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Analysis of Investment Efficiency in New Energy Projects by Traditional Energy Enterprises: A Case Study of Rooftop Photovoltaic Power Projects in the Chongqing Regional Market

Runqi Zeng[1]*, Xiangyu Wen[1], Xiaochong Gou[1], Na Wang[2], Ziqi Zhou[2], Lin Peng[3]

[1]Sichuan Huayou Group Co., Ltd., Chengdu 610094, Sichuan Province, China
[2]Chongqing University of Science and Technology, Shapingba District, Chongqing 401331, China
[3]Chongqing Gas Field, PetroChina Southwest Oil and Gas Field Company, Chongqing, China 400700

***Corresponding author:** Runqi Zeng, zrq@petrochina.com.cn

Abstract: Under the "dual carbon" goals, transitioning effectively in the traditional energy industry requires investment in photovoltaic (PV) power projects as a major development direction. Accurately assessing the investment efficiency of PV projects is a crucial reference for project decision-making. This study analyzed PV power generation evaluation methods and project efficiency models, integrating national and industry reports to select an appropriate model for calculating PV project efficiency. Using facilities suitable for rooftop PV projects in certain traditional energy enterprises in Chongqing as examples, the study calculated that the internal rates of return (IRR) for all test sites exceeded the enterprises' capital costs, confirming their investment value. Recommendations include: (1) Prioritizing projects with higher efficiency; (2) Simultaneous implementation of projects with similar efficiency in the same administrative area; (3) Maximizing surplus electricity revenue in cases of excess generation. This research aims to support traditional energy enterprises in transitioning to new energy projects and offers a reference for calculating investment efficiency in various PV power projects, including ground-mounted and wall-mounted PV systems.

Keywords: Rooftop photovoltaics; Investment efficiency; Internal rate of return

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1. Introduction

Since the 18th National Congress of the Communist Party of China, President Xi Jinping has repeatedly emphasized the importance of promoting the development of new and clean energy, introducing a new energy security strategy of "Four Revolutions and One Cooperation," with energy system reform as one of the four revolutions. New energy encompasses resources such as photovoltaics, nuclear power, and wind energy, as well as distributed electricity and energy for vehicles. Policies such as the "Implementation Plan for Promoting High-Quality Development of New Energy in the New Era, the 14th Five-Year Plan for Energy Development in Chongqing (2021–2025)," and the "Opinions on Promoting High-Quality Development of Photovoltaics in New Residential Buildings" have called for accelerating the development of the distributed photovoltaics (PV) industry and promoting the use of new energy in the construction sector. They also encourage the simultaneous development of new housing and PV facilities.

These policies have provided strong support for the PV industry, enhancing the investment efficiency of PV power projects and fostering orderly development of the new energy sector. As PV power technology in China advances, costs continue to decline, market size expands, and PV power generation becomes a key method for transforming the energy structure and achieving carbon peak and neutrality goals.

Against this backdrop, many traditional energy enterprises in Chongqing are actively responding to national policies by implementing green, low-carbon strategies and vigorously expanding new energy businesses. With numerous suitable structures, such as canopies, for promoting rooftop PV installations, these enterprises consider rooftop PV investments a strategic priority. However, the projects' long investment cycles and significant upfront costs have made their economic feasibility a focus of industry attention.

Reliable investment efficiency data serves as a critical reference for project implementation. Starting with the need to calculate project efficiency for rooftop PV power projects, this paper explores methods for evaluating solar energy resources and calculating PV power generation. It presents a complete process for calculating project investment costs and revenues, using solar resource data to assess the investment efficiency of PV projects at 242 sites in Chongqing. The aim is to determine the IRR and dynamic payback period of each project, providing decision-making recommendations for traditional energy enterprises regarding rooftop PV investments.

