Sustainable green campus in NEPAL: 3E analysis

Bharosh Kumar Yadav[1,*], Pankaj Kumar Rauniyar[2], K. Sudhakar[3,4], Tri Ratna Bajracharya[5] and S. Shanmuga Priya[6]

[1]Department of Mechanical Engineering, Tribhuvan University, Institute of Engineering, Purwanchal Campus, 56700 Dharan-08, Nepal; [2]Department of Electrical Engineering, Tribhuvan University, Institute of Engineering, Purwanchal Campus, 56700 Dharan-08, Nepal; [3]Faculty of Mechanical and Automotive Engineering Technology, University Malaysia Pahang, Pekan, 26600, Pahang, Malaysia; [4]Automotive Engineering Centre, Universiti Malaysia Pahang, Pekan, 26600, Pahang, Malaysia; [5]Department of Mechanical Engineering, Tribhuvan University, Institute of Engineering, Pulchowk Campus, 44700 KTM, Nepal; [6]Department of Chemical Engineering, Manipal Institute of Technology, Manipal Academy of Higher Education, Manipal, 576104, Karnataka, India

Abstract

In today's world, where global warming is one of the greatest human challenges, sustainable energy generation is becoming increasingly relevant. The use of green and clean energy sources is the best way to minimize CO_2, CO, NO_X and other emissions of conventional energy usage. Solar photovoltaic (PV) systems are more beneficial and an exciting application to set up an eco-friendly green educational campus. In this regard, the potential sites within Tribhuvan University, Institute of Engineering, Purwanchal Campus, Dharan city, Nepal are analysed for grid-tied solar PV power plant installation to meet the 100% energy demand of the campus using energy, economic and environment-friendly analysis. The daily, monthly and annual load and solar irradiance data of past years of the campus have been analysed to estimate the solar PV plant's capacity and system performance using PVSYST V7.0 software analysis tools .The simulation results show that 110 kWp of solar PV power plant will be sufficient for the entire campus to qualify for the first fully green-powered campus in Nepal, which corresponds to fulfill 66.4 MWh/year daytime energy demand out of total 161 MWh/year energy consumption of the campus with a capacity to generate a total of 181.5 MWh/year energy from the designed solar PV system. The result also shows that 115.1 MWh/year of surplus energy produced from the PV power plant can be injected into the utility grid to yield considerable savings in utility cost. On the basis of these results, campus authorities and stakeholders may commit to investing and implementing of this project to ensure that the campus is completely green.

Keywords: TU-IOE; green campus; performance ratio; PV potential; specific yield; irradiance

*Corresponding author: bharosh@ioepc.edu.np

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1. INTRODUCTION

The advancement of science and technology is rising at a rapid pace around the world. Technology is blamed for much of the pollution that has led to environmental destruction over the past few years. However, the increasing number of colleges, institutes and campuses is related to advances in science and technology. Various science and technology educational institutions and scholars around the world need to address this subject in order to find ways to protect the environment. Therefore, there is a growing need to develop green and sustainable campuses, which have minimal impact on the environment.

Tan *et al.* summarised the rapid growth of higher education in China, raising the burden for building a sustainable, entirely green campus instead of using electrical resources. They also studied growth and the green campus trend and proposed a method for

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boosting the creation of green campus in China [1]. Richard *et al.* presented the effects of energy conservation and solar energy in order to minimise electrical energy usage. The solar installation at Kwame Nkrumah University of Science and Technology Kumasi-Ghana also created an opportunity for electricity savings of USD 69.1 million over a 20-year period with a payback of USD 6 years [2]. Guerrieri *et al.* carried out a quantitative study at the University of Palermo, considering the campus as a small-scale model of the entire city to carry out the carbon profile transition [3]. Nayak *et al.* conducted simulation studies of 1 MW of solar thermal power plants at the Bombay IIT Library under New Delhi's climate conditions, generating 1365 MWh of solar energy annually [4]. Galvin and Healy introduced the Green New Challenges Agreement for Social Science-based Green Energy in the United States and suggested a strong chance of implementing a green policy [5]. Gavrilyeva *et al.* aggregated data on the public domain and published on greenhouse gas estimation by the Federal State Statistics Service, an energy corporation in the Sakha Republic (Yakutia) [6]. Sarbassov *et al.* carried out a compositional study of municipal solid waste generated at Astana International Airport and analysed various scenarios for waste management in terms of greenhouse gas emissions. The major fractions (over 50%) of the total municipal solid waste produced at Astana International Airport [7] were found to be recyclable and fuel fractions.

Rivas *et al.* defined the state of pollution from four European cities using matrix factorization. Airport emissions have been found to contribute to the highest concentration of emissions and are the key source of pollution in cities as the wind blows directly from the airport to cities [8]. Longo *et al.* presented measurement methods using the Environmental Lifecycle Effect of Solar Air Conditioning (ELISA) for the estimation of life-cycle energy and applied three different methods in Greece for which the photovoltaic (PV)-assisted solar system approach was found to be advantageous than other life-cycle energy and environmental efficiency methods [9]. Elshurafa *et al.* did a pilot study and carried out an economic analysis in Saudi Arabia on mosque rooftops and found that the net price of solar PV was 22% lower than electricity bills [10]. However, Mah *et al.* studies indicated that the Hong Kong government's policy to control PV pricing policy and shortened payback periods would build barriers to increasing people's interest in the installation of solar PVs [11].

Sukumaran and Sudhakar *et al.* conducted possible studies and analysis analyses of solar PV installations with the aid of computational tools at Kuantan airport, Malaysia [12]. The annual energy and energy output of the 12-megawatt power plant at Cochin International Airport, India, were evaluated. They also estimated the cost of thermal losses and suggested cooling methods to minimize thermal losses in PV solar power plants [13]. Performance analysis of first-year operating data provided using the PV simulation software tool PVSyst and SolarGis found to be very similar to the calculated values of Cochin International Airport Limited, India [14]. With the help of the online PV simulation tool software SISIFO, they proposed a 2 MWp PV solar power plant will be adequate for Raj Bhoj International Airport, India, to make fully solar powered [15].

Mewes *et al.* researched and measured the required area for the construction of solar PV power plants in the existing building at the Royal Institute of Technology in Stockholm, Sweden [16]. Lee *et al.* studied the economic feasibility of the solar PV at the University of New Heaven, New England, campus and the result indicated that the payback period and operating expenses are not healthy to invest [17]. Tsoutsos *et al.* proposed the installation of a 2 MWp grid-connection solar PV system to the Technical University of Crete (TUC), Greece, and the results of the simulation using PVSYST tool software estimated the safe and healthy activity of the plant. However, they indicated that future changes could be made to the construction of a new facility in TUC campuses [18]. Wang *et al.* conducted a case study on green campus for multi-functional buildings such as offices, labs, residences, etc., and measured the overall energy performance of the system along with CO2 emissions [19]. Baitule and Sudhakar conducted a simulation analysis of 5 MW of solar power plants at MANIT, Bhopal, India campus. They have carried out a thorough and feasibility study to determine the financial and environmental benefits of a sustainable green campus [20].

