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Planning of Rooftop Solar Power Plant at Academic Campus: VVIT Purnea as a Case Study

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ABSTRACT In recent years, academic campuses have focused on important activities such as education, research, and social services leads to they are reported to have a significant impact on their energy consumption. In other-hand, the Indian government has paid great attention to the development of renewable energy sources, especially on solar. Evaluating the site-selection process for PV plants is essential for securing available areas for solar power plant installation in limited spaces. In this respect, this study conducts a case study on selecting the site for PV panel installation at Vidya Vihar Institute of Technology (VVIT) Purnea by using google image of the site and shadow analysis at two different time interval. All the system design analysis is performed using the sketchup software. Using geographic location, Annual solar power energy that can be generated, and corresponding total carbon saving is evaluated. Thus, this study may help for the feasibility study of the solar rooftop plant, we have carried a detailed Electricity Bill analysis and shadow analysis of the site to determine the size of the solar power plant and its approximate cost. In addition to this, commercial details and payback calculations are also performed in this paper.

KEYWORDS Energy Consumption, Academic Campus, IITGN, Solar PV Generation, Electricity bill, Energy conservation measures.

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1. INTRODUCTION

India, which has a population of 1.3 billion, has a huge demand for energy to support its quickly expanding economy. India has been working for more than 70 years to become energy independent, having been a country with a power deficit at the moment of independence. With more than 4 lakh MW of installed electricity capacity, we are currently a powersurplus nation. The proportion of renewable energy in India's power generation mix is quickly increasing in accordance with the country's aims for sustainable development. India has a huge potential for solar energy generation. India's geographical surface receives around 5,000 trillion kWh of incident energy annually, with the majority of areas receiving 4–7 kWh per square meter each day (Prakash et al., 2022). Solar photovoltaic (PV) power may be efficiently utilized in India, offering enormous scalability. Additionally, solar energy offers the option of distributed power generation and permits quick capacity expansion with minimal lead periods. Presently, India consumes over 1.13 trillion kWh per year while producing roughly 1.38 trillion kWh per year (Pandey, Pandey, & Tumuluru, 2022), indicating that production capacity is just a little bit more than actual demand. Due consideration was given to it as a result of India's enormous potential for decentralised solar installations. By 2030, the nation wants to have installed 500 Gigawatts (GW) of renewable energy, of which 280 GW (more than 60%) will be solar. India had 165.94 GW of installed renewable energy capacity (including hydro) as of October 2022, making up 40.6% of the nation's total installed power capacity. The Indian government promised to reach 100 GW solar power by the end of 2022 in which 40 GW of the generation were intended to come from Rooftop Solar (RTS). India had achieved just 7.9 GW of installed rooftop solar capacity as of June 2022. India's RTS programme has received a four-year extension and now aims at achieving its target of 40 GW RTS capacity addition, by March 2026.

A CEEW analysis found that DISCOMS might save Rs. 0.22per unit of power produced by rooftop solar installations. The residential categories offer the highest benefits, which can amount to up to Rs. 0.75 per unit. Academic institutions are among the industries that use a significant quantity of energy. Even though solar PV technology has evolved and there are places where it may be installed, the majority of academic institutions still rely on grid power or conventional fuel. Only a small number of academic institutions use solar energy "Solar energy generation on campus." Illinois Climate Action Plan (ICAP), 2020". By leveraging the available space on campus, institutional solar projects reduce power costs while also enhancing the institute's reputation. Around the world, numerous types of research on large-scale photovoltaic have been conducted, some of which have also involved university institutions. The authors of (Hasapis et al, 2017) aims to outline the design process for a sizable PV plant in an effort to move TUC campus closer to having only green energy sources. They found 2 MWp on-grid solar plant can produce1899 MWh annual electricity that fulfills 47% of campus demand saving 1,234 CO2e te and have estimated payback period of 4.2 years. In (Baitule & Sudhakar, 2017), authors have identified and assess the viability of an academic campus at MANIT in Bhopal, India, powered entirely by solar energy. A solar-based PV facility with a 5 MW capacity is anticipated to provide 8,000MWh of electricity per year in MANIT Bhopal while loweringits carbon footprint by 173,318 tonnes. In an another study, the authors of (Debbarma, Sudhakar, & Baredar, 2017) have designed and analysed a rooftop solar PV system for the MANIT hostel building and came to the conclusion that it would pay for itself in 8.2 years. Similar to this, (Khatri, 2016) conducted a case study financial analysis of a solar PV plant for a girls hostel building.

