

# A Feasibility Study of Solar Photovoltaic Systems in University Buildings under the ESG Framework

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## Abstract

The deployment of solar photovoltaic (PV) systems in university buildings represents a critical component of the transition toward sustainable campus energy management. Grounded in the Environmental, Social, and Governance (ESG) framework, this study aims to comprehensively assess the feasibility and performance of a rooftop PV system at a university in China. A mixed-methods approach was employed, including PVsyst-based energy simulation, a structured questionnaire survey (n = 486), and multiple linear regression analysis. The simulation results estimate an annual electricity output of 773,503 kWh, corresponding to a reduction of 603.33 tons of CO<sub>2</sub> emissions. Survey data reveal a generally high level of user satisfaction, with statistically significant gender differences observed in perceptions of resource conservation (p = 0.033). Regression analysis identifies electricity usage time as the most influential factor affecting consumption ( $\beta = 0.692$ , p < 0.001). The findings underscore the environmental and social benefits of PV implementation in university contexts, while also highlighting the necessity of data-driven governance strategies to enhance energy efficiency and system sustainability.

**Keywords:** Solar Photovoltaic, ESG Framework, University Campus, Carbon Emissions, User Satisfaction

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## 1. Introduction

With the advancement of China's "dual carbon" goals (carbon peaking and carbon neutrality) solar photovoltaic (PV) systems have emerged as a critical component of the clean energy transition. From 2014 to 2023, China's electricity consumption surged from 5,523.3 billion kWh to 9,224.1 billion kWh, with the tertiary sector experiencing a rapid annual growth rate of 12.2%. During the same period, solar PV generation expanded dramatically from 25 billion kWh to 583.3 billion kWh. In Henan Province, electricity usage in the tertiary sector increased by 216%, primarily driven by the expansion of universities. Campus building areas grew from 50.11 to 81.3 million m<sup>2</sup>, highlighting universities as ideal sites for PV system deployment due to their large roof areas and stable energy demand.

Globally, the ESG (Environmental, Social, Governance) framework has become a widely adopted approach for evaluating the sustainability of PV systems. Environmentally, PV systems are proven to significantly reduce carbon emissions when compared to fossil fuel-based energy (Zhang, 2022; Nakatani et al., 2024). However, life cycle impacts, including

emissions from panel manufacturing, should also be considered (Yang et al., 2024). Socially, user satisfaction and environmental awareness are key indicators of success. Research suggests that user-centered PV system design, complemented by policy incentives, can enhance public acceptance and promote sustainable behaviors (Muhammad et al., 2023; Al-Refaie & Lepkova, 2024). Governance-wise, multiple linear regression and other data-driven methods have been widely applied to model electricity consumption and guide energy management strategies in universities (Lin, 2023; Fumo & Biswas, 2015). Effective governance further relies on policy support and technical integration (Xu et al., 2023).

This study applies the ESG framework to comprehensively evaluate the performance of a rooftop PV system installed at a university in Henan Province. By integrating PVsyst simulation, carbon reduction analysis, questionnaire surveys, and statistical modeling, the research aims to assess environmental impact, social acceptance, and governance effectiveness. The findings are expected to provide empirical insights for the promotion and optimization of campus-based PV systems in support of China's green energy transformation.

## 2. Research Steps and Methodology

### 2.1 Research Framework and Evaluation Dimensions

This study adopts a multidimensional evaluation framework based on ESG (Environmental, Social, and Governance) principles to comprehensively assess the performance of solar photovoltaic (PV) systems in university buildings. The evaluation is divided into three dimensions:

#### 2.2.1 Environmental Dimension Evaluation

This dimension focuses on assessing the carbon emission reduction benefits of the rooftop PV system. Specifically, the study calculates the amount of CO<sub>2</sub> emissions avoided annually by converting the systems electricity generation into an equivalent carbon offset compared to coal-fired electricity. This provides a quantitative measure of the environmental contribution of the PV system in mitigating greenhouse gas emissions.