Surendra *et al.* analysed the current status of renewable energy in Nepal and found that Nepal has 6.8 sunshine hours a day with solar insolation intensity varying from 3.9 to 5.1 kWh/m2/day (the national average is ∼4.7 kWh/m2/day). Their research study has shown that 0.01% of the total area of Nepal can produce 8 GWh/day solar energy, which is 2920 GWh/year, which is more than the electricity produced by the Nepal Electricity Authority in 2008/09 (i.e. 1839.5 GWh) [21]. The production of solar PV and the adoption of the solar market have been described as potential in various public and private sectors in Nepal. The total number and installed capacity of solar PV in Nepal are shown in Table 1 [22].

The two primary issues related to the environmental effects of campuses are noise and pollution. Air pollution is considered to be a key environmental problem for the countries of South Asia: Nepal, India, Pakistan, Bangladesh and Afghanistan. Nepal ranks eighth out of 79 countries in terms of air pollution by estimating average concentrations of PM2.5 (μg/m3) and most polluted cities in the world [23].

On the occasion of World Environment Day, 5 June 2020, the Government of Nepal (GON) inaugurated a first step of 1.25 MW out of 25 MW of Nepal's largest solar power plant to be fed into the national grid of the Devighat Electric Project in Trishul. According to NEA Managing Director Kulman Ghising, next project of 10 MW will be implemented under contract with the Chinese company Risen Energy, as a part of the World Bank's Grid Solar and Energy Efficiency Project [24].

The literature review confirms that the educational science and technology institute sector plays an invaluable and magnificent role in the economy of the country, but it also contributes to greenhouse gases and other emission factors. In addition, the educational institution has a major impact on the community. It is clear that campuses that use large portions of glare land that lead to air and groundwater pollution also generate massive amounts of waste and consume excess electricity. The edifying use

Table 1. *Total number of systems and total installed capacity [22].*

SN.	PV system	Installed capacity (Watt peak)	Number of systems
1	Solar home system (SHS)	5 624 475	206 152
2	Small solar home system (SSHS)	737 258	155 574
3	Solar PV in communication sector	1 243 894	943
4	Institutional solar PV system (ISPS)	537 216	415
5	Solar PV pumping system (PVPS)	135 969	76
	Total	8 278 812	363 160

of energy and the main concerns are that the resulting gases such as CO_2 and NO_X contribute to the accumulation of greenhouse gases that adversely affect the environment. The idea of 'Green Campus' has resulted in a new approach to reconciling the existing requirements of society with environmentally sustainable practices. A green campus is the best initiative that could be taken to resolve the problems facing the sector. The planting of Agro vegetables also cools the panel and increases the power generation [25]. Poudel *et al.* have researched the current energy crisis in Nepal and the Nepalese government's investment initiatives to support green and sustainable energy [26]. In Nepal, spring means the months from March to May, summer from June to August, autumn from September to November and winter from December to February [27].

Based on the literature review, specific work on a green campus based on energy, environmental and economic feasibility studies have not yet been carried out. Therefore, the present research work is aimed to bridge the research gap concerning a sustainable green campus in Nepal. With this in mind, this research was undertaken to explore the parameters for evaluating the green output of Tribhuvan University (TU), Institute of Engineering (IOE), Purwanchal Campus, Dharan, Nepal. In this research, the energy consumption was analysed in order to study the feasibility of installing PV plants for a 100% sustainable campus. The most appropriate locations within the campus suitable for the Installation of the PV plant are selected. Energy, economic and environmental (3E) analysis is carried out for the conceptual solar PV power plant to meet the annual electricity demand of TU, IOE, Purwanchal Campus, Nepal.

2. METHODOLOGY

2.1. Site condition and area selection

Nepal is endowed with abundant renewable energy resources [28]. TU, IOE, Nepal have altogether five government constituents' engineering campuses in the whole Nepal. Purwanchal Campus is formerly known as the Eastern Region Campus as one of the constituent campuses of TU, IOE, Nepal. The campus (geographical location: latitude 26.79°N, longitude 87.29°E with altitude 311 m) is a comprehensive and pioneer engineering institute funded by the GON, which is spread over an area of 22.54 hectares (35 bighas) land as shown in Figure 1. This campus is considered as the second largest constituent campuses of IOE in terms of the

Table 2. *Global horizontal irradiance and temperature value throughout the year.*

Months	Global horizontal irradiance ($kWh/m^2/mth$)	Global horizontal diffuse ($kWh/m^2/mth$)	Temperature (°C)
January	127.0	36.8	13.8
February	133.8	47.8	18.6
March	168.6	65.6	24.3
April	180.1	87.7	29.0
May	183.2	95.7	30.3
June	159.6	95.5	29.6
July	150.0	80.3	28.6
August	153.6	93.4	28.7
September	140.8	71.1	27.6
October	138.8	66.3	25.8
November	130.1	40.1	20.8
December	122.5	39.9	15.8
Year	1788.1	820.2	24.4

territory [29]. The campus site encounters low temperatures of 13.8°C and increases to a high of 30.3°C [30]. Table 2 summarizes the irradiance, diffuse and temperature profiles throughout the year at TU, IOE, Purwanchal Campus. It can be seen that the global irradiance is maximum in April and May, whereas the minimum in December. The average global horizontal irradiance and diffuse of the proposed site are 1788.1 $kWh/m^2/month$ and 820.2 $kWh/m^2/month$, respectively, with a yearly average temperature of 24.4°C. The proposed campus site for solar PV plant installations receives a generous amount of solar light during the year and has a minimum temperature of 15.8°C (min.) to 30.3°C (max.) with an average low wind speed of 3.601 km/h per year [30].

Installation of a solar PV power system at campus premises uses substantial amount of empty land that can be used to set up a solar PV power plant. The map of the campus along with the glare of the land is shown below. The entire campus, including administration building, departmental building, classrooms, street lights, canteens, campus headquarters, HOD, Deputy HOD, faculty cabins, etc., shall be considered for study. The annual and monthly (peak) energy usage of the campus is ∼161 MWh/year and 13 417 kWh [21], respectively.