2. Literature review

Solar energy, characterized by its widespread availability and inexhaustibility, is a renewable resource with relatively low current utilization rates. PV is the primary means of harnessing solar energy. PV applications mainly include rooftop PV, ground-mounted PV, and wall-mounted PV. Ground-mounted PV systems require additional land and favorable sunlight conditions and are relatively expensive. Wall-mounted PV systems, typically installed vertically to integrate with building structures, have lower energy conversion efficiency. In contrast, rooftop PV systems are gaining significant attention due to higher sunlight intensity, longer sunlight exposure, and superior energy conversion efficiency per unit area [1,2].

Accurately evaluating the potential of solar energy resources is a critical prerequisite for their development. Resource evaluation methods can connect the distribution of local solar energy resources with project design and development plans for renewable energy, thereby improving utilization rates and conversion efficiency [3]. To effectively utilize solar resources in Chongqing, it is essential to establish an objective and reliable evaluation for this region. Located in East Asia, adjacent to the Pacific Ocean, China predominantly features plains, enabling it to receive ample wind and solar energy. However, Wang *et al.* classified Chongqing's solar resources as belonging to the fourth category—a region with scarce solar resources [4].

Significant progress has been made in assessing solar and wind energy, with extensive research yielding fruitful results. These include evaluation methods based on spatial analysis, analytic hierarchy process, and resource theories. For instance, Li *et al.* introduced a comprehensive indicator system from the perspectives of solar resource potential and grid-connected PV system performance. They developed a formula for estimating grid-connected electricity output and applied it to assess PV generation potential in Wuhan [5]. However, traditional evaluation methods, while yielding precise results, often require substantial time. To address these limitations, GIS automation theory was introduced. GIS automation effectively reflects the spatial distribution of regional buildings, enabling refined energy assessments while enhancing the application value of the evaluation techniques.

Wang *et al.* utilized the spatial analysis capabilities of GIS platforms to study the spatial distribution of solar radiation intensity and PV generation potential across China [4]. Zhang *et al.* established refined evaluation indicators and standards for solar and wind energy from the perspectives of resource abundance, stability, and usability [3]. Wu *et al.* developed a comprehensive wind energy resource assessment method for the Bohai Rim terrestrial area using GIS technology, incorporating an inverse distance weighted spatial interpolation model based on wind energy density [6]. Similarly, Wang *et al.* proposed a PV power plant siting and generation potential prediction model based on ArcGIS and multi-factor evaluation, focusing on the spatiotemporal distribution of China's PV resources [7].

Existing studies have also employed industry report data to reasonably and accurately estimate the costs associated with PV installations, yielding reliable experimental results. Hu *et al.* predicted China's LCOE, initial investment, and operation and maintenance costs using historical "China Wind and Solar Energy Yearbook" reports and the "2022–2023 China PV Industry Development Roadmap." By analyzing PV generation potential along Chinese highways, they provided accurate assessments of generation potential and investment costs for such projects [8].

Xue *et al.* explored the operational strategies of distributed PV systems under three different investment entities and established a lifecycle cost-benefit model for distributed PV. Their study effectively calculated the performance of a grid-connected PV project integrated with commercial park buildings [9]. Wen and Gao using a distributed PV station project combining aquaculture and PV as an example, integrated investment decision-making tools such as IRR, NPV, and payback period analyses to enhance the scientific basis of investment decisions [10]. Jiang *et al.* conducted an economic analysis of CIGS PV curtain walls using lifecycle theory, focusing on incremental costs and benefits throughout the lifecycle. Using Shenyang as a case study, they concluded that such applications are economically viable [11].

While traditional indicator models yield precise evaluations, they are often complex and time-consuming. The introduction of GIS technology offers an effective method to reflect the spatial distribution of test points and provides more accurate estimates of PV generation. By leveraging solar radiation data and calculating project unit energy output, combined with traditional efficiency assessment models, it is possible to determine the economic efficiency of projects effectively and accurately.

3. Data sources and project overview

3.1. Data sources

The data utilized in this study are listed in **Table 1**.

