valley School confirmed that the modelling approach undertaken in this study was reliable as the simulated and empirical payback periods closely aligned (11.8 years vs. 11.5 years). Seasonal variations showed maximum generation during the dry summer months.

Although the social survey revealed strong interest in institutional solar PV adoption, the concerns about switching costs and roof space remained. Clear policy interventions, including but not limited to targeted incentives, mandates for institutional PV installation, and community-based solutions, were required for the broader adoption of solar PV systems. Implementing these policies can enhance grid stability, reduce carbon emissions, and encourage distributed generation, delivering shared benefits to users and the government.

Limitations of this study include relatively smaller survey sample, partial consumption data, and single-site validation. Future work should explore battery-integrated systems, full-year consumption modeling and multi-site validation to strengthen evidence for scaling rooftop PV in Nepal's institutional and commercial sectors.

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