Installation of a solar PV power plant on campus should describe the solar sustainability of the campus. Vast glare land of campus will get utilized in economical way with the installation of PV arrays resulting in correct use of resources. The total area

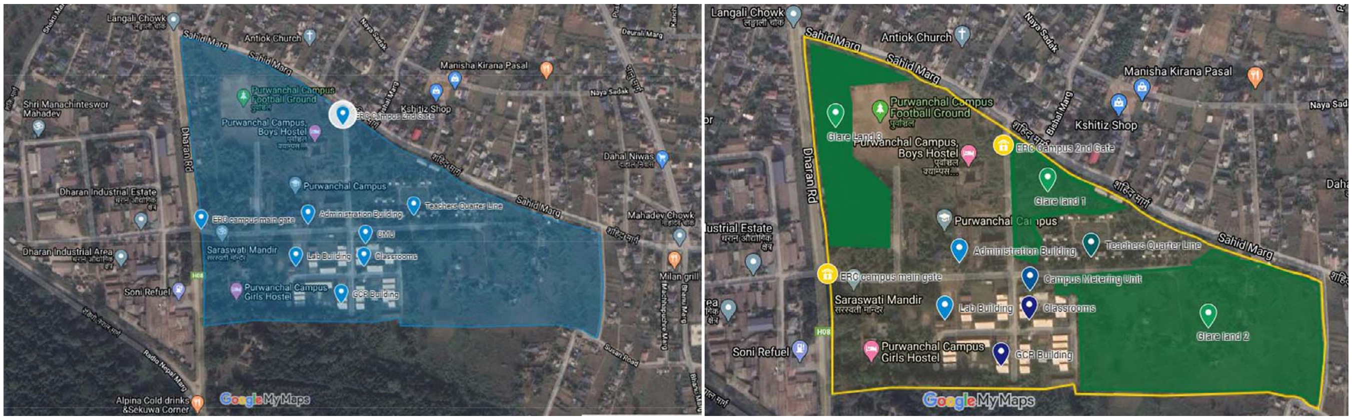

Figure 1. *TU, IOE, Purwanchal Campus, Dharan, map and glare land.*

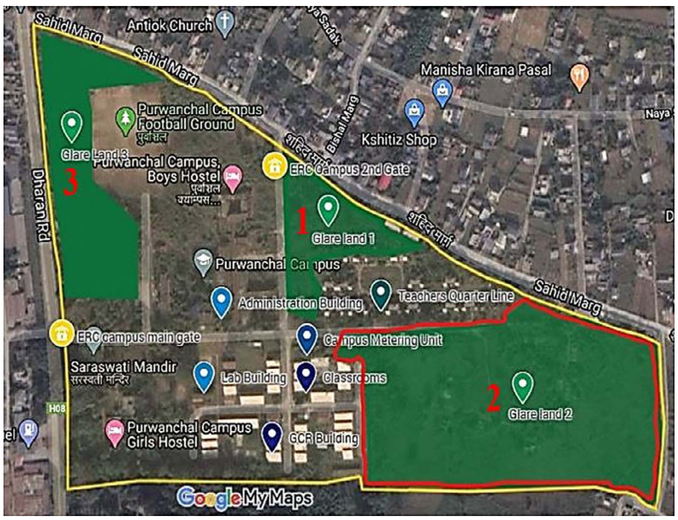

Figure 2. *Suitable area for the solar PV power plant installation.*

needed for the construction of the proposed solar PV power plant on campus will be 737 m² of land. According to the Solar Panel Installation Guide [43], the campus glare land shown in Figure 2 is a suitable location based on installation criteria such as campus metering unit distances, a relatively wide land area in which the size of the plant can be increased in the coming days, and, most significantly, glare land is provided direct sunlight providing optimal conditions for the installation of a solar panel [43].

2.2. Energy consumption and load profile

For the determination of the total solar energy needed to meet the campus load requirement, the annual electricity consumption bills for the period 2011–2019 AD were obtained from the Nepal Electricity Authority (Dharan branch) [21]. The campus uses the time-of-day metre to calculate its monthly electrical energy usage, which is the easiest and most accurate data source to find out. According to the campus authority, there was a substantial rise in electrical loads attributable to construction in the year 2014 AD. In order to make the estimate more reliable, the corresponding data for the period 2011–2014 AD were ignored due to excessive construction work. In the estimate, the campus electricity bills for the period 2015–2019 AD, i.e. the monthly energy usage of 5 years, are selected for analysis as shown in Table 3. In addition, the maximum energy consumed for the fiscal year 2019 is selected for calculation in order to make the planned PV solar power plant sustainable. Energy consumption data from the past 5 years of the TU, IOE, Purwanchal Campus, were analysed showing the rising annual energy consumption rate.

The above table indicates that the total energy needed to meet the campus load demand were 129 774 kWh, 138 347 kWh, 167 286 kWh, 166 843 kWh and 161 791 kWh for the calendar years 2015, 2016, 2017, 2018 and 2019 AD, respectively. From the above table, it can be shown that the demand for energy consumption on campus is growing in order. NEA campus energy bills from 2015 to 2019 AD are used for the analysis. The most recent data for the year 2019 AD are used to assess the monthly energy consumption requirement of the campus shown in Figure 3. The gross annual electrical energy usage of the campus (2019 AD) is ∼161 MWh/year units, which is equivalent to 450 units per day [21].

2.3. System design using PVSYST

It is an important activity to minimize the cost of renewable energy using PV panel design engineering, installation to the required location of the site and construction process, bearing in mind the cost of solar power, to be competitively lower than the rate of hydro-electricity after a few years of use. The PVSYST V7.0 simulation software was used to customize the Institute's load consumption with a grid-connected PV solar power plant design. The PV power plant generates green energy from a solar array to meet the campus energy requirements. During the simulation in PVSYST V7.0, the monthly energy consumption of each month was calculated on the basis of energy consumption data of 2019 [38–39]. Preliminary rough estimates in PVSYST have been made for the 100 kWp to 120 kWp system, which will be able to produce the required amount of solar energy about 161 MWh to meet the annual energy consumption requirement of the campus to be fully solar powered.