Table 1. Data sources

Data	Source
Solar radiation levels	Solargis (https://solargis.com/cn)
PV system lifespan	Literature sources
Industrial and commercial electricity prices	Chongqing Pricing Notice [2023] No. 575 (https://fzggw.cq.gov.cn/zwgk/zfxxgkml/jgxx/jgzc/202301/t20230131_11553007.html)
Investment cost data	China Photovoltaic Industry Association (https://www.chinapv.org.cn/Industry/resource_1380.html)
Chongqing administrative divisions	Administrative Division Network (http://www.xzqh.org/show/china/50/2020.html)

3.2. Project overview

Given the circumstances of traditional energy enterprises in Chongqing, there are numerous potential sites within the city for rooftop PV investments. This study calculates data for 242 project sites: 72 located in central urban areas, 86 in new urban districts, 34 in southeastern Chongqing, and 53 in northeastern Chongqing. Using QGIS software, the spatial distribution of the 242 test points is shown in **Figure 1**. While the central urban areas and new districts cover smaller land areas, their test points are more concentrated compared to the relatively dispersed southeastern and northeastern regions.

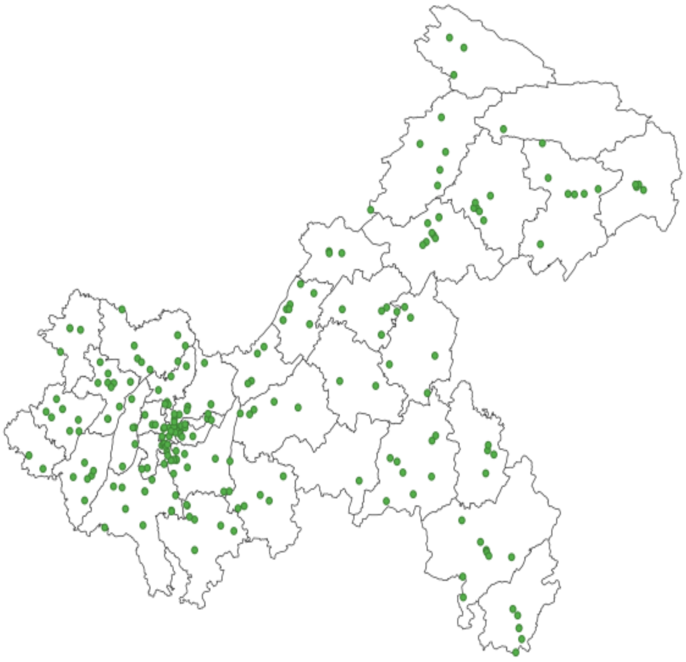

Figure 1. Spatial distribution of test points in Chongqing

Data analysis reveals that 26% of the 242 test points exhibit horizontal solar radiation levels between 855 kWh/kWp and 866 kWh/kWp, while 73% fall between 844 kWh/kWp and 888 kWh/kWp. Based on the solar resource distribution data published by the National Energy Administration (**Table 2**), Chongqing is classified as a region with average solar resource distribution. Additionally, given the substantial electricity demand specific to traditional energy enterprises, the electricity generated by rooftop PV systems is assumed to be used entirely for internal consumption, excluding any surplus electricity fed into the grid or associated revenues.

Table 2. National solar radiation levels and regional distribution

Category	Annual total (MJ/m²)	Annual total (kWh/m²)	Average annual irradiance (W/m²)	Main regions
Most abundant	≥ 6,300	≥ 1,750	≥ 200	Western Inner Mongolia (Ejina Banner), western Gansu (Jiuquan), and similar areas
Very abundant	5,040–6,300	1,400–1,750	160–200	Most of Xinjiang, eastern Inner Mongolia (east of Ejina Banner), and similar areas
Moderately abundant	3,780–5,040	1,050–1,400	120–160	Northern Inner Mongolia (north of 50°N), most of Heilongjiang, and similar areas
Average	< 3780	< 1,050	< 120	Eastern Sichuan, most of Chongqing, north-central Guizhou, and similar areas

3.3. Assumptions

Currently, China's distribution grid exhibits low levels of intelligence, limiting its capacity to integrate distributed renewable energy. The government is actively promoting research in this area and exploring demonstration projects for DC distribution grids adapted for distributed renewable energy. Therefore, this study assumes that all rooftop PV projects, upon completion, will successfully connect to DC distribution grids.