In (Obeng, Gyamfi, Derkyi, Kabo-bah, & Peprah, 2020), examining the viability of installing three distinct PV technology plants on the UENR Nsoatre Campus, Ghana to develop a 50 MW on-grid solar PV plant. To support clean energy initiative in campus, solar PV generation with a total capacity of about 500 kWp is also installed on the IITGN distribution network. All solar panels are rooftop mounted except solar carport area (Jha, Tiwari, & Pindoriya, 2022). Authors of (Ahshan, Al-Abri, Al-Zakwani, Ambu-Saidi, & Hossain, 2020), proposed a 98 kWp on-grid solar power plant which meets the Sultan Qaboos University (SQU) sports complex energy demand of 78.6 MWh/year and also may export 56 MWh/year of electricity to the utility grid. In (Sharma, & Kannan, 2015) evaluates the BITS Pilani, Dubai Campus's implementation of the Green Campus Initiative (GCI) by measuring the campus' carbon footprint output.

In the work presented in reference (Jha, 2019, 2020), a comprehensive 24-hour day-ahead scheduling strategy for solar photovoltaic (PV) based distributed generators (DGs) was introduced, with the primary objectives of optimizing the operational cost of the system and enhancing the overall performance of the distribution network.

In the above cited literature, either an economic or technical study of a big or small-scale PV plant has been done, but a simultaneous techno-economic planning based on the electricity bill and a shadow analysis of the site has not yet been done. This study aims to address the research gap left by the absence of a thorough and comprehensive review of the viability of a solar campus in earlier studies. Additionally, there is a dearth of information about India's development of sustainable green campuses. Through a case study, this project aims to close a research gap and recommend a sustainable VVIT campus.

2. STUDY METHODOLOGY

Vidya Vihar Institute of Technology (VVIT) Purnea is an engineering college established in 2009 by Vidya Vihar educational trust at Purnea, Bihar. It is affiliated to Aryabhatta Knowledge University, Patna and has approval of AICTE, New Delhi. The 17-acre college campus is located in a rapidly growing industrial region of Purnea and has a serene, verdant environment that is ideal for learning and creative thought. The entire campus is comprised of administrative and academic buildings, a workshop, a library, housing for students and staff.

2.1 Geographical Location of VVIT Purnea

Geographically, VVIT Purnea is located at Latitude 25.742476^{o} North and Longitude 87.461214^{o} East. The elevation from the sea level is approx. 118 ft. Google image of site is shown in Fig. 1.

Figure 1: Google image of site

2.2 Weather Data of Purnea

Purnea is in the northern hemisphere. Weather data of purnea is depicted in Table. 1. From Table 1 it is observed that, in Purnea, summer starts from late June until early September. The summer months are June, July, August, and September. The month with the most days with rain is July (28.13 days). December had the fewest days with precipitation (0.87 days). It has a pleasant environment that is typically warm and temperate.