#### 2.2.2 Social Dimension

Evaluation This dimension evaluates the social impact of the PV system on university stakeholders, particularly in terms of environmental awareness, satisfaction, and electricity demand. It includes:

Satisfaction Survey: Conduct a survey of faculty and students to analyze the satisfaction with quality and safety, resource conservation, and environmental livability before and after the installation of the solar energy system.

Power Demand Matching: Compare actual PV generation with building electricity consumption to assess the effectiveness of the system in meeting actual energy demand.

#### 2.2.3 Governance Dimension Evaluation

This dimension focuses on the stability of solar PV equipment and the management of electricity consumption, including:

Lighting Efficiency: Measuring lighting intensity in the building before and after installation to assess visual comfort and system stability.

Energy consumption changes: Compare building electricity consumption before and after solar installation to study the energy-saving impact of photovoltaic systems.

Electricity Management Modeling: Using regression analysis to build predictive models of electricity demand based on variables such as human traffic, appliance load, and environmental conditions.

## 2.2 Data Collection and Analytical Methods

To ensure comprehensive analysis, the study employs a combination of field monitoring, questionnaires, interviews, and software-based data analysis. The overall data collection and analysis strategy is summarized by dimension below:

### 2.2.1 Environmental Dimension

#### Data Collection:

##### Meteorological Data:

Collected from the Meteororm database, including solar radiation intensity and wind speed, which affect system performance.

##### Electricity Generation

Data: Real-time PV output is monitored via smart meters and acquisition systems, and validated against PVSYST simulation results.

#### Research Method:

Quantitative analysis is conducted by converting real-time electricity generation data into CO<sub>2</sub> emission reductions using standardized emission factors. The reduction in carbon emissions is calculated by comparing the carbon intensity of coal-fired electricity generation, approximately 0.820 kg CO<sub>2</sub> per kWh, with the life-cycle emissions of rooftop solar photovoltaic (PV) systems, which are estimated at 41 g CO<sub>2</sub>-

eq per kWh (IPCC, 2014). This results in a net reduction of approximately 0.78 kg CO<sub>2</sub> for each kilowatt-hour of electricity generated by the rooftop PV system.

### 2.2.2 Social Dimension

#### Data Collection:

This study systematically collected satisfaction data on solar photovoltaic systems from 194 teachers and 292 students through the design of questionnaires and the conduction of interviews, while tracking the trend of changes in their environmental awareness. At the same time, an electric meter and data acquisition system were used to monitor the power generation of the photovoltaic system in real-time, combined with the actual electricity consumption data of the building, to evaluate the contribution of the photovoltaic system in meeting energy demand.

#### Research Methods:

In the social dimension of the study, a structured questionnaire was used for data collection, and statistical analysis was conducted using SPSS software. Descriptive statistics were applied to understand the basic characteristics of the sample and ensure data representativeness. Reliability analysis assessed the internal consistency of the scale to ensure measurement stability, while validity analysis (via principal component analysis) verified the structural soundness of the questionnaire.

Independent sample t-tests were used to compare differences in satisfaction and environmental awareness between groups (e.g., by gender or identity), and one-way ANOVA examined the effects of variables such as age and education level on user responses. Pearson correlation analysis was conducted to explore the relationships among the satisfaction dimensions. Together, these methods formed a rigorous and comprehensive analytical framework that provided a solid empirical foundation for subsequent modeling and conclusions.

### 2.2.3 Governance Dimension

#### Data Collection:

This study collected a complete year of data from Yellow River Jiaotong University:

Illuminance measurements were conducted at different locations and times before and after the installation of photovoltaic devices to detect changes in lighting.

Variable data: collected data on electricity consumption of the building, power of electrical equipment, electricity usage time, and pedestrian traffic in the building.

#### Research Methods:

Paired Sample T-Test: Assesses statistical significance in lighting intensity and energy use before and after installation.

Multiple Linear Regression: Develops predictive models of building electricity demand based on usage and environmental factors, supporting the development of energy management strategies.