4. Project investment and benefit assessment

The siting of rooftop PV projects must consider environmental and cost factors as well as topographical and geographical conditions related to solar energy availability. See **Table 3** for details.

Table 3. Project parameters

Parameter	Value	Unit
Module conversion efficiency	0.82	-
Correction factor	0.8	-
Unit electricity price	0.597975	Chinese yuan/kWh
PV module lifespan	25	years
Construction period	1	year
Initial investment cost	3.18	Chinese yuan/W
Operation and maintenance cost	0.047	Chinese yuan/(W/year)

The net present value (NPV) is calculated as:

$$V_{NPV} = \sum_{t=1}^{N} \frac{1}{(1+i)^t}(B_t - C_t)$$

where V_{NPV} is the NPV of the rooftop PV project over its lifestyle (Chinese yuan), B_t is the cash inflow in year t (Chinese yuan), C_t is the cash outflow in year t (Chinese yuan), and i is the discount rate (%).

The internal rate of return (IRR) is calculated as:

$$\sum_{t=1}^{N} \frac{1}{(1+I_{RR})^t}(B_t - C_t) = 0$$

where I_{RR} is the internal rate of return (%) and $(B_t - C_t)$ is the net cash flow in year t (Chinese yuan).

The dynamic payback period is defined as the time at which the cumulative NPV of net cash flows becomes zero. It is calculated as:

$$T = t^{'} - 1 + \frac{\left|\sum_{t=1}^{t^{'}-1} \frac{1}{(1+i_0)^t}(B_t - C_t)\right|}{\frac{1}{(1+i_0)^{t^{'}}}(B_{t'} - C_{t'})}$$

where T is the dynamic payback period (years) and t' is the year in which NPV becomes positive.

Theoretical annual power generation is calculated as:

$$P = H \cdot A \cdot \eta \cdot K$$

where P is the annual power generation (kWh), H is the total annual solar radiation (kWh/m²), A is the PV array area (m²), η is the module conversion efficiency, and K is the correction factor.

Cash inflows are calculated as:

$$B_t = P \cdot E$$

where B_t is the cash inflow in year t (Chinese yuan), P is the annual power generation (kWh), and E is the unit electricity price (Chinese yuan/kWh).

4.1. Results

Given the large number of test sites (242), only the top 5 and bottom 5 sites are listed in **Table 4**.

Table 4. Benefit assessment results

Test site	Investment performance
Provincial Highway 110 (Tianfu Town, Wengjia Village, North of Tea Plantation)	Excellent
Provincial Highway 103 (Qixia Township)	Excellent
Wangxia Road	Excellent
Group 7, Da'e Community	Excellent
106 Provincial Road (11 km Southeast, near Zhiping Primary School)	Excellent
...	...
Northwest of Sand Interchange and G50 Highway Intersection (150 m)	Poor
Hanguan Road No. 2	Poor
Yuqian Village	Poor
Group 2, Lion Community, Gaogu Town	Poor
Foshan East Road No. 104	Poor

Most sites exhibit concentrated IRR, as shown in **Figure 2**. **Figure 3** and **Table 5** indicate that sites with excellent performance are primarily located in northeastern Chongqing, while sites with good or poor performance are concentrated in central urban areas and new districts. Most sites have dynamic payback periods between 6.8 and 7.1 years, aligning with existing studies (e.g., Xue *et al.* [9], Wen and Gao [10], Lu *et al.* [12]) on PV projects, as shown in **Figure 4**.

