A method for evaluating photovoltaic potential in China based on GIS platform

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Abstract. Solar photovoltaic systems are commonly utilized in China. However, the associated research is still lack of its resource potential analysis in all regions in China. Based on the existed data about solar radiation and system conversion efficiency data, a new method for distributed photovoltaic potential assessment has been presented. The experiment of three kinds of solar photovoltaic system has been set up for the purpose of analyzing the relationship between conversion efficiency and environmental parameters. This paper fits the relationship between conversion efficiency and solar radiation intensity. This method takes into account the amount of solar radiation that is effectively generated and drives away the weak values. With the spatial analysis function of geographic information system (GIS) platform, frequency distribution of solar radiation intensity and PV potential in China can be derived. Furthermore, analytical results show that monocrystalline-silicon PV generation in the north-western and northern areas have reached a level of more than 200 kWh/(m².a), making those areas be suitable for the development of PV system. However, the potential for southwest areas reaches a level of only 130 kWh/(m².a). This paper can provide the baseline reference for solar energy development planning.

1. Introduction
Photovoltaic power generation plays an important role. Large-scale development and application of photovoltaic systems will gradually optimize the energy structure. Photovoltaic (PV) technology has been used for many years. In China, there are four types of solar energy resources. The key problem is the actual solar energy potential in actual engineering. Consequently, Jaroslav Hofierk and Yosoon Choi reported city-wide application of distributed PV needs to be involved at planning stage of community scale, instead of individual buildings [1,2]. The exploration of necessary technical support on regional energy planning is in urgent need.

Scholars use different methods to analyze solar energy resources. Salvador Izquierdo et al studied the potential of large-scale photovoltaic energy systems with available roof area distribution [3]. Rylatt M, Stuart Gadsden et al analyzed the solar energy resources of the photovoltaic energy system with the TRNSYS and 3D urban models [4], and they also carried out the study of solar potential with GIS [5,6]. Ramachandra T V, et al used the GIS system to map the potential map [7]. Sadik Kucuksari with GIS found the optimal size and locations for PV project [8]. Juan M used multi-objective decision and GIS to explore the solar energy potential of Karnataka state [9]. Ramachandra T V, et al focuses talukwise mapping of renewable energy (solar, wind and small hydroenergy) potential for Karnataka.
using GIS [10]. Bent Sørensen, et al used satellite data based on the use of GIS systems to map solar energy resources map [11], and carried out the application of solar photovoltaic research. In China, researches focus on solar energy resources and solar cell module performance research. Zhou Y used the total solar radiation and sunshine hours on the spatial distribution of solar energy resources and resource potential assessment [12]. Liao Z L established a simplified mathematical model for nonlinear engineering of batteries [13].

The rest of the paper explains the proposed framework in details as follows: In section 2, the proposed method of calculating the potential of photovoltaic power generation efficiency based on solar radiation and real time. Experiment is set up to analyze the relationship between the conversion efficiency and the environmental parameters of monocrystalline silicon (MS), polysilicon silicon (PS) and thin film (TF) modules under the same environmental conditions. In section 3, a case is studied on PV potential the solar radiation intensity frequency and PV generation potential spatial distribution. Section 4 summarizes main conclusions.

2. Methodology

2.1. Evaluation method of photovoltaic resource potential

In China, solar energy utilization is based on the division of the four types of regions according to solar radiation quantity (RQ). I areas (resource-rich zone): annual radiation is in the 6700-8370 MJ/m². II areas (more resource-rich): annual radiation is in the 5400-6700 MJ/m². III areas (resources with the general): annual radiation is in the 4200-5400 MJ/m². IV areas: annual radiation in the 4200 MJ/m² below. This area is the least solar energy resources in China. The characteristic index is solar radiation intensity (RI) per unit area and the number of sunshine hours. In order to simplify the calculation, it is found that the annual output energy of the PV system usually used equation (1) in engineering applications [14].

\[ E_{\text{pv, out}} = A_{\text{pv, s}} \eta R I \]  

(1)

In fact, this simplified calculation is theory. The electricity generation efficiency of PV system is mainly influenced by RI and the temperature of the PV panel, and RI determines the generation current. The temperatures of the PV panel mainly influence the power generation voltage, which are determined by the outdoor air temperature and RI [15]. In fact, the conversion efficiency is the change value with different RI. This paper presents a real-time output power that the annual output energy of the PV system is more accurate, such as equation (2).

\[ E_{\text{pv, out}} = A_{\text{pv, s}} \cdot e_{\text{pv}} = A_{\text{pv, s}} \int_{1}^{8760} RI(t) \eta(t) dt \]  

(2)

Taking the radiation quantity as the characteristic index, the traditional solar energy map is divided into four parts, which can neither identify the diversity within the same resource partition, nor show the distinction when applied with specific technologies. In this paper, the resource of photovoltaic potential is considered conversion efficiency of solar energy resource potential, which is affected by the two factors of RI (t) and \( \eta(t) \).