## 3. Results and discussion

### 3.1 Environmental Dimension

#### 3.1.1 Solar Radiation, Temperature, and Performance Ratio

As shown in Figure 1, monthly solar radiation levels in Jiaozuo exhibit a distinct seasonal pattern, with the highest radiation occurring from April to August. Figure 2 demonstrates corresponding temperature variations, showing peak ambient temperatures during July and August, often exceeding 27°C. These two environmental variables significantly influence photovoltaic performance.

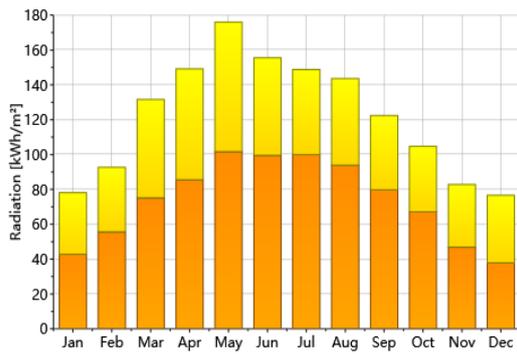


Figure 1. Changes in solar radiation per month throughout the year

Temperature variations are also shown in Figure 2. When temperatures rise, the operational efficiency of the photovoltaic system tends to decrease. This effect is especially noticeable in the high-temperature months such as July and August, where elevated temperatures may lead to reduced efficiency of the solar panels.

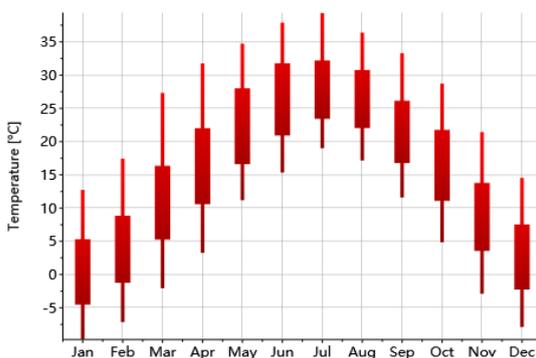


Figure 2. Monthly Temperature Variation Throughout the Year

### 3.1.2 Power Generation and Environmental Benefits

To quantify the actual power generation capacity of the photovoltaic system, this study employed the PVsyst software for generation simulation. By inputting meteorological data into PVsyst, the simulation results illustrate the variations in the photovoltaic system's power output under different monthly and meteorological conditions, which are then compared with the actual generated power.

In the simulation data, "E\_mock" represents the simulated annual power generation of the photovoltaic system, while "E\_Actual" denotes the actual annual power generation (measured in kWh), reflecting the system's performance during real operation.

Although summer months received high solar irradiation, the performance ratio (PR) showed a decline - for example, July reached 149 kWh/m<sup>2</sup>, but PR dropped to 0.841 (see Table 1). This indicates that high irradiation alone does not guarantee optimal system efficiency, highlighting the need for improved PV system design and operation.

Based on PVsyst simulation using Typical Meteorological Year (TMY) data, the estimated annual energy output of the rooftop PV system was 788,449 kWh, while the actual measured output reached 773,503 kWh, indicating a minor deviation of 1.89%. This close

alignment demonstrates both the high reliability of the PV system and the accuracy of the simulation model.

The monthly power generation peaked in May at 80,284 kWh, and was lowest in December at 47,514 kWh, corresponding to seasonal solar radiation and temperature fluctuations. Despite favorable irradiation conditions, the summer months (June - August)

showed slightly lower PR values due to heat-related efficiency drops, consistent with findings in PV literature.

According to the emission factor of 0.78 kg of carbon dioxide/kWh, the annual carbon emission reduction brought by the photovoltaic system can reach 603.33 tons of carbon dioxide, which fully demonstrates the environmental value of the system.