Table 1: Monthly weather data of Purnea

		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Avg. Temperature	**°C**	16.9°	20.1°	25.3°	28.4°	28.3°	28.3°	28°	28.1°	27.4°	25.6°	22.2°	18.6°
	°F	62.4°	68.2°	77.6°	83.1°	83°	83°	82.4°	82.5°	81.3°	78°	72°	65.4°
Min. Temperature	**°C**	11.2°	13.8°	18.5°	22.4°	23.9°	25.2°	25.6°	25.6°	24.8°	21.7°	16.7°	12.8°
	°F	52.1°	56.9°	65.3°	72.3°	75°	77.4°	78.2°	78.1°	76.6°	71.1°	62.1°	55°
Max. Temperature	**°C**	22.9°	26.3°	32°	34.6°	33.2°	32.1°	31.3°	31.5°	30.8°	29.8°	27.8°	24.5°
	°F	73.3°	79.4°	89.5°	94.3°	91.8°	89.7°	88.3°	88.6°	87.5°	85.6°	82.1°	76.2°
Rainy Days (d)		1	2	2	6	13	18	21	20	18	8	1	1
Avg. Sun Hours (hours)		8.4	9.3	10.2	8.9	7.4	6.7	7.1	7.4	7.2	8.3	8.9	8.2

In Purnea, the summers are significantly rainier than the winters. This climate falls under the Koppen and Geiger classification of Cwa. The typical annual temperature in Purnea is 24.8° C (76.6°F). April is the hottest month of the year, with an average temperature of 28.4°C (83.1°F). January sees the lowest average temperatures of the year, hovering about 16.9°C (62.4°F). In Purnea, the average number of daily hours of sunshine is maximum in March. There are 315.13 hours of sunshine in total in March, or 10.17hours of sunshine on average each day. The average number of sunshine hours per day in Purnea is lowest in January. There are 252.66 hours of total sunshine in January, or 8.15 hours of sunshine on average each day. In Purnea, the annual sunshine total is estimated to be 2978.89 hours. There are 98.02 hours of sunshine on average each month.

2.3 Weather Data of Purnea

The sun path diagram at VVIT, Purnea over the year, is shown in Figure 2. Sun path describes the apparent arc-like path that the Sun appears to take across the sky on a daily and seasonal basis when the Earth revolves and orbits the Sun. Here, you can see the position of the sun and the times when it will be sunny in Purnea, India. For economically sound judgments on solar collector area, orientation, landscaping, summer shading, and the cost-effective use of solar trackers, precise location-specific knowledge about the sun path and climatic conditions is crucial.

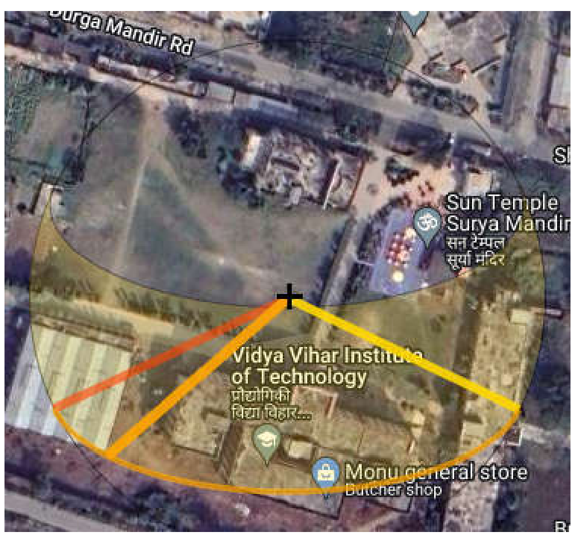
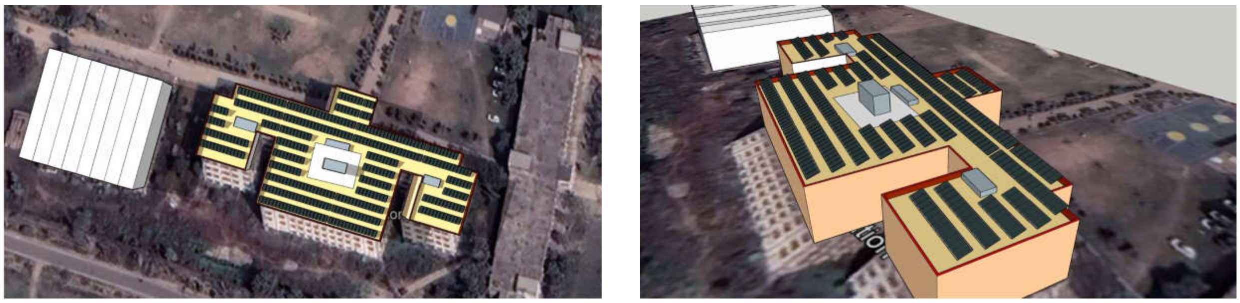