2.2. Experimental testing

2.2.1. Summary of PV System. In order to scientifically estimate the actual regional adaptability of PV panels, an experimental platform was performed to find out the relationship between conversion efficiency and solar radiation intensity (RI) of three kinds of PV panels (Figure 1. The diagram of the experimental system).

This on-line monitoring platform focuses on PV panels of monocrystalline silicon (MS), polycrystalline silicon (PS) and thin film (TF) PV panels, which designed with basic capacity of about
1 kW (table 1). Monitored data collected by the data acquisition system (DAS) are radiation intensity, outdoor air temperature, outdoor wind speed, surface temperature of PV modules, power generation and so on (table 2).

![Diagram of the experimental system](image)

**Figure 1.** The diagram of the experimental system.

### Table 1. Characteristic parameters of designed PV modules.

| PV module type | Size of modules (m) | The number of panels | Installed capacity (W) |
|----------------|---------------------|-----------------------|------------------------|
| MS             | 1.580×0.808         | 6                     | 1020                   |
| PS             | 1.655×0.992         | 6                     | 1320                   |
| TF             | 1.330×1.100         | 10                    | 1150                   |

### Table 2. Main test instrument.

| Instruments                  | The performance parameters                                                                 |
|------------------------------|--------------------------------------------------------------------------------------------|
| Ultrasonic anemometer        | wind speed: 0.01 m/s, measuring range 0 ~ 70m/s, ±0.3 m/s wind Direction: 1°, measurement range 0° ~ 360° accuracy ±2° |
| TBQ-2 Irradiation meter      | the test range is 0 ~ 2000W/m², Signal output 0 ~ 20 mV measurement range -40〜350°C, ±0.5%accuracy |
| T-type thermocouple          | Temperature sensor                                                                             |
| Electric meter               | Active level 1, RS485, MODBUS—RTU                                                             |

2.2.2. *Results of the experiments.* Based on the experimental results, we got the data such as RI and the outdoor air temperature and wind speed (Figure 2. Radiation intensity, outdoor air temperature and wind velocity in Shanghai).

The data of the power generation and radiation intensity are analyzed. The experimental error of operating conditions is eliminated. The conversion efficiency of PV system is calculated according to the equation (3).

\[
\eta(t) = \frac{E_{\text{pv}}(t)}{R_{\text{t}}(t) \times A_{\text{m}}} \times 100%
\]  

(3)

As addressed in Figure 3. Conversion efficiency and radiation intensity of three types of PV panels, the conversion efficiency tends to be steady when RI exceeds 200 W/m², based on which, the frequency analysis can be done to identify the stable PV solar resource partitions with the dividing line of 200 W/m². It should be mentioned that the unsteady scope of RI below 200 W/m² also makes
contribution to the power consumption, so it is a conservative method in this paper to evaluate the PV-related solar energy. With the errors eliminated, these real-time data are gathered and dealt with according to equations (2) and (3) to get the real-time efficiency. On this basis, the relationship of conversion efficiency can be fitted as table 3.

Figure 2. Radiation intensity, outdoor air temperature and wind velocity in Shanghai.

Figure 3. Conversion efficiency and radiation intensity of three types of PV panels.

Table 3. Relationship of conversion efficiency and RI for three photovoltaic modules.
| PV module type | The limits of RI (W/m²) | Relationship of conversion efficiency and RI |
|----------------|------------------------|-------------------------------------------|
| MS             | 10 ≤ RI ≤ 200          | 3.5781ln[RI(t)]-4.0401                   |
|                | RI ≥ 200               | -0.0006 RI(t)+14.798                     |
| PS             | 10 ≤ RI ≤ 200          | 3.4155ln[RI(t)]-5.0545                   |
|                | RI ≥ 200               | -0.0012 RI(t)+12.71                      |
| TF             | 10 ≤ RI ≤ 200          | 1.9076ln[RI(t)]-3.4561                   |
|                | RI ≥ 200               | -0.0003 RI(t)+6.7909                     |

Figure 3 shows under the same environment parameters, the highest efficiency of MS panel, PS and TF, PV panel in turn. There is a strong correlation between different types, and conversion efficiency and RI are the same principle. Under low intensity (less than 100 W/m²), the conversion efficiency is growing rapidly. With the increase of RI, conversion efficiency growth is slow. When RI is about 200 W/m², conversion efficiency is gradually stabilized.

2.3. Geodatabase
PV system utilization evaluation database is based on the GIS map of the administrative map, and multi-attribute which affects the meteorological data, the resource distribution and energy price into the GIS database, the structure is shown in Figure 4. The flow chart of data processing in GIS database.