Table 3. *TU, IOE, Purwanchal Campus Energy consumption statistic (2015–2019).*

Month number	Month name	Energy consumption (kWh)				
		2015	2016	2017	2018	2019
1	January	10 262	10 769	12 648	12 066	11 994
2	February	9856	10 153	12 534	11 402	11 213
3	March	10 146	9634	12 378	11 488	10 302
4	April	10 349	9548	18 792	12 681	11 203
5	May	10 363	10 753	19 676	13 927	14 420
6	June	10 593	12 753	14 274	16 209	17 014
7	July	10 890	14 019	13 564	18 010	17 939
8	August	11 962	14 092	15 464	18 598	17 786
9	September	12 230	12 451	13 026	17 163	15 259
10	October	11 703	10 935	12 018	12 934	11 590
11	November	10 996	11 547	11 351	10 697	10 982
12	December	10 424	11 693	11 561	11 668	12 089
12 Months	Yearly	129 774	138 347	167 286	166 843	161 791

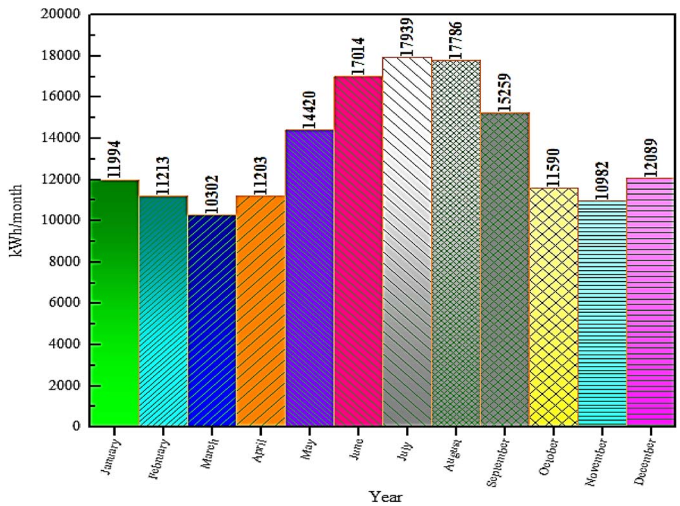

Figure 3. *TU, IOE, Purwanchal Campus, monthly needs (kWh/months).*

2.4. Load input

In addition, the generation of the PV system should not be less than the total energy consumption of 2019, i.e. 161 MWh/year considered during design. The TU, IOE, Purwanchal Campus, energy consumption in (kWh)/month is evaluated for the design of the solar PV power plant, which will be able to meet the energy demand of the campus as shown in Figure 3. The overall energy consumption corresponding to AD 2019 is estimated using PVSYST, which is 161 MWh/year. Campus load consumption should be greater than that, which can be fed to the grid, but not less than the monthly campus requires.

2.5. Description of the proposed solar plant

The campus proposed block diagram of the grid-connection solar PV power plant system consists of different components that are shown in Figure 4.

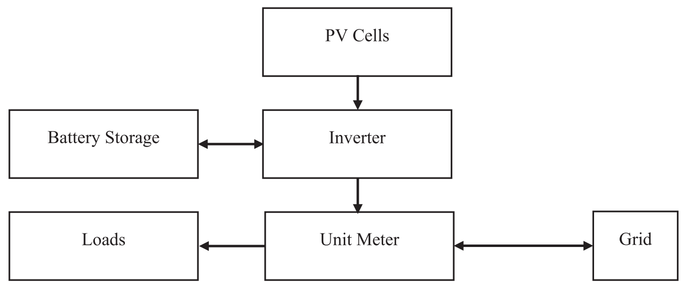

Figure 4. *Block representation of major solar installation components at the campus.*

Table 4. *PV module characteristics.*

Model	SYP 295S
Watts	295 Wp
V_{MPP}	30.5 V
V_{OC}	44.8 V
I_{MP}	8.29
I_{SC}	8.7
Efficiency	>15.2%

2.6. PV module

The selection of the PV module for simulation is greatly inspired by its availability, reliability and the actual cost [31]. Taking these points into account, the Si-poly PV module SYP295S manufactured by Risen Energy Co. Ltd. is chosen in the design. The PV module is selected after going through the manufacturer data source. The PV module characteristics and the proposed solar plant details are set out in Table 4. The polycrystalline panel is chosen for its low cost compared to monocrystalline panels. The arrangement of an array in this study is fixed to a 30-degree tilt of the solar PV panel to obtain the desired amount of solar energy [32].

For the operating condition, G_{oper} equals 1000 W/m^2, and the temperature of 25 degrees centigrade, the maximum power point of the selected PV module is 295.9 Wp. Other essential

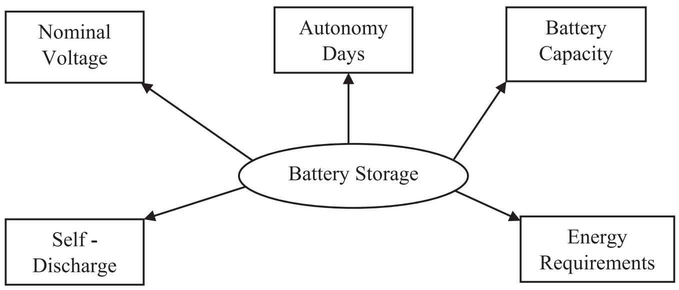

Figure 5. *Battery selection criteria.*

module parameters seen at this condition were Diode quality factor (Gamma) equal to 1.016, shunt resistance of 450 Ω, the series resistance of 0.37 Ω, maximum power point in terms of current (I_{mpp}) equals to 8.170 A and temperature coefficient of −0.43% per degree centigrade. The size of the selected panel is 1956 × 992 × 50 mm with a total module area of 737 m^2. Furthermore, each module has a weight of 24 kg and an efficiency of >15.2% per module area.

2.7. Battery bank

The Dharan city is facilitated with the installation of station 33 kV lines and proposed site supply distribution of 11/0.4 kV distribution system [21]. It will be easier to receive the surplus electricity to feed into the grid, therefore in this study, grid-connected system is proposed.

However, a small battery bank can be installed just to serve as an emergency backup for a small time. In the present study, the battery bank has not been considered due to its limited lifetime of 4–5 years in general or at most 10 years, and battery selection criteria of the proposed PV solar power plant can be done according to the load profile requirements of the campus, which is shown in block diagram Figure 5 [33–34].

2.8. Inverter and Charger

The inverter and charger are a critical component of the solar power system. Since the solar panel capacity of the site is 110 kWp, the inverter minimum size requirement must not be <70% of it i.e. 134 kW. ABB Inverters with 134 kW (570–800 Volts) single unit grid system have been chosen during the design and simulation. The inverter chosen for this study is capable of producing active as well as reactive loads and its technical detail specifications are listed in Table 5. In this study, ABB, PVI-134.0-TL grid inverter is used for handling the electrical energy from PV modules and storing it to the battery as well as feeding to the grid. This inverter has two maximum power point tracking (MPPT) inputs with multi-MPPT feature [35–37]. For simulation, the input side of the inverter receives MPP voltage ranging from 570 V to 800 V. The maximum PV power and PV current are 137 KW and 246 A, respectively. Also, the threshold power in the input side is taken as 800 W. These specifications are set to handle the power that we receive from the PV panels. The intended output of the inverter is triphased 50 Hz AC power. The grid voltage needs to deal with 400 V and the nominal AC power and current are 134 kVA and 203 A, respectively.