Figure 2: Sun path diagram at VVIT

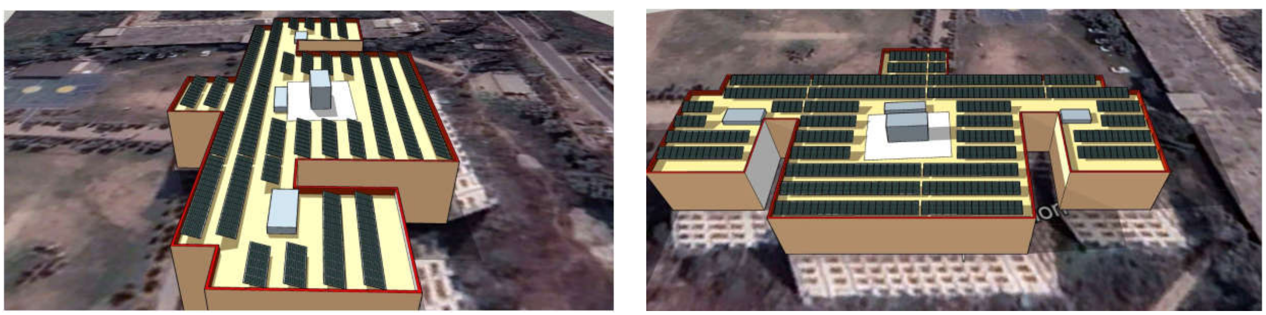
Figure 3 shows the top and side view of the academic building of VVIT Purnea, where we are planning to install solar PV power plant. Fig. 4 shows shadows pattern of academic building of VVIT Purnea for June month at 09:00 AM & 04:00PM for setting up a rooftop Grid-connected Solar Photovoltaic Power Plant. To demonstrate the variability of shadow pattern in winter season, Fig. 5 shows shadows pattern of same building of VVIT Purnea for December month at 09:00 AM& 04:00 PM. Only Shadow free areas have been considered for installation of the Solar PV Plant.



(a) (b)

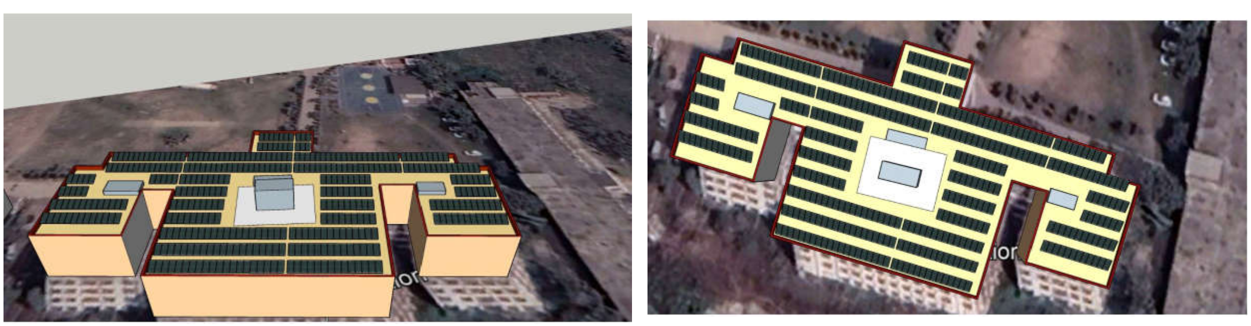
Figure 3: (a) Top view (b) Side view of academic building of VVIT Purnea

The above shadow analysis is done using the googles ketchup software. The type of solar PV module mounting arrangement is of Hot Dipped Galvanized Iron (HDGI) structure and module inclination is considered as South facing (Azimuth: 10 & 20.0^{o} tilt).



