Potential Assessment of Rooftop Photovoltaic Power Generation in Wide Areas

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Abstract. The concept of low-carbon environmental protection is being taken into consideration by more and more countries and regions. As a clean renewable energy, technology of solar power generation has been developed rapidly. This paper proposed the method of the potential assessment of rooftop photovoltaic (PV) power generation in wide areas. The influence factors were analyzed with the actual data, including the planning site and weather condition. The rooftop area was calculated with consideration the rooftop area coefficient, available area coefficient and cell panel coverage coefficient. For different planning sites, the coefficients were different. Then, based on long-term historical data, the predicted value of power generation per unit area of photovoltaic panels is obtained. According to the total panel area data and the unit panel power generation data, the regional photovoltaic power generation is obtained. The method proposed in this paper is used to calculate the rooftop photovoltaic power generation in Hebei Province. The method proposed in this paper can be applied to a wide range of rooftop photovoltaic power generation potential assessments with different planning types.

Keywords: Rooftop photovoltaics · Potential assessment · Construction land planning

1 Introduction

More and more countries use "carbon emissions" as an indicator to measure a country's energy structure. In 2021, China's carbon emissions will exceed 11.9 billion tons, accounting for 33% of the global total. Energy conservation and emission reduction are urgently needed. In order to achieve the strategic goals of carbon neutrality and carbon peaking, China's energy structure transformation must be accelerated [1]. As one of the most mature power generation technologies, photovoltaic power generation potential assessment is of great significance to the transformation of energy structure [2].

In terms of the environment, a large number of scholars have analyzed the urban climate environment, taking into account dust, solar irradiance and other factors, and

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evaluated the photovoltaic potential of urban areas with photographic technology [3–5]. In terms of roof available area, [6] takes Milan, Italy as an example to evaluate the potential of photovoltaic power generation by calculating the area utilization coefficient, but it lacks the analysis of different types of buildings [7]. Based on satellite imagery, computer vision technology was used to extract the roof contour area for photovoltaic resource assessment in rural areas [8]. uses the popular deep learning technology for ultra-short-term forecasting of photovoltaic power generation, but it is not suitable for wide-scale forecasting. Some scholars also evaluate the potential of photovoltaic power generation from the aspects of photovoltaic installation installation and shadow shielding [9].

This paper studied a method for evaluating the potential of rooftop photovoltaic power generation that comprehensively considers factors such as the environment and the type of building planning. Taking Hebei Province, China as an example, the change trend of photovoltaic power generation in Hebei Province in the past ten years was investigated, and the potential evaluation of rooftop photovoltaic power generation in Hebei Province was carried out.

2 Factors Influencing the Potential of Rooftop Photovoltaics

Rooftop photovoltaic power generation has great uncertainty and is affected by many external factors, not only by the weather conditions but also by the form of the building. Therefore, the analysis of PV power generation influence factors is a key part to evaluate the potential of PV power generation.

2.1 Meteorological Factors

Rooftop photovoltaic power generation is related to various meteorological factors such as local solar radiation, ambient temperature, cloud density, and air pollution index. Photovoltaic power generation is a chemical process that converts solar energy into electrical energy, so solar irradiance directly affects photovoltaic power generation. Under the same irradiation conditions, the increase of the ambient temperature will lead to a decrease in the efficiency of photovoltaic modules, thus reducing photovoltaic power generation [10]. Cloud cover and air pollution affect photovoltaic power generation mainly by affecting the amount of solar radiation reaching the ground.

Figure 1 shows that the environmental air quality of Hebei province is constantly improving, and the days of dust particles and heavy pollution are decreasing year by year [11]. This will enable photovoltaic panels to obtain more solar radiation, and play a positive role in the development of rooftop PV, forming a virtuous cycle.

2.2 Architectural Planning Factors

There are many types of urban building planning, and the characteristics of the combination of different planning buildings and photovoltaics are quite different [12]. Compared to the diversity of urban construction sites, construction land in rural areas is relatively

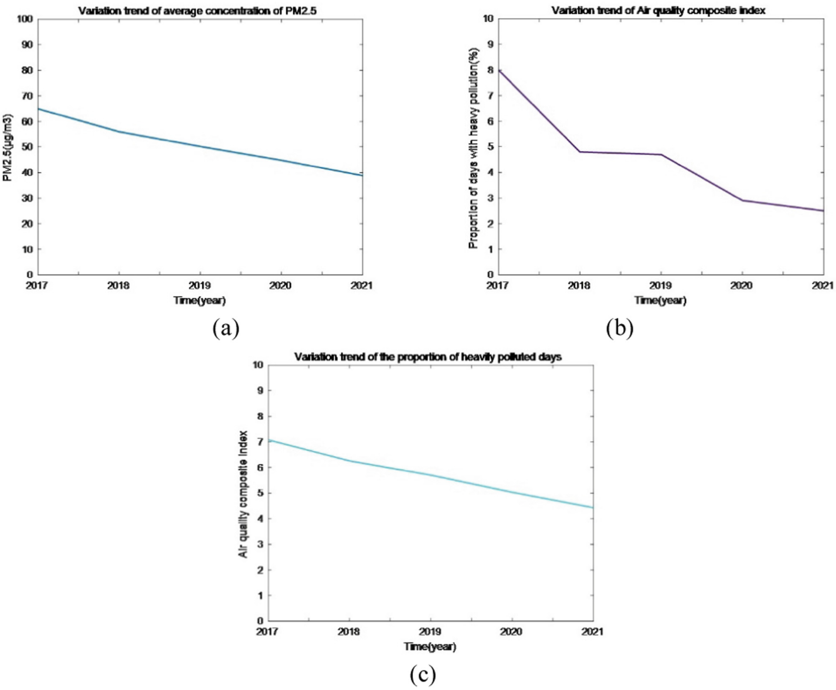

Fig. 1. Trends in environmental change in Hebei Province (2017–2021)

single, focusing mainly on the roofs of residential buildings for people and livestock, uniformly referred to as rural settlement sites.

Undulating buildings will cause serious urban shadow occlusion, making the construction environment of rooftop PV more complex. Moreover, the distance between buildings is also an important factor affecting the solar radiation area of the roof. In China, building sunshine spacing has different requirements in different construction land types, mainly concentrated in residential areas and some public building areas.

According to "code for classification ofurban land use and planning standards of development land", urban construction land can be divided into 8 categories, 35 middle categories and 43 sub-categories. First, exclude green space, square and other types of land that cannot be installed photovoltaic; Secondly, industrial land and logistics and storage land with similar layout should be combined. Finally, according to the characteristics of rooftop PV potential assessment of urban buildings, urban construction land is divided into four categories: residential land, land for public administration and public services (public land), land for commercial service facilities (commercial land) and industrial land (including land for logistics and warehousing).

3 PV Power Generation Assessment Methods

Through the analysis of the influencing factors of photovoltaic power generation, the construction land type and meteorological environment are taken as the main research direction of photovoltaic power generation evaluation, and the installation inclination of photovoltaic panel and the selection of cell panel type are considered as auxiliary factors.

Finally, a relatively complete evaluation model of rooftop PV power generation is formed (Fig. 2).

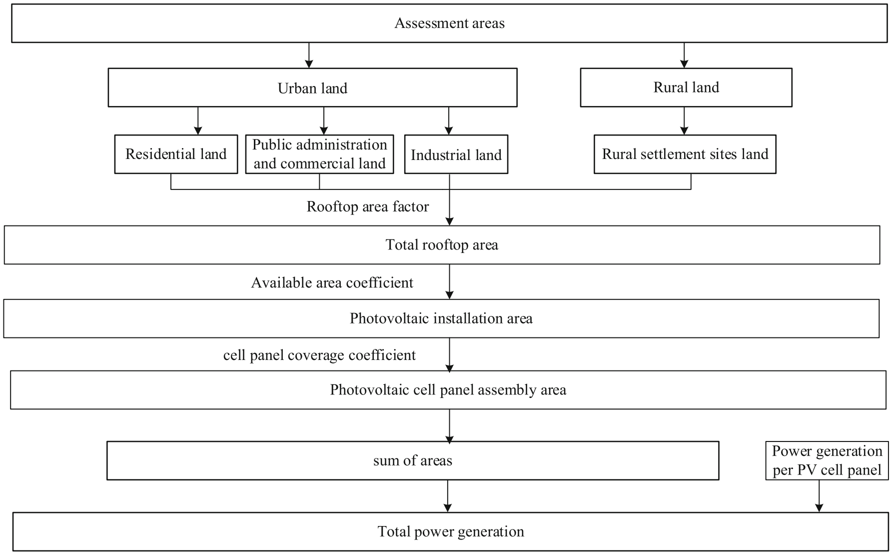

Fig. 2. Flow chart of rooftop PV generation evaluation

3.1 PV Panel Area Calculation

By investigating the construction land data released by the government, analyzing the relationship between the construction land and the roof area ratio, the roof area is indirectly calculated, and then the photovoltaic panel area is obtained.

The building floor area can be found from government published data. In order to calculate the actual roof area, the roof area coefficient is introduced. It is related to building density and roof shape, expressed by f_t.

Similarly, an available area coefficient should be introduced to calculate the available area of rooftop photovoltaic based on the actual roof area. It is related to the building plan and the number of building floors, expressed by f_{pv}.

In order to obtain the PV panel surface area from the rooftop PV available area, it is also necessary to introduce a PV panel coverage factor. It is related to the size and installation inclination of photovoltaic cell panel, expressed by f_a

$$f_a = \frac{c}{d} = (\cos(\beta) + \cot(\alpha) \times \sin(\beta))^{-1} \tag{1}$$

Among them, c is the width of the PV panels, d is the spacing between panels, β is the installation inclination, and α is the shading angle.

By introducing the above three utilization coefficients, the photovoltaic panel module area can be obtained from the construction land area. However, due to the large difference in the area ratio of different construction land, different types of construction land need to be analyzed separately. According to the analysis of architectural planning in Chapter 2, the area ratios of five types of land use, including residential land, public land, commercial land, industrial land and rural residential areas, are statistically calculated.

After investigating building density, building height and other building indicators, it is found that the indicators of public land and commercial land are relatively similar, and they are combined into one land type (Table 2, Table 3 and Table 4).

Table 1. Utilization coefficient statistics table

Nature of land	Rooftop area coefficient (f_t)	Available area coefficient (f_{pv})	Cell panel coverage coefficient (f_a)
Residential land	0.8	0.38	0.39
Public and commercial land	0.87	0.6	0.39
Industrial land	0.86	0.8	0.39
Rural settlement sites	0.8	0.4	0.39
Other prohibited land	/	/	/

The area of photovoltaic panels can be obtained by

$$A_{tot} = \sum_{i}^{i=4} A_{r(i)} \cdot f_{t(i)} \cdot f_{pv(i)} \cdot f_{a(i)} \tag{2}$$

Among them, A_{tot} is the PV cell panel module area, A_r is actual building footprint, different i's indicate different building types ($i = 1, 2, 3, 4$, corresponds to the four building types in Table 1).

3.2 Calculation of Electricity Production from Cell Panels

The solar panels were selected from Trina Solar TSM-250-P05A polycrystalline silicon cells with the following parameters.

Table 2. TSM-250-P05A solar cell panel basic parameters

Peak operating voltage (V)	Peak operating current (A)	Rated power (Wp)	Component sizes (mm)	Conversion efficiency (%)
30.3	8.27	250	1650 × 992 × 35	16

In this paper, the total PV power generation is evaluated based on the annual power generation per unit area and the total cell area, considering the power generation per cell panel in the last 10 years. The specific calculation method is shown in Fig. 3.

Firstly, input the parameters of cell pool model and system operation efficiency through the known website, and then the system automatically analyzes the meteorological factors such as irradiance and temperature to obtain the energy generation data of cell pool per unit area [13]. Secondly, the power generation per unit area of the cell panel in the last ten years is combined and the average value is taken as the calculated value, and finally multiplied with the total area of the cell panel to obtain the total power generation.

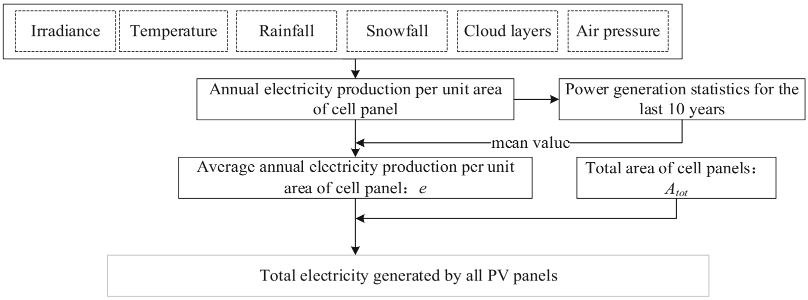

Fig. 3. Rooftop PV power generation calculation method

The calculation formula of annual rooftop PV power generation is as follows:

$$E = \frac{A_{tot}}{a} \times e \tag{3}$$

The calculation formula of installed capacity is as follows:

$$R = \frac{A_{tot}}{a} \times P \tag{4}$$

Among them, A_{tot} is the total area of the PV panel, a is the area per panel, e is the annual power generation per panel, and P is the rated power per panel.

4 Rooftop PV Power Generation Assessment in Hebei Province

The following takes Hebei Province, China as an example, to collect various building planning data to calculate the rooftop photovoltaic power generation (Fig. 4).

(1) Construction Land Area Statistics in Hebei Province

(2) Power generation per unit of cell panel

Table 3. Hebei province each land type area statistics

Nature of land	Residential land	Public and commercial land	Industrial land	Rural settlement sites
Area (km^2)	592	371.3	552.4	9280

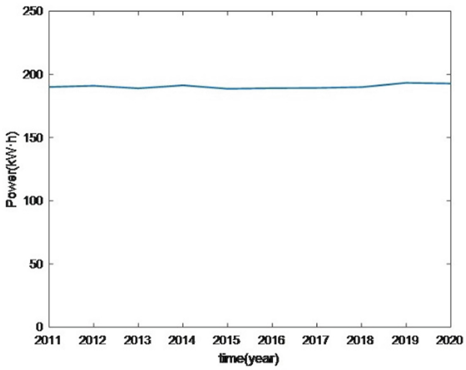

Fig. 4. Annual electricity production per unit area of cell panel in Hebei Province, 2011–2020

It shows that the annual power generation per unit cell panel in Hebei Province fluctuates around 190 kWh, and its average value of 190.473 kWh is taken as the annual power generation per unit cell panel.

(3) Installation inclination
The latitude of Hebei Province lies between 36°03′ and 42°40′, the central dimension is 39°, as Hebei Province is located in the northern hemisphere, its azimuth angle is 0°. According to [14], the installation inclination of PV cell panels in Hebei Province is 36°.
(4) Calculation results

The results of the calculations are shown in the table below.

Table 4. Photovoltaic power generation calculation results (Hebei province)

Indicators	Total rooftop area (km^2)	PV panel surface area (km^2)	Installed Capacity (GW)	Annual power Generation (GWh)	Effective hours (h)
Values	8696	1452	221.79	168984.7	762

It shows that there is huge potential for the development of rooftop PV in Hebei Province, with over 200 GW of installed capacity available for urban and rural rooftop PV.

5 Conclusion

In this paper, various meteorological factors and architectural planning factors affecting photovoltaic power generation are investigated. In order to calculate the actual photovoltaic panel surface area, three utilization coefficients are introduced. Finally, by collecting meteorological as well as site planning data from Hebei Province, the calculation of rooftop PV power generation was carried out for Hebei Province.

The method proposed in this paper can be applied to the potential assessment of photovoltaic power generation in wide areas, which has a certain reference significance for the development of distributed rooftop PV construction in wide areas.

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