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Study on Environmental and Economic Benefits of Photovoltaic integration with Iron and Steel Plants in Hebei Province

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ABSTRACT

Under the strategic goal of "peak carbon dioxide emissions and carbon neutrality" in China, industries with high energy consumption and high pollution, such as iron and steel plants, are facing great pressure of energy conservation and emission reduction, and are in urgent need of green and low-carbon transformation. In this paper, 46 iron and steel plants in Hebei province are taken as examples. GIS spatial analysis and environmental emission list method are used to build a comprehensive evaluation model of rooftop photovoltaic, and to calculate the technical potential, energy saving and emission reduction benefits and economic feasibility of deploying rooftop photovoltaic in iron and steel plants. Finally, carbon trading mechanism is introduced to analyze its impact on the carbon trading market. It is found that 46 iron and steel plants save 216,700 tons of standard coal, reduce 144,700 tons of CO_2 emissions and reduce 1,500 tons of SO_2, NO_X, PM and other air pollutants every year. The economic benefit of power generation self-use mode is greater than that of grid-fed mode, with an average return on investment of 140% and a payback period of 5.5 years. The results verify that rooftop photovoltaic in iron and steel plants has dual benefits of energy saving and emission reduction and economy, and this data can provide a feasible path for iron and steel plants to use photovoltaic for green and low-carbon transformation.

Keywords: PV integration, iron and steel industry, economic performance, environmental benefits, carbon trade.

1. INTRODUCTION

Iron and steel industry is a typical industry with high power consumption. According to statistics in 2019, the annual power consumption of steel plants nationwide was 453.3 billion KWh, which is equivalent to the annual power demand of Guangdong Province. Its huge power demand is mainly met by thermal power generation, but thermal power generation will consume a lot of coal resources, emit greenhouse gases and air pollutants such as SO_2, NO_X and PM. Hebei Province is a big iron and steel producing province in China, so the energy consumption and environmental pollution problems caused by the production activities of iron and steel plants in Hebei Province are more serious, and it is very urgent to use clean electricity instead of some thermal power to achieve energy conservation and emission reduction in iron and steel plants in Hebei Province.

Among all kinds of renewable energy, solar energy has become the fastest developing renewable energy because of its obvious advantages of cleanness, safety and inexhaustible. The huge development potential of photovoltaic power generation continuously drives it from traditional centralized photovoltaic power station to new application field. Roof photovoltaic has become one of the representatives of photovoltaic application innovation because of its obvious economic applicability.

Looking back at the previous literature, we can see that the current research pays less attention to the deployment of rooftop photovoltaic with high energy consumption infrastructure. As a new mode integrating renewable energy generation and industrial electricity, industrial rooftop photovoltaic has great development potential.

In this study, the model of combining rooftop photovoltaic with iron and steel enterprises was proposed, and the multi-disciplinary theories and methods, such as GIS spatial analysis and cost-volume-profit analysis, were comprehensively used to build a benefit evaluation model and accurately calculate it, which provided a powerful analysis tool for evaluating the environmental and economic benefits of rooftop photovoltaic in iron and steel plants in Hebei Province.

2. METHODOLOGY

2.1 Evaluation method of technological potential

In this paper, the available roof area, total solar radiation, photovoltaic installation capacity and power generation capacity are selected as the evaluation indexes of roof photovoltaic technology potential. The usable area of roof is measured by Locaspace software, and the total solar radiation is obtained from WorldClim database of ESRI ArcGIS® software [1]. The annual power generation of rooftop photovoltaic mainly depends on the installed Capacity of photovoltaic power station. The photovoltaic installation capacity is calculated by Eq.(1), the annual power generation is calculated by Eq. (2), and the power generation in the whole life cycle of the photovoltaic system is calculated by Eq. (3). [2] The life cycle of photovoltaic system is usually defined as 25 years [3].

$$\mathrm{Capacity} = \frac{\mathrm{area_{avaliable}}}{\mathrm{area_{PV}}} \times \mathrm{P_{max}} \times \gamma \quad (1)$$

$$E_p = H_A \times \frac{Capacity}{E_s} \times K \quad (2)$$

$$E_{p,total} = \sum_{i=1}^{25} H_A \times \frac{Capacity}{E_s} \times K \times (1-D)^i \quad (3)$$