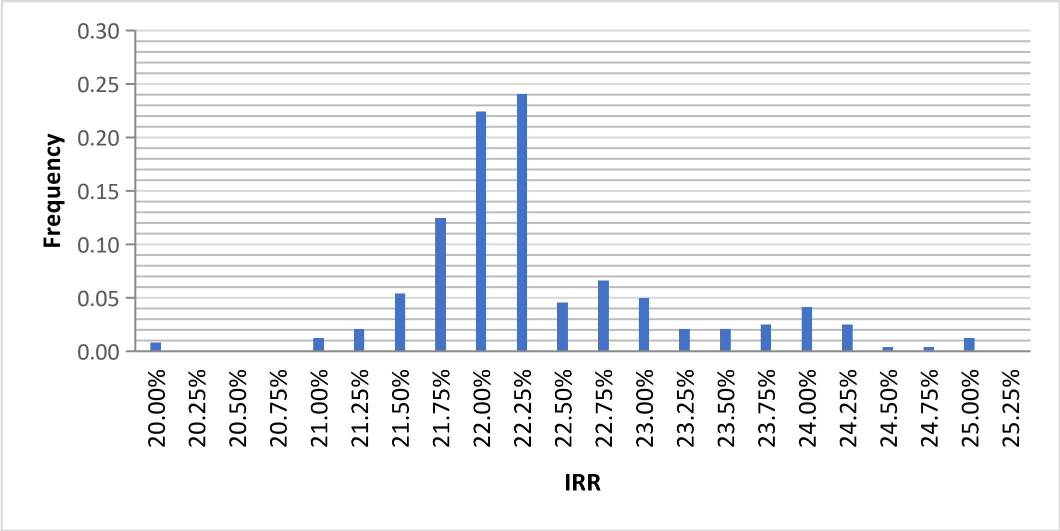

Figure 2. IRR-frequency chart

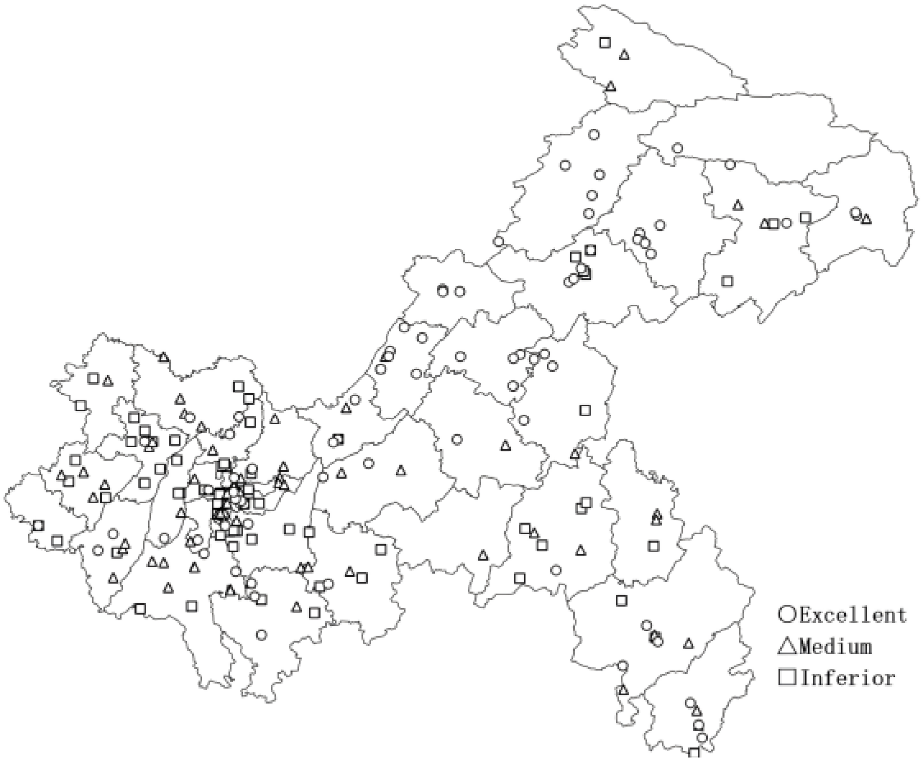

Figure 3. Spatial distribution of measurement points

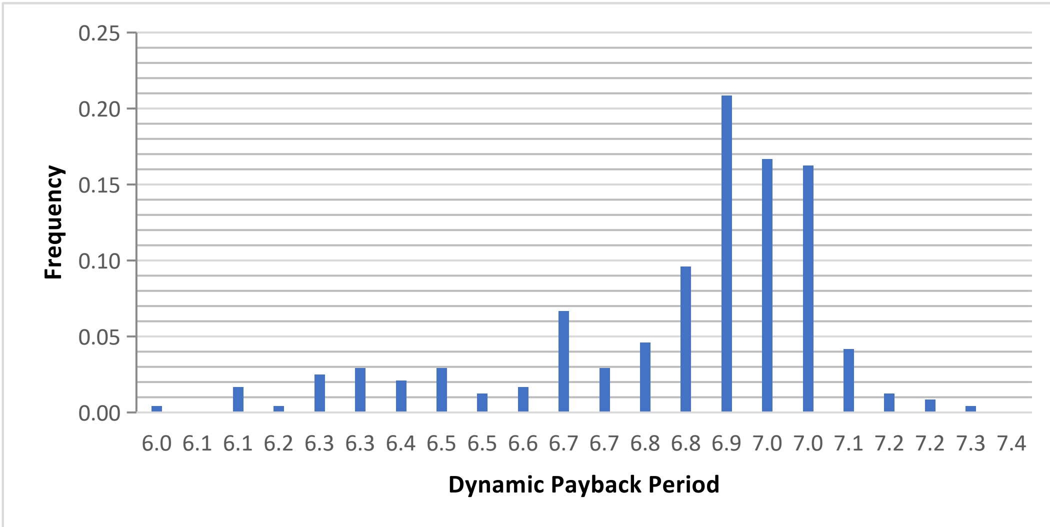

Figure 4. Dynamic payback period-frequency chart

Table 5. Test site distribution by region

Region	Excellent	Good	Poor	Total
Central urban area	14	28	30	72
New urban districts	18	33	34	85
Southeastern Wuling Mountain area	11	12	10	33
Northeastern Three Gorges area	37	7	8	52
Total	80	80	82	242

In conclusion, all 242 test sites exhibit IRRs higher than enterprise capital costs, indicating high investment value. Sites such as Provincial Highway 110 (Tianfu Town, Wengjia Village) and Provincial Highway 103 (Qixia Township) offer the highest investment returns, with dynamic payback periods of around six years. Sites such as Sand Interchange, G50 Highway Intersection, and Foshan East Road No. 104 show the lowest returns, with payback periods of around 7.4 years, though still above enterprise capital cost rates. These findings provide a valuable reference for enterprise decision-making regarding rooftop PV project investments in the Chongqing region.

5. Conclusion and outlook

By analyzing scholars' methodologies for photovoltaic (PV) power generation assessment and project benefit models, and integrating data from national and industry reports, this study proposed relevant assumptions and selected appropriate benefit calculation models for PV projects. Using traditional energy enterprises as examples, it evaluated the economic benefits of rooftop PV power generation projects at various test sites. Based on the experimental results, the following recommendations are provided for traditional energy enterprises entering the PV power generation sector:

(1) Phased investments: Given the large number of sites, upfront investments might lead to financial strain. Enterprises can adopt a phased approach by prioritizing investments in projects with excellent returns.

(2) Simultaneous implementation: Projects with similar benefits within the same administrative region can be implemented concurrently. This approach can accelerate project execution, improve operational efficiency, and reduce costs related to transportation and labor.

(3) Monitoring and grid connection: Enterprises should continuously monitor power generation. If surplus power is available, it should be connected to the grid promptly, enabling cost savings on electricity while generating additional revenue from surplus power.

This research aims to support the transition of traditional energy enterprises into the renewable energy sector while offering a reference for benefit assessments of various PV projects, including ground-mounted and wall-mounted PV systems.

Certain factors were excluded from this study, such as the impact of investment costs and electricity savings on taxes, as well as expenses related to transformer capacity expansion at test sites. As a result, the final calculations may slightly differ from actual scenarios.

In future research, the authors plan to delve deeper into various factors affecting project benefits to derive more precise calculations, propose more reasonable conclusions, and offer actionable recommendations.

Disclosure statement

The authors declare no conflict of interest.

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