![Figure 4. The flow chart of data processing in GIS database.](image-url)

3. Case study
3.1. Frequency analysis of solar RI
The author uses the meteorological data of 270 weather stations in the special meteorological data set of Building Thermal Environment Analysis in China, which includes the annual radiation quantity, the annual level of radiation parameters of each site. The total number of radiation hours is [4300, 4550]
hours. Using renewable energy on-line monitoring system and PV module experimental data, we study the characteristics of solar radiation and power generation system, etc.

![Image of spatial distribution of PV power potential](image)

**Figure 5.** Spatial distribution of PV power potential (a) Sunshine hours between 0-100 W/m², (b) Sunshine hours between 100-200 W/m² and (c) Sunshine hours above 200 W/m².

Solar resource evaluation modified by the PV technical parameters. The data yielded by the testing imply a steady zone of conversion efficiency, when the RI exceeds 200 W/m². Divided into two sections of 0-200 W/m² and above 200 W/m², frequency analysis of horizontal RI is carried out by writing a program with Microsoft SQL, taking advantage of hourly horizontal RI of 270 weather stations. The results are shown in Figure 5. Spatial distribution of PV power potential (a) Sunshine hours between 0-100 W/m², (b) Sunshine hours between 100-200 W/m² and (c) Sunshine hours above 200 W/m². The results of frequency analysis can be divided into 3 partitions with Kriging interpolation algorithm [16], which can identify the technical-related disparity of solar PV resources.

In figure 5, radiation frequency of 0-100 W/m² in most of the southwest area achieves 1300-1600 hours, which exceeds 1/3 of the total radiation hours. The radiation frequency above 200 W/m² in most of the northwest area achieves 2600 hours.

Taking MS module system as an example, the distribution of the photovoltaic power generation potential is shown in figure 6 by using the equation (2) and the GIS platform.

The annual power production varies from 127 to 267 kWh/m², covering the mainland of China. Figure 6. Annual power generation of MS panel per square meter of roof area shows the potential
distribution of power generation. Northwest and north have a high PV utilization potential.

![Map showing distribution of power generation](image)

**Figure 6.** Annual power generation of MS panel per square meter of roof area.

3.2. *Evaluation method of solar photovoltaic resource potential in Shanghai*

This paper takes Shanghai City as an example, by using the method above, we can get the conclusion that there are 8760 hours in a whole year, 4418 hours of RI is zero, 28.9% of the rest of the time are in the inefficient zone, but only nearly 17.7% are high efficient area as shown in figure 7.

According to equations (2) and (4), annual capacity of MS, PS and TF PV panels installed on the building roof in Shanghai are 180.9, 151.1, 82.3 kWh/(m².a).

![Graph showing frequency and cumulative probability distribution](image)

**Figure 7.** Frequency and the cumulative probability distribution of annual radiation intensity in Shanghai.

4. **Conclusions**

As demonstrated in the results section, this paper puts forward the regional potential analysis with the help of a GIS platform. In the future research, we will investigate the building roof in all studied cities. There are still further issues needed to be discussed as follows.

- The experimental platform of solar photovoltaic system was established, and the data of the test results were analyzed and analyzed to obtain the photovoltaic efficiency equation of MS, PS and TF cell module system.
With the spatial analysis of GIS platform, RI analysis in all parts in China showed that the radiation intensity of more than 200 W/m² was more than 2600 hours in the northwest and most parts of the north and about 1600 hours in the southwest.

With the monocrystalline silicon module as an example, the potential of photovoltaic generation in China is distributed at [127,267] kWh/m²a, which is up to 200 kWh/m²a. The northwest and north regions, suitable for the development of PV system.

RI distribution in Shanghai has been studied, and 71.1% of sunshine hours are more than 100 W / m², which are near-efficient and efficient.

With the implementation of the distributed solar PV subsidy policy, the adaptability of solar PV systems should be further analyzed throughout the country according to local radiation resource conditions, energy prices and government subsidy policies.

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Appendix

| Nomenclature | Description | RQ | solar radiation quantity |
|--------------|-------------|----|--------------------------|
| Appv, s      | the surface area of the solar cells of the system,m² | RI(t) | The radiation intensity for t time, W/m² |
| ηpv          | annual electricity generation per unit i a area | η(t) | the real-time conversion efficiency for t time, % |
| Epv,out      | the annual power generation for installed pv panel,W | ηe | the mean annual power conversion efficiency coefficient for PV system |
| MS           | PV panels of monocrystalline silicon | ηmono | the real-time conversion efficiency for MS PV system, % |
| PS           | polycrystalline silicon | ηthin | the real-time conversion efficiency for TF PV system ,% |
| RI           | solar radiation intensity | ηpoly | the real-time conversion efficiency for PS PV system, % |
| TF           | thin film PV panels |              |                          |

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