**Table 1. Annual power generation data**

month	GlobHor	DiffHor	T_Amb	FF	E_mock	E_Actual	PR
	kWh/m <sup>2</sup>	kWh/m <sup>2</sup>	°C	m/s	kWh	kWh	ratio
January	78	43	0.48	2.4	51119	50182	0.951
February	93	56	3.81	2.6	57519	56453	0.937
March	132	75	10.78	2.9	66633	65387	0.905
April	149	86	16.39	2.9	76445	74986	0.878
May	176	102	22.48	2.7	81846	80284	0.857
June	156	100	26.48	2.4	76645	75166	0.841
July	149	100	27.98	2.2	76340	74893	0.841
August	144	94	26.38	2.1	75017	73571	0.849
September	122	80	21.26	2	66749	65460	0.866
October	105	67	16.29	2.1	60790	59641	0.889
November	83	47	8.69	2.3	50927	49966	0.919
December	77	38	2.8	2.4	48419	47514	0.94
Year	1461	886	15.38	2.4	788449	773503	0.882

### 3.2 Social Dimension

This study focuses on user satisfaction with solar photovoltaic (PV) systems in universities and their influence on environmental awareness. A structured questionnaire was designed to assess three key dimensions: Quality and Safety, Resource Conservation, and Environmental Livability. Each item was measured using a five-point Likert scale, ranging from 1 (Strongly Disagree) to 5 (Strongly Agree), in order to quantify respondents' subjective evaluations and perceptions. The structure and content of the questionnaire were informed by the methodology and scale construction approach proposed by Xu (2020) in his study "A Study on Resident Satisfaction with Green Housing".

To ensure the representativeness and scientific validity of the data, this study employed a stratified random sampling method, categorizing the university population by gender and identity (students and faculty) and distributing questionnaires proportionally. Based on a total university population of approximately 22,000 individuals (including around 20,300 students and 1,700 faculty members),

the required sample size was calculated using Taro Yamane's (1967) formula, assuming a 5% margin of error and a 95% confidence level. The theoretical minimum sample size was 393. A total of 500 questionnaires were distributed, and 486 valid responses were collected, exceeding the minimum requirement and ensuring the reliability of statistical analysis.

In terms of gender distribution, 174 respondents (35.8%) were male, and 312 (64.2%) were female. Regarding identity, 292 (60.1%) were students and 194 (39.9%) were teachers. The age distribution was relatively balanced: 26.3% were aged 18 - 25, 24.5% were 25 - 45, 24.9% were over 45, and 24.3% were under 18 years old. As for education level, 34.4% had a diploma or below, 33.7% held a bachelor's degree, and 31.9% had a master's degree or higher. Regarding time at the university, 28.0% had been there for more than five years, 24.5% for 3 - 5 years, 25.1% for 1 - 3 years, and 22.4% for less than one year. Overall, the sample structure is well-balanced and covers a wide range of demographic characteristics, enhancing the generalizability and interpretive value of the study findings.

### 3.2.1 Reliability and Validity

As shown in Table 2, the internal consistency across all dimensions was excellent (Cronbach's  $\alpha > 0.94$ ). KMO values exceeded 0.91, and Bartlett's test results ( $p < 0.001$ ) confirmed data suitability for factor analysis. The cumulative variance explained for each dimension was also high, ranging from 81.14% to 84.04%, indicating robust construct validity.

### 3.2.2 Group Differences in User Satisfaction

To assess whether demographic factors influenced satisfaction with the PV system, t-tests and ANOVA were performed as shown in Table 3.

The results indicated that gender had a statistically significant effect only on the Resource Conservation dimension ( $p = 0.033$ ), with female users reporting higher satisfaction ( $M = 4.09$ ) than males ( $M = 3.86$ ), suggesting that females may be more responsive to energy-saving efforts. Additionally, education level showed a significant effect on the Quality and Safety dimension ( $p = 0.046$ ), indicating that perceived quality may be influenced by users' educational backgrounds. In contrast, no significant differences were observed between students and faculty, or across variables such as age, length of stay on campus, and level of understanding of PV systems ( $p > 0.05$ ).