Table 5. *Inverter specifications.*

Model	PVI-134.0-TL
Nominal AC power	134 kVA
MPPT voltage range	570–800 V
Nominal AC current	203 Amps
Dimensions	1250 × 850 × 1077 mm
Output	3 Phase, 50 Hz
Efficiency	97.94%

2.9. 3E ANALYSIS

In this work, a holistic 3E approach is used for the analysis. The research methodology is shown in Figure 6 to assess the performance of the proposed solar PV power plant. The solar PV power plant system is designed and simulated using PVSYST V7.0 tool software.

2.10. Yield factor (Y_f)

It is the ratio of net energy output to the DC power output of the existing solar PV array. It presents the total amount of time the PV array will need to operate at its rated power to provide the same electricity. The yield units are hours, or kWh/kWp [37, 40]. The yield factor (specific yield) is calculated as follows:

$$\text{Yield Factor} = \frac{\text{PV array Energy Output (kWh)}}{\text{The capacity of the installed solar PV plant (kWp)}} = 1619 \tag{10}$$

2.11. Capacity factor

The capacity factor (C_f) is the ratio of actual energy output over a given period to the maximum feasible electrical energy over that period. This capacity factor can be calculated for 1 year and also for 1 month to obtain observations in seasonal fluctuations. The capacity factor is given by [40, 41]. The capacity factor is given by:

$$\text{Capacity factor} = \frac{\text{Yield factor}}{\text{Operating time in hours}} = 0.18 \tag{11}$$

2.12. Performance ratio

The performance ratio (PR) is a parameter that shows the long-range effect of losses on the output of solar power. PR is calculated monthly or annually and is dependent on the temperature of the PV module. The PR value differs from season to season based

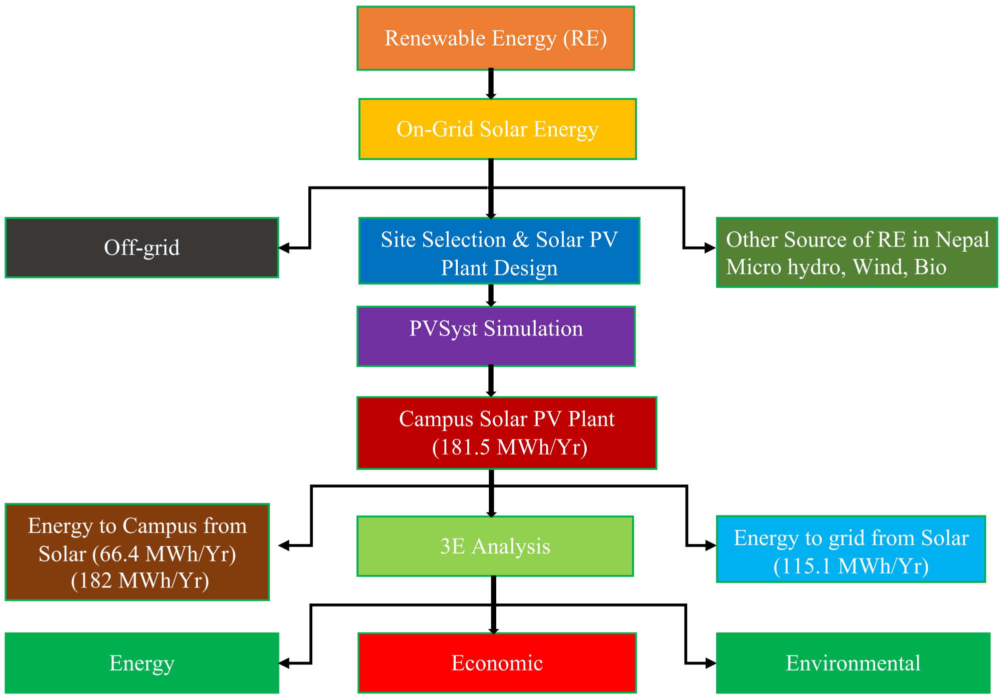

Figure 6. *Flowchart describing the methodology of the study.*

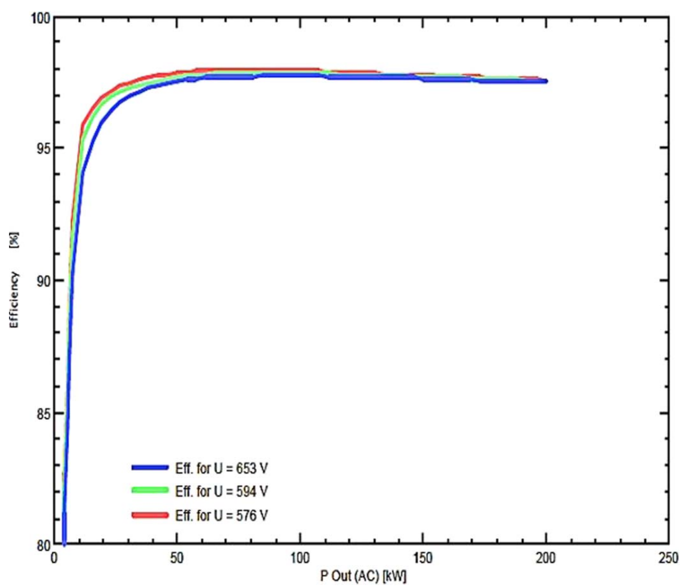

Figure 7. *Efficiency curve of the inverter from the simulation.*

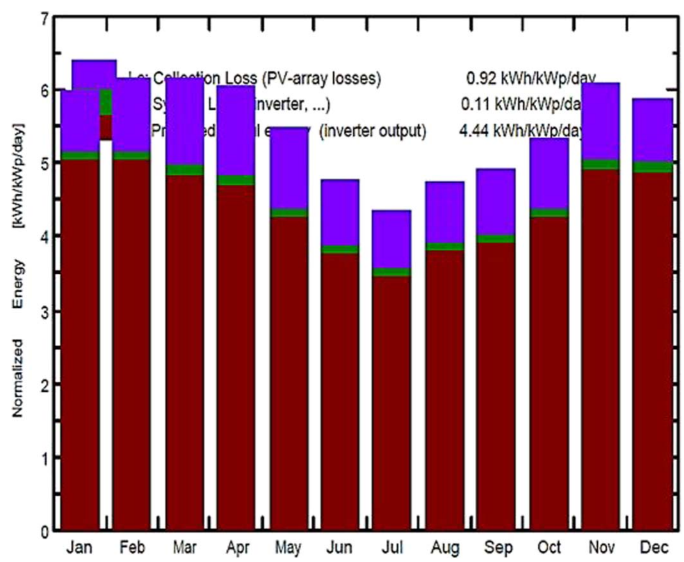

Figure 8. *Normalized productions (per installed kWp): nominal power 157 kWp.*

on the PV cells being irradiated by the sun. PR is calculated as [40, 41].

$$\text{Performance Ratio} = \frac{\text{Yield factor}}{\text{Solar irradiance} \times \text{Area of the PV Plant}} = 81.16\% \quad (12)$$

2.13. PV of Annuity

The present value (PV) of annuity is calculated as follows:

$$\text{PV of Annuity} = \text{P}\left[\frac{(1+\text{i})^{\text{n}} - 1}{\text{i}\,(1+\text{i})^{\text{n}}}\right]. \quad (13)$$

Where P = periodic payment, i = rate per period and n = number of period.