(a) (b)

Figure 4: Shadow pattern of academic building for June-2022at (a) 09:00 AM (b) 04:00 PM



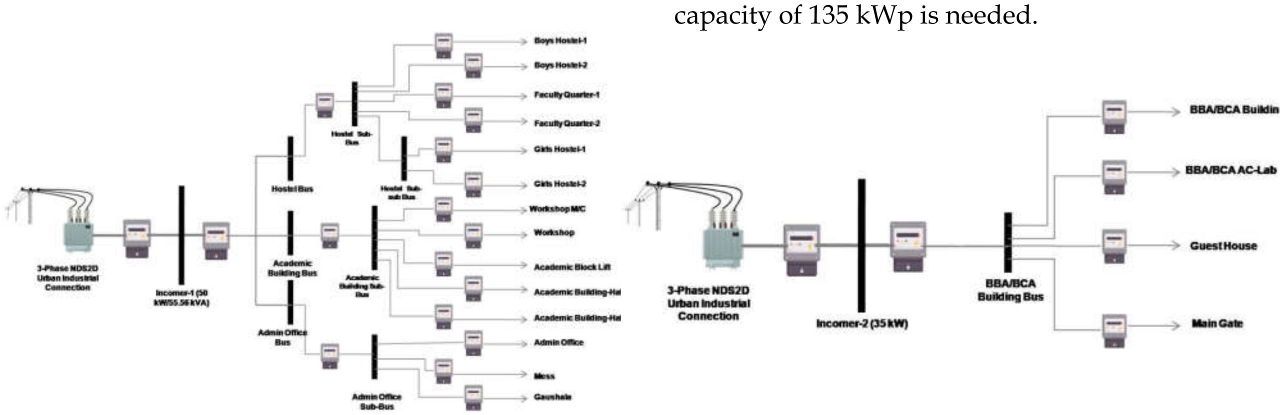
(a) (b)

Figure 5: Shadow pattern of academic building for December-2022 at (a) 09:00 AM (b) 04:00 PM

3. Electricity Bill Analysis

The VVIT Purnea received electricity from North Bihar Power Distribution Company Limited (NBPDCL) and falls under the LT category, which defines energy supply to low tension users having 11 kV lines for commercial purpose. The VVIT Purnea has taken two LT 3-Phase connections from NBPDCL having a contract demand of 55 kW and 35 kW respectively. Primary distribution (11 kV) utilized underground cable of 3Cx240sq.mm, while secondary distribution (415 kV) used underground cable measuring 3.5Cx300sq.mm. A multi-function energy meter is installed at the grid incomer, which measures the power, voltage, current, power factor and total energy consumption of the VVIT network. Specifically, Fig. 6here depicts the both radial network having contract demand of 55 kW and 35 kW of VVIT Purnea network as a single-line diagram.

Campus yearly energy consumption reports, monthly electricity bills, peak power demand, and other sources were used for the analysis of the campus's energy consumption. The average monthly energy consumption are 25642 and6512 units from above mentioned two connections. The tariff structure for calculation of fixed charge on contact demand and the energy consumption beyond the contract demand results in the inclusion of excess demand charge in electricity bill. According to the grid tariff's of NBPDCL the average electricity bill is of INR 195431 while considering tariff of INR 10.87 per unit. According to VVIT Purnea's energy usage patterns, a solar power plant with a total capacity of 135 kWp is needed.



(a) (b)

Figure 6: (a) Single line diagram of VVIT Purnea radial distribution network having contract demand of (a) 55 kW (b) 35 kW

4. SOLAR PV SYSTEM DESIGN

PV system design encompasses all decisions that must be made in order to dimension the PV system. It includes the tilt angle, orientation, inter-row space, and PV array sizing, among other things. Technology selection entails selecting the most efficient module, inverter, mounting structure, transformer, and other project-required accessories.