Table 2. Reliability and Validity of User Satisfaction Questionnaire across Three Dimensions

Dimension	Items	Cronbach's $\alpha$	KMO	Variance Explained (%)
Quality and Safety	6	0.955	0.94	81.96
Resource Conservation	5	0.942	0.913	84.04
Environmental Livability	8	0.969	0.969	81.14

Table 3. Group Differences in User Satisfaction Based on Demographic Variables

Variable	Significant Effect	Dimension	P
Gender	Yes (Females > Males)	Resource Conservation	0.033
Education Level	Yes	Quality and Safety	0.046
Other Demographics	No	All Dimensions	>0.05

### 3.2.3 Correlation Between Dimensions

As shown in Table 4, Pearson correlation analysis revealed no

statistically significant relationships among the three satisfaction dimensions, suggesting that users view quality and safety, resource conservation, and environmental livability as distinct constructs.

Table 4. Correlation Between Satisfaction Dimensions

Dimension Pair	r	P	Sig.
Quality & Safety vs Resource Conservation	0.029	0.518	Not Sig.
Quality & Safety vs Environmental Livability	0.07	0.125	Not Sig.
Resource Conservation vs Environmental Livability	-0.036	0.429	Not Sig.

### 3.2.4 Summary and Interpretation

The results suggest that the solar PV system enjoys broad social acceptance across campus groups. Female respondents show higher sensitivity to energy conservation aspects, which can guide the design of targeted energy education initiatives. The independence of perception dimensions further emphasizes the need for differentiated strategies to improve user satisfaction and engagement with campus sustainability efforts.

### 3.3 Governance Dimension

To evaluate the governance impact of solar photovoltaic (PV) systems in campus buildings, this study combined

independent-sample t-tests and multiple linear regression to assess changes in electricity performance and the key influencing factors.

#### 3.3.1 System Stability and Electricity Use

Based on independent sample t-test results shown in Table 5, no significant difference was found in illuminance levels before and after the installation of the photovoltaic (PV) system ( $t = -0.832, p = 0.407$ ), indicating that lighting quality remained stable. A significant difference was observed between PV power generation and electricity consumption ( $t = 3.658, p = 0.001$ ), with power generation ( $M = 64,458.58 \text{ kWh}$ ) exceeding total electricity usage ( $M = 52,262.07 \text{ kWh}$ ), demonstrating the system's sufficient energy supply capacity. Moreover, electricity consumption before and after installation also showed a significant increase ( $t = -4.848, p < 0.001$ ), rising from  $59,794.65 \text{ kWh}$

to 62,066.97 kWh. This increase may be attributed to post-installation commissioning, expanded equipment use, and growing campus activity rather than inefficiency of the PV system itself. These findings emphasize

the need for refined energy consumption planning and dynamic load management to ensure the sustainability of solar energy integration in university buildings.

**Table 5. T-Test Results: PV Installation Impact on Lighting and Electricity Consumption**

Independent sample T-test				
Indicator	M	SD	t	p
Before installation	230.7292	24.69006	-0.832	0.407
After installation	235.2833	28.75704		
Power generation	64458.58	11512.72	3.658	0.001
Electricity Consumption	52262.07	928.91		
Before installation	59794.65	1087.26	-4.848	< 0.001
Electricity consumption				
After installation	62066.97	1206.01		
Electricity consumption				

### 3.3.2 Key Factors Influencing

#### Electricity Consumption

To identify the key drivers of building electricity consumption, a multiple linear regression analysis was conducted using seven independent variables, including electricity usage time, air conditioning power, computer power, printer power, multimedia power, the power of other electrical appliances, and flow of people.

### Significant Influencing Factors

As shown in Table 6,

electricity usage time was the most significant factor influencing electricity consumption ( $\beta=0.692$ ,  $p < 0.001$ ), indicating that longer usage duration substantially increases energy demand. Other significant positive contributors included air conditioning power ( $\beta=0.178$ ,  $p < 0.001$ ), multimedia power ( $\beta=0.099$ ,  $p = 0.002$ ), computer power ( $\beta=0.086$ ,  $p = 0.010$ ), and the power of other electrical appliances ( $\beta=0.050$ ,  $p = 0.045$ ), all of which reflect varying degrees of equipment-driven electricity use. In contrast,

printer power ( $\beta= 0.026, p = 0.280$ ) and flow of people ( $\beta= -0.027, p = 0.354$ ) were not statistically significant, suggesting minimal or indirect influence on electricity consumption patterns.