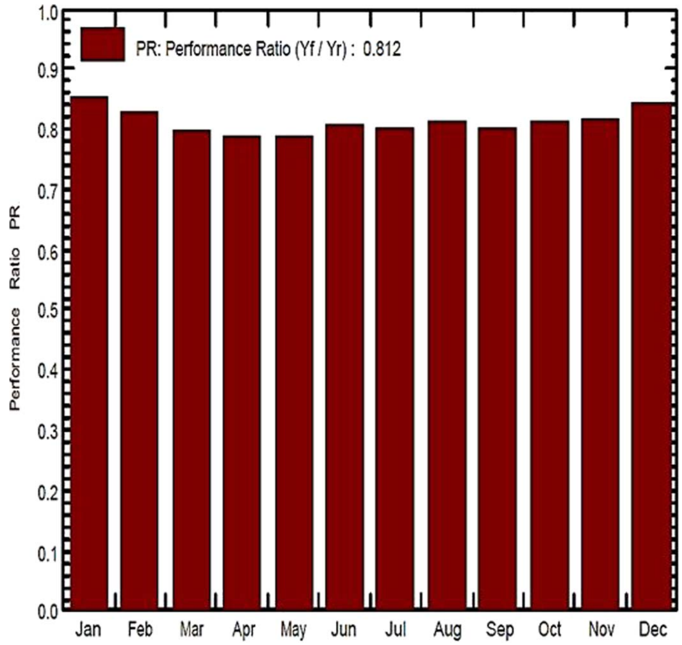

Figure 9. *PR 13.92.*

2.14. FV of Annuity

The future value (FV) of annuity is calculated as follows:

$$\text{FVofAnnuity} = P\left[\frac{(1+i)^n - 1}{i}\right]. \quad (14)$$

Where P = periodic payment, i = rate per period and n = number of period.

2.15. Nominal Discount Rate

The nominal discount rate (d) is calculated as follows:

$$d = (1+r)\ (1+i) - 1. \quad (15)$$

Where, d = nominal discount rate, r = real discount rate and i = inflation rate.

3. RESULTS AND DISCUSSIONS

3.1. Preliminary design of the plant

The monthly energy requirements for the planned campus solar PV power plant are shown in Figure 3. At the optimum solar energy generation, the orientation of the solar PV panel is fixed at 30° tilt towards the plane and the azimuth angle is set to 0°. It is shown that the solar panel generates green energy that meets the annual load requirements of almost 66.4 MWh. It is also shown that residual energy can be fed to the grid every month. Inverter efficiency is one of the most important parameters to be considered in this analysis. These specifications show that this inverter achieves a maximum efficiency of 97.94%. An effective nominal power limit of 134 kW is also defined. Above this, the performance declined drastically. The efficiency versus DC Power is shown in Figure 7, which details the efficiency values for other conditions. The PV plant is equipped with 20 strings of 295 Wp solar panels. Each string consists of 19 panels in series, making a total of 380 panels with a rated STC array power of 112 kWp.

3.2. Energy Analysis

The proposed solar PV grid-connected power plant system at the campus generates 181.5 MWh/year of electricity with a specific output of 1619 kWh/kWp/year, a PR of 81.16% and solar fraction 41.20%. Normalized productions (per installed kWp) with nominal output of 112 kWp, PR and the balances of the proposed campus solar PV grid-connected power plant system are shown in Figures 8–9 and Table 6, respectively.

Table 6 indicates that the cumulative global irradiance available annually at the proposed campus site is 1788.1 kWh/m^2. Annually, 181.5 MWh of energy can be generated from the array, with 66.4 MWh of energy from solar to load, while 94.51 MWh of energy from the grid and 115.08 MWh of energy can be injected to the grid from the solar PV system. As a result, the net solar energy exported to the grid would be 115.08 MWh as per simulation performance. The system is designed in such a way that the grid can import energy from panels as well as inject energy for higher reliability as the instant output of solar PV panels depending upon the irradiance. However, the daily variations in the PV generation cannot be predicted. The daily input/output global irradiance is shown in Figure 10.

The total effective radiation on collectors of solar PV panels is 1919.6 kWh/m^2 and with an efficient panel of 15.25%, 215.8 MWh energy provided by an array of 112 kWp throughout the year. Total energy losses over the year, including the radiation loss (−0.38%), temperature loss (−12.49%), module quality loss (0.75%), mismatch loss (−1.00%), Ohmic wiring loss (−0.79%), inverter loss during operation (−2.41%) and inverter loss due to voltage threshold (−0.11%) as shown in Figure 11. The PV loss due to temperature seems quite high, due to weather conditions and higher atmospheric temperature at the proposed site.

3.3. Economic analysis

The economical evaluation of the solar plant at TU, IOE, Purwanchal Campus, to make it completely green is presented in Table 7. The total installation cost for the 110 kWp plant will be 74 700.00 USD, which will be about Rs. 74 lakhs 70 thousand (Nepali Rupee) to produce 181.5 MWh of energy per year. The campus solar plant will be able to sell 115 MWh of surplus energy and the remaining 66.4 MWh will be used by the campus itself in 1 year.

The long-term comprehensive financial balance of the grid-connected solar PV power plant is estimated as shown in Table 8. The lifetime of the project is 20 years from 2021 and return on

Table 6. *Balances and main results of the proposed grid-connected solar PV plant.*

Year	GlobHor kWh/m^2	DiffHor kWh/m^2	T_Amb °C	GlobInc kWh/m^2	GlobEff kWh/m^2	EArray MWh	E_User MWh	E_Solar MWh	E_Grid MWh	EFrGrid MWh
January	127.0	36.84	13.82	184.9	178.5	18.05	12.19	5.034	12.59	7.15
February	133.8	47.77	18.55	171.8	165.8	16.31	11.80	4.874	11.05	6.92
March	168.6	65.56	24.25	189.7	182.8	17.35	10.63	4.505	12.43	6.12
April	180.1	87.71	29.03	180.9	173.2	16.29	9.10	4.182	11.74	4.92
May	183.2	95.67	30.33	169.5	162.0	15.30	12.43	5.545	9.38	6.89
June	159.6	95.52	29.59	142.3	136.1	13.16	16.41	7.031	5.78	9.38
July	150.0	80.29	28.64	134.3	128.7	12.43	17.62	6.883	5.20	10.74
August	153.6	93.38	28.66	146.8	141.2	13.70	18.26	7.489	5.87	10.77
September	140.7	71.09	27.57	147.2	142.0	13.58	17.31	6.746	6.50	10.57
October	138.8	66.34	25.75	164.8	159.2	15.31	13.21	5.354	9.58	7.85
November	130.1	40.13	20.76	181.4	175.2	17.03	9.97	4.008	12.62	5.97
December	122.5	39.89	15.81	181.1	175.0	17.49	11.99	4.753	12.32	7.24
Yearly total	1788.1	820.18	24.42	1994.8	1919.6	186.00	160.91	66.404	115.08	94.51