4.1 PV Module Selection

The solar PV module, which harnesses sunlight to deliver power in electrical form, requires the most investment of any component (Fu, Feldman, & Margolis, 2018). As a result, the physical characteristics, electrical characteristics, life/warranty, conversion efficiency, cost, and so on of the module should be thoroughly investigated. In terms of warranty, most modules have a design life of more than 20 years, but the degradation rate may increase significantly after 30 years (Dunlop, Halton, & Ossenbrink, 2005). As a result, the warranty must be a criterion for selecting a solar PV module. According to the standard power warranty, PV modules should deliver 90% of their initial nominal value after 10 years and 80% after 25years. Based on a market survey and considerations such as availability, cost, size, weight, power requirement, electrical characteristics, and so on, a polycrystalline photovoltaic module of 335 Wp power manufactured by Waaree was chosen for the project. The maximum power and efficiency of that PV module is 335 Wp and 17.01% respectively. The maximum power voltage and current rating are 37.8 V and 8.74 A. whereas, the open circuit voltage and short circuit current permodule is 46.9 V and 9.14 A. Rooftop solar installation is the design chosen for the VVIT Campus solar plants. Academic buildings are chosen for this project due to it is south facing and thus it is excellent for solar deployment. The total 404Nos. modules will be required to develop 13 kWp solar power plants and approx. 1350 square meter area will be required.

4.2 Inverter

To convert Direct Current (DC) electricity generated by the PV modules to Alternating Current (AC) power, an inverter is needed. They come in both central and string varieties, and the user and system requirements will determine which one is best for them. When selecting an inverter, aspects including cost, compatibility with grid requirements, maintenance capacity, and PV module compatibility should be taken into account. The inverter should have a 125 kW capacity based on the project's size. The inverter chosen for the project is an ABB central inverter because of its marketability and previous project usage.

4.3 Mounting Structure

In terms of PV mounting structures, either fixed-tilt or tracking types can be used depending on the application, but they must be simple and stable, have proper orientation and life, and meet the system's design parameters (tilt angle, orientation). Hot Dipped Galvanized Iron (HDGI) structure is considered for mounting the solar module. It is suitable for both ground and rooftop mounting, as well as flat and pitched roofs.

When solar panels are perpendicular to the sun's rays, they are most efficient. The default tilt angle for maximizing annual energy production, which is equal to the station's latitude plus 15^o in winter and minus 15^oin summer (Lunde, 1980). The VVIT Campus has latitude of 25.7 degrees. As a result, we choose 20 as the tilt angle. The azimuth (orientation) is considered as 10^o

5. PERFORMANCE ANALYSIS

The information gathered from primary and secondary sources was first organised and tabulated in Microsoft Excel for future reference. PV syst PC software was used for data analysis, calculation, and simulation. Input data for software was prepared in the appropriate file formats. All relevant data, such as meteorological data, module data, inverter data, losses data, orientation data, energy tariff data, and financial data of all relevant parameters, were supplied as input to the PV syst, so that the software could calculate all required output parameters from those data and provide the result.

5.1 Economic Analysis

The breakdown of various costs based on the guidelines of India's Central Electricity Regulatory Commission (CERC) &Ministry of Renewable Energy, GoI. The total annual cost is estimated to be around 58.80 Lakh INR including GST of 8.9%. Economic and energy studies entail analysing energy-related input data to calculate the total monthly energy available from the system while accounting for various losses that occur throughout the system. It also includes calculating self-consumed power, grid power, and grid power supplied to the grid. During the energy analysis, the system's performance ratio can be evaluated. The economic analysis considers financial transactions such as capital investment and operating and maintenance expenses, as well as the annual cash flow over the course of the project. It necessitates the cost of each component and service, as well as the tariff to purchase from the grid.

For plant feasibility, the most important factor is the plant's energy cost. The 135 kWp solar PV plant will generate 4434497 units of energy in 25 years, assuming a generation rate of 4 units per kWp. The payback period is the time it takes to recoup the cost of an investment and it is defined as the ratio of initial investment to the revenue generated per year. With the consideration of INR 10.80 as a grid tariff and2.50% as acceleration in grid tariff, the payback period of135 kWp solar PV project will be of 2.97 years. As can be seen from the long-term financial balance sheet, the institute will saved more than 5.05 crores over the system's entire lifecycle of 25 years.

5.2 CO_2 Emission Statistics

Currently, the VVIT campus's primary source of power is grid supply. There is, however, a diesel power generator plant for backup supply during grid power outages. Renewable energy system GHG emissions are attributed to the indirect emissions and do not cause any direct emissions. Solar PVGHG emissions are due to the energy spent during the manufacturing of the panels. The designed roof-top solar PV will produce approximately 197 MWh units of energy per year, and the Lifecycle Carbon Emission (LCE) from various sources to produce electricity is estimated over a 25-year project life. It is estimated that proposed rooftop solar PV saves about 3809.85 tonnes of CO_2 equivalent over its lifetime, which is compare against the electricity produced by a conventional power generation sources.

6. OPPORTUNITY AND CHALLENGES

There are numerous potential for large-scale commercial on grid solar PV projects in India. If the project is completed on schedule, it will be the first private institution in Bihar who haves solar PV project as well it will enhance the campus's reputation for using green energy and promoting related technology. The proposed solar PV power plant will help the college meet its energy needs and save money. From a business perspective, the project appears to be a wise investment because it offers a significant return on investment during the project's lifespan.

The initiative, however, faces several difficulties. A large scale project needs a significant financial commitment and a longer time frame to be completed. The investment will be impacted by changes in the inflation rate during this time. Similar to this, it appears that the government's subsidy for the production of green energy is too small in comparison to the project's investment. Due to the Campus's insufficient budget, it is difficult for it to be built using only self-funding; therefore, it needs a low-interest loan and subsidy from the government.

Introducing a subsidy based on power production policy for large-scale solar PV is necessary to address the obstacles to the development of the future large-scale institutional photovoltaic project and ensure that such a plant can receive a commensurate amount of funding. Government guarantees for low-interest loans should be made available to businesses looking to invest in solar PV installations. Similar to this, the government should take the initiative to use the room spaces of all public buildings to generate solar PV power, and private organisations should be encouraged to do the same by offering subsidy programs.

7. CONCLUSION

The VVIT Purnea, one of the biggest private institutions in Bihar, would have been the site of this study, which looked at the viability of a 135 kWp on-grid solar PV plant. The project location's irradiance level, climate, geographic feature, environmental circumstances, power needs, and grid characteristics are ideal for the installation of solar PV Plant. It was determined that the campus has sufficient rooftop space and acceptable solar irradiation for the development of a 135kWp solar PV power plant.

Over the course of the plant's 25-year lifespan, this project is anticipated to generate 4434497 units of clean energy. Since the Institute uses the majority of its energy during the day, or the solar day, transmission losses can be significantly decreased. Over the course of 25 years, this project will allow the Institute to save 5.05 crores of Indian rupees. In its lifespan, this plant will be able to mitigate GHG emissions by 3809.85t CO_2, which is a large amount. By lowering GHG emissions in comparison to alternative fuel sources, these projects will safeguard the environment. The lifespan of solar photovoltaic technology is only 25 years. However, because the campus as ample land space for the plant to be put into service, its proposed capacity may be increased in the future. The proposed solar plant will provide the Institute with the perfect opportunity to help the present Indian Government's goal of producing 40 GW RTS by March 2026. In terms of sustainable development and India's commitment to the UN sustainable development goals, the Institute campus being self-sufficient will be a groundbreaking move. Generally, the academic institutions and other major enterprises with expansive open rooftop spaces may construct solar PV plants there. The government should take the lead in promoting private sectors by offering subsidy programs.

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