### Multicollinearity and

### Residuals

All variance inflation factor (VIF) values are below 10 (range: 1.079 - 6.158), suggesting no serious multicollinearity among independent variables. Additionally, residuals were randomly and evenly distributed, satisfying the assumptions for regression analysis and confirming the model's robustness.

**Table 6. Results of multiple linear regression analysis: main factors affecting building electricity consumption**

Variable	regression coefficient	Standard Error	Beta	t	p	VIF
Constant	49616.269	553.752	—	89.600	<0.001	—
Electricity usage time	48.006	3.947	0.692	12.164	<0.001	6.158
Air conditioning power	0.999	0.284	0.178	3.522	<0.001	4.840
Computer power	0.930	0.353	0.086	2.631	0.010	2.037
Printer	1.622	1.490	0.026	1.089	0.280	1.079
Multimedia	0.681	0.208	0.099	3.273	0.002	1.749
Power of other electrical appliances	0.322	0.158	0.050	2.036	0.045	1.140
Flow of people	-0.025	0.027	-0.027	-0.933	0.354	1.584

The multiple linear regression equation for building electricity consumption is derived as follows:  $Y^{\wedge}=49616.269+48.006X1+0.999X2+0.930X3+1.622X4+0.681X5+0.322X6-0.025X7$

$Y^{\wedge}$ : Predicted electricity consumption

X1: Electricity usage time (hours), indicates the total operating time of the equipment.

X2: Air conditioning power (kW), which indicates the power requirement of the air conditioning equipment.

X3: Computer Power (kW), which indicates the power requirements of computer equipment.

X4: Printer Power (kW) indicates the power requirement of the printer device.

X5: Multimedia power (kW) indicates the power requirement of multimedia equipment (such as projectors, speakers, etc.).

X6: Other electrical power (kW) represents the power demand of all other equipment not listed separately, such as electric lights, electronic clocks, etc.

X7: Flow of people refers to the number or density of people flowing in a space.

Based on this equation, a multivariable linear regression (MLR) analysis model for building electricity consumption can be constructed. It is applied to predict electricity consumption in universities, identifying abnormal deviations in electricity use, and managing electricity consumption.

#### 4. Conclusion

This study, based on the ESG framework, systematically evaluated the application performance of solar photovoltaic (PV) systems in university buildings from three dimensions: environmental, social, and governance. The evaluation was supported by empirical evidence through field data collection, questionnaire surveys, and multiple linear regression analysis.

##### Research results on ESG in solar photovoltaic systems

**In the environmental dimension:** the PV system achieved an average annual power generation of 773,503 kWh, resulting in an estimated annual carbon reduction of approximately 603.33 tonnes. These figures demonstrate significant decarbonization benefits and ecological value, aligning with the sustainable development goals of higher education institutions.

**In the social dimension:** overall user satisfaction was relatively high. Female users reported significantly higher satisfaction in the "resource conservation" dimension than males ( $p = 0.033$ ). Moreover, the more familiar users were with the PV system, the higher their satisfaction, indicating that enhanced awareness and education efforts can increase system acceptance.

**In the governance dimension:** the system did not significantly affect lighting quality ( $p = 0.407$ ), but total electricity consumption increased markedly after installation ( $p < 0.001$ ), which warrants attention. Regression analysis identified electricity usage duration as the most influential factor ( $\beta = 0.692$ ), while high-power devices also contributed significantly to the load, highlighting the importance of behavioral management and equipment control in campus energy governance.

Solar PV systems demonstrate strong technical feasibility, environmental benefits, and social acceptance in the university context. However, their continued application requires more refined governance approaches and supporting mechanisms to

maximize the effectiveness of green energy utilization. The PV system demonstrates technical and operational feasibility, yet economic feasibility and long-term maintenance costs warrant further study.

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