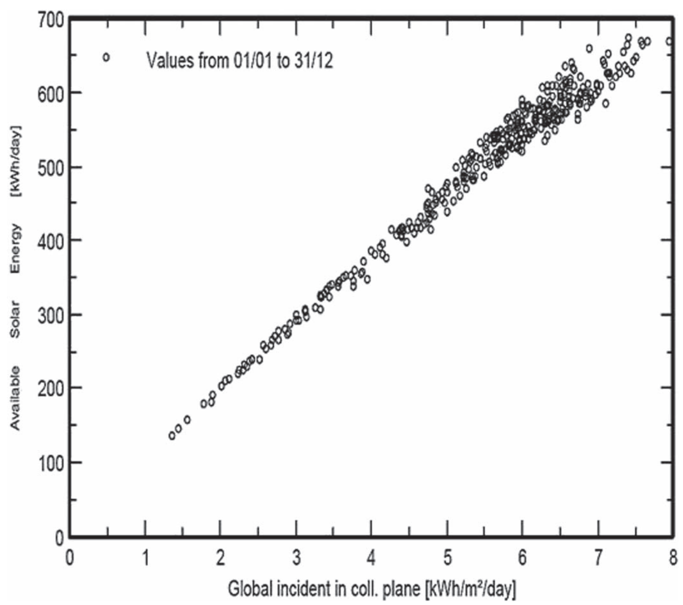

Figure 10. *Daily input/output diagram showing global irradiance (kWh/m^2/day).*

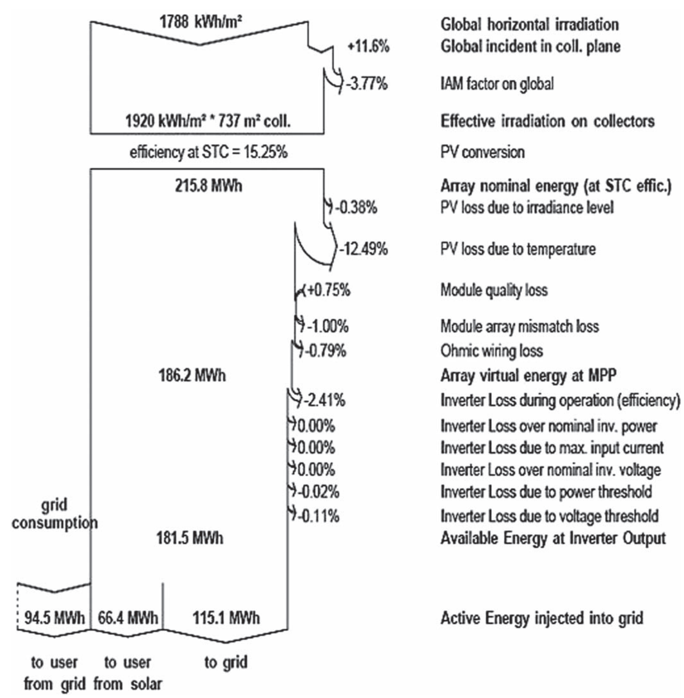

Figure 11. *Energy loss over the whole year.*

investment (ROI) is also calculated. The net profit of the campus will be 242 618.33 USD, more than double the net investment of ~Rs. 2 crores 43 lakhs (Nepali Rupee) by the end of project life. The payback period of the project is very good for the investor at 4.7 years with an ROI of 324.8%. The annual net benefit and total cash flow of this grid-connected solar system are shown in Figure 12 and Figure 13, respectively.

3.4. Environmental analysis

CO_2 emissions are estimated over a lifetime of 20 years for the grid-connected PV plant system. The total CO_2 emissions produced are 201.68 tonnes, the CO_2 emissions replaced are 10.9 tonnes and the CO_2 emissions of 191.8 tonnes will be balanced annually with the degradation of 1.0% of the solar PV plant. The lifecycle emissions of the plant and its detail are shown in Table 9 and the saved CO_2 savings with time are shown in Figure 14, respectively.

4. CONCLUSIONS

The following observations are drawn from the feasibility assessment of green campus:

- The total horizontal irradiance on the collector plane of the solar panel at TU, IOE, Purwanchal Campus, Dharan, throughout the year is found to be 1920 kWh/m^2.

Table 7. *Economic evaluation.*

SN.	Item	Unit	Unit cost (USD)	Capital costs (USD)
1.	PV modules (SYP295S)	380	120.00/unit	45 600.00
2.	Supports for module	380	20.00/unit	7600.00
3.	Inverter (PVI-200.0-TL)			10 000.00
4.	Studies and analysis			
	Engineering		1000.00	
	Permitting other admin fesses		1000.00	
	Environmental studies		1000.00	
	Economic analysis		1000.00	
5.	Installation			
	Grid connection		1500.00	
	Wiring		1500.00	
	Settings		1500.00	
	Transport		1500.00	
	Accessories, fasteners		1500.00	
6.	Total Investment			74 700.00
7.	Depreciable asset			64 700.00
8.	Operating costs			
	Maintenance			
	Reparation		1000.00/year	
	Salaries		1000.00/year	
9.	System summary			
	Total installation cost		74 700.00 USD	
	Operating cost (incl. inflation 1.00%/year)		2201.90 USD/year	
	Unused energy		66.4 MWh/year	
	Energy sold to the grid		115 MWh/year	
	Cost of produced energy (LCOE)		0.045 USD/kWh	