Where $\mathrm{area_{avaliable}}$ is the available area of steel plant roof, $\mathrm{area_{PV}}$ is the required area for each solar panel installation, $\mathrm{P_{max}}$ is the maximum capacity of each solar panel, and γ is the overall performance coefficient of photovoltaic power generation system, which is usually between 0.75 and 0.85. This paper uses 0.78 for calculation. H_A is the total solar radiation in horizontal plane every year, E_s is the radiance under standard conditions, and K is the comprehensive efficiency coefficient. i is the year, and D is the annual loss rate of photovoltaic modules.

2.2 Evaluation method of environmental benefit

In this paper, standard coal saving, annual CO_2 emission reduction, annual SO_2 emission reduction, annual NO_x emission reduction, annual PM emission reduction and annual $PM_{2.5}$ emission reduction are taken as the environmental benefit evaluation indexes of rooftop photovoltaic. It is assumed that all the power generated by thermal power plants is generated by standard coal combustion. Table 1 shows the standard coal consumption and pollutant emission factors of coal-fired power plants in Hebei Province.

Table 1. Standard coal consumption/pollutant emission factors of coal-fired power plants in Hebei Province

name	factor (g/kWh)
standard coal	297.00
carbon dioxide（CO_2）	199.00
sulphur dioxide（SO_2）	0.8043
oxynitride（NO_X）	0.9140
PM	0.1828
$PM_{2.5}$	0.1462

Among them, the pollutant degree electric emission factor of coal-fired power plants in Hebei Province is derived from reference[4], and the carbon dioxide degree electric emission factor is derived from the relevant data of energy conservation and emission reduction of State Grid Co., Ltd. in China Electric Power Yearbook in 2018.

2.3 Evaluation method of economic benefit

Taking the net present value, return on investment and payback period of rooftop photovoltaic project as index, the economic feasibility is evaluated. The cost calculation formula of rooftop photovoltaic in the whole life cycle is as follows:

$$\mathrm{LC} = \sum_{\mathrm{i=1}}^{25} \frac{((\mathrm{C_{equipment,i}} + \mathrm{C_{O\&M,i}}) \times \mathrm{Capacity}}{1.05^{\mathrm{i}}} \quad (4)$$

In which LC represents the cost of the whole life cycle (yuan), $\mathrm{C_{equipment,i}}$ represents the unit equipment investment cost and equipment replacement cost in the first year (yuan), $\mathrm{C_{O\&M,i}}$ represents the unit O&M cost in the first year (yuan), and the discounted value is set at 5%.

The income calculation formula of rooftop photovoltaic power generation project K in the whole life cycle is as follows:

$$Revenue_k = \sum_{i=1}^{25} E_{p,i} \times \frac{P_k}{1.05^i} \quad (5)$$

In which P_k is the electricity price of the k^{th} building, and $E_{p,i}$ is the annual power generation of the i^{th} year.

The net present value NPV is the algebraic sum of the present value of the cash outflow paid by the investment project and the present value of the cash inflow generated by the investment. Only when the net cash flow value of the investment project is greater than or equal to 0, the investment is feasible. Return on investment (ROI) refers to the value that should be returned through investment, that is, the economic return that an enterprise gets from an investment activity. Dynamic payback period is the payback period calculated after the net cash flow of investment projects in each year is converted into present value according to the benchmark rate of return. The calculation formula of the three is as follows:

$$NPV = \sum_{i=1}^{n} \frac{B^i - C^i}{(1+r_0)^i} \quad (6)$$

$$ROI = \frac{NI}{C} \times 100\% \quad (7)$$

$$T = t' - 1 + \frac{\sum_{i=1}^{t'-1} \frac{B^i - C^i}{(1+r_0)^i}}{\frac{B^{t'} - C^{t'}}{(1+r_0)^{t'}}} \quad (8)$$

In which B^i is the cash inflow in the first year, C^i is the cash outflow in the first i year, r_0 is the benchmark discount rate (%), which is assumed to be 5% in this paper; NI is the profit, C is the cost, and T is the dynamic payback period; t' is the year when the net present value is greater than 0.

3. RESULTS AND DISCUSSIONS

3.1 Analysis of technological potential

The geographical distribution of 46 iron and steel plants in Hebei Province are shown in Figure 1. The total usable roof area is 3.78 square kilometers, the largest of which can reach 419,000 square meters. The solar radiation intensity in most areas of Hebei Province is concentrated in 1500~1600W/m^2, and the dispersion degree is low, and the power generation peak of photovoltaic system appears around 14 o'clock.

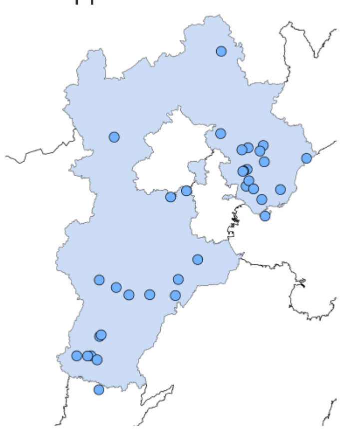

Fig. 1. Geographical location distribution of 46 steel plants

Based on the available area and solar radiation intensity data obtained from the research, the technical indicators such as photovoltaic installed potential, annual power generation and life cycle power generation of steel plants can be further estimated. From the statistical results, it can be found that 46% of steel plants have photovoltaic potential less than 10 MW, 32% have photovoltaic potential between 10 and 20 MW, and the remaining 22% have photovoltaic potential above 20 MW. According to the data of photovoltaic annual power generation potential of each steel plant, 39% of steel plants have annual power generation less than 10 MWh, 33% have annual power generation between 10 and 20 MWh, 13% have annual power generation between 20 and 30 MWh, and 15% have annual power generation above 30 MWh.

3.2 Analysis of environmental benefit

Assuming that the electricity consumption of iron and steel plants in Hebei Province mainly comes from thermal power generation mainly burning standard coal, the total emission reduction of corresponding indicators of 46 iron and steel plants is shown in the following table:

Table 2. Environmental benefit indicators

Emission reduction targets (saving/emission reduction)	Annual benefits	Total benefits in 25 years
Standard coal (10^4t)	21.67	481.48
CO_2 (10^4t)	14.47	320.99
SO_2 (t)	587	13039
NO_x (t)	667	14817
PM (t)	133	2963
$PM_{2.5}$ (t)	107	2371

3.3 Analysis of economic feasibility

In this paper, the total cost of 46 steel plants in the 25-year life cycle of rooftop photovoltaic is calculated, and the cost is divided into three categories: initial investment cost, equipment renewal cost and operation and maintenance cost, which are shown in Figure 2. As the initial investment cost is too high, it is considered to introduce a loan with a quota of 70% of the initial investment, an annual interest rate of 8%, a repayment period of 5 years, and amortization of the cost to the first to fifth years. The calculated results have been discounted, with a discount rate of 5%. In addition, a certain amount of operation and maintenance costs are required every year, and the battery components are updated every five years, and the original inverter is updated every ten years, which will also cause additional equipment update costs. The calculation results show that the photovoltaic capacity is different due to the different available roof area of each steel plant, and the total cost investment of each steel plant is quite different, ranging from 2 million yuan to 200 million yuan.

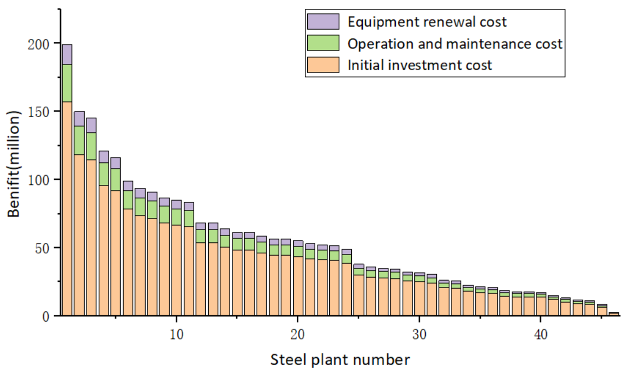

Fig. 2 Total life cycle cost of 46 steel plants

Roof photovoltaic power generation in steel plants can produce economic benefits in two modes. First, the power generation self-use mode, the saved electricity cost is the income of the steel plant; Second, feed-in grid mode, generating electricity and selling it to the grid to generate revenue. Because there is a difference between the price of industrial electricity and the price of electricity sold into the power grid, the benefits generated by the two modes are different. In this paper, the benefits of the two operating modes are compared, so as to establish a suitable operating mode for rooftop photovoltaic in steel plants, and evaluate the benefits level of rooftop photovoltaic projects. As shown in fig. 3 and fig. 4, the economic benefits obtained by steel mills in the mode of power generation for their own use are greater than those obtained by feeding into the grid, and the profits generated by 94% of steel mills in the mode of power generation for their own use are 10-20 times that of feeding into the grid.

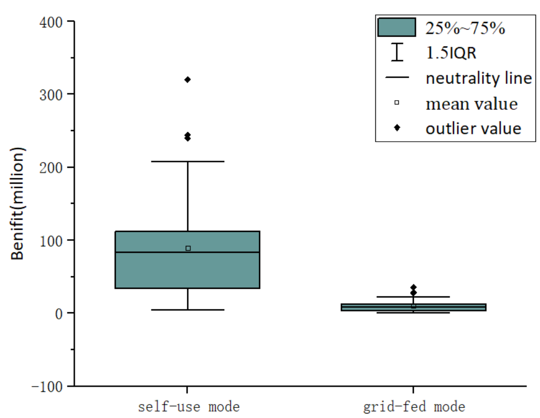

Fig. 3 Box diagram of profit distribution under two modes

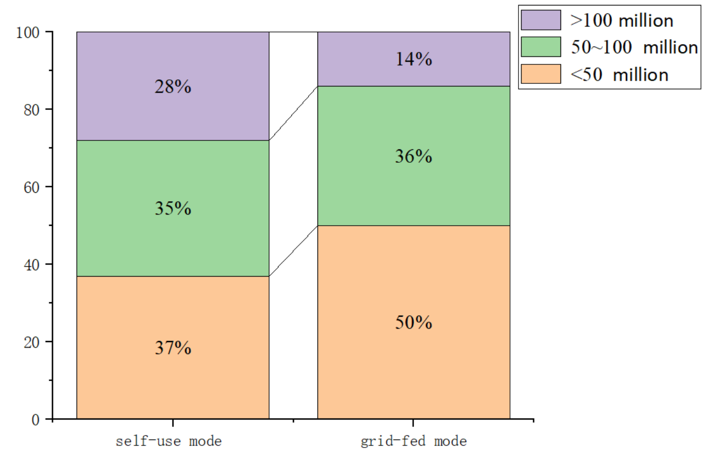

Fig. 4 Percentage of profit distribution under two modes

The return on investment and payback period of 46 iron and steel plants under the two modes are calculated and compared. Under the self-use mode of power generation, the return on investment of most steel plants ranges from 130% to 150%, with the highest being 148% and the lowest being 104%. Under the grid-fed mode, the return on investment of most steel plants is between 0% and 20%, and the return on investment is small. According to the calculation results of investment payback period, the average payback period is 5.5 years in power generation mode and 20.5 years in grid feed mode. It can be seen that the ROI in power generation self-use mode is much larger than that in grid-fed mode, and the payback period is shorter than that in grid-fed mode.

4. DISCUSSION AND CONCLUSION

The main research contributions of this paper are as follows:

1.Put forward the scheme of combining steel plant with roof photovoltaic and calculate its application potential

Based on the current situation of high energy consumption in iron and steel plants and the problems of coal consumption and environmental pollution caused by the extensive use of thermal power generation, combined with the research status of rooftop photovoltaic at home and abroad, this paper puts forward the scheme of deploying rooftop photovoltaic in iron and steel plants, and selects 16 evaluation indexes from three aspects of technical potential, energy saving and emission reduction benefits and economic feasibility, and constructs an evaluation system of rooftop photovoltaic power generation benefits. This study evaluates the potential size, emission reduction potential and economic performance of photovoltaic deployment in iron and steel plants in Hebei