Table 8. *Detailed economic results (USD).*

Year	Sold Energy	Run. Costs	Deprec. allow.	Taxable income	Tax 0.00%	After-tax Profit	Self-cons. Saving	Cumul. Profit	% amorti
2021	11 508	2000	0	9508	0	9508	6560	−58 632	21.5%
2022	11 508	2020	0	9488	0	9488	6560	−42 584	43.0%
2023	11 508	2040	0	9468	0	9468	6560	−26 557	64.4%
2024	11 508	2061	0	9447	0	9447	6560	−10 550	85.9%
2025	11 508	2081	0	9427	0	9427	6560	5437	107.3%
2026	11 508	2102	0	9406	0	9406	6560	21 403	128.7%
2027	11 508	2123	0	9385	0	9385	6560	37 348	150.0%
2028	11 508	2144	0	9364	0	9364	6560	53 271	171.3%
2029	11 508	2166	0	9342	0	9342	6560	69 173	192.6%
2030	11 508	2187	0	9320	0	9320	6560	85 054	213.9%
2031	11 508	2209	0	9299	0	9299	6560	100 912	235.1%
2032	11 508	2231	0	9276	0	9276	6560	116 749	256.3%
2033	11 508	2254	0	9254	0	9254	6560	132 563	277.5%
2034	11 508	2276	0	9232	0	9232	6560	148 355	298.6%
2035	11 508	2299	0	9209	0	9209	6560	164 123	319.7%
2036	11 508	2322	0	9186	0	9186	6560	179 869	340.8%
2037	11 508	2345	0	9163	0	9163	6560	195 592	361.8%
2038	11 508	2369	0	9139	0	9139	6560	211 291	382.9%
2039	11 508	2392	0	9116	0	9116	6560	226 967	403.8%
2040	11 508	2416	0	9092	0	9092	6560	242 618	424.8%
Total	230 156	44 038	0	186 118	0	186 118	131 200	242 618	424.8%

- The design of the system includes a solar PV system of 110 kWp, to fulfill the energy consumption of the campus (161 MWh/year) with the capacity to produce a total of 181.5 MWh/year energy with a tilt angle of 30 degrees and an azimuth angle of 0 degrees. Further, the solar PV grid-connected plant can generate a sufficient amount of solar energy annually to fulfill the energy consumption of the campus as well as to inject the surplus energy to the grid.

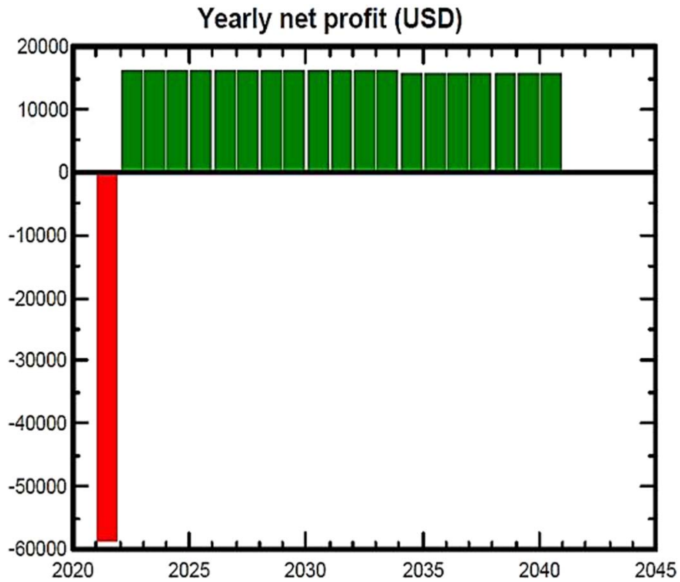

Figure 12. *Yearly net profit (USD).*

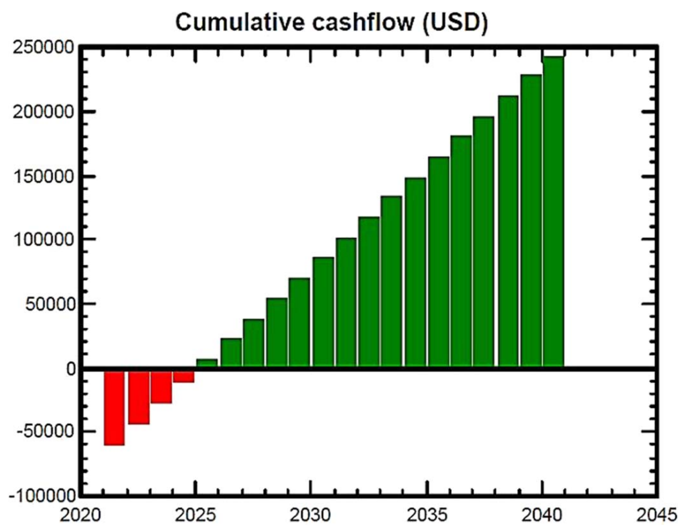

Figure 13. *Cumulative cash flow (USD).*

Table 9. *System lifecycle emissions.*

SN.	Item	Modules	Supports
1.	LCE	1713 $kgCO_2/kWp$	0.02 $kgCO_2/kg$
2.	Quality	118 kWp	3990 kg
3.	Sub-Total ($kgCO_2$)	201 596	79.8

• It is recommended that an appropriate battery bank be used to provide power backup for a few hours, which can be applied to improve the efficiency of both solar power failure and grid failure.

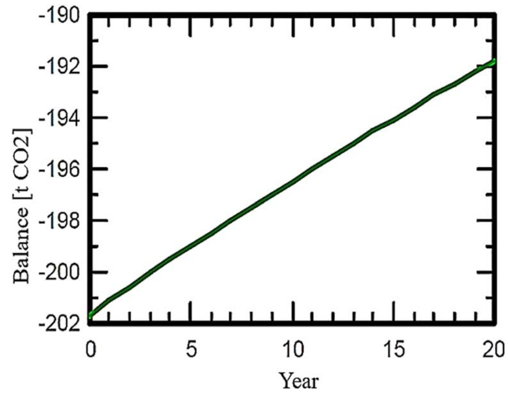

Figure 14. *Saved CO_2 emission versus time.*

• The expected PR of plant is 81.16% with the specific production (yield factor) of 1619 kWh/kWp/year. The major loss in the system is due to temperature (12.49%), which can be minimized using active and passive cooling techniques.

• The construction of solar PV power plant on campus will be cost-effective on the basis of economic and environmental analysis. Based on these results, campus authorities and stakeholders will gain more confidence in the implementation of this project to ensure that the campus is completely green.

• The concept of a fully green campus (Net Zero campus) can set an example by contributing to the protection of the environment. Plenty of vacant spaces within the campus premises can also be utilized with the concept of organic farming in between the panels.

• This work was carried out as a guidance document on the system design and analysis of grid-tied Solar PV system. A future plan of the campus to set up the PV plant to meet the future energy demand and to enable significant savings in bulk electricity bills is envisaged.

• The future work of the study may focus on the criteria for selecting batteries and smart net metering of the PV microgrid according to the campus load requirements that have not been considered due to the high initial cost and short life of the traditional battery backup (i.e. typically 4–5 years and maximum 10 years). Necessary improvements could be included in the future to satisfy any unique requirements such as battery backup implementation and system of higher capacity.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could influence the work reported in the submitted manuscript. The opinion/findings/insights/discussions in the document are solely of the authors and do not necessarily reflect the opinion of any organization involved directly or indirectly. Hence the authors are not responsible for any consequences thereof with the use of information presented in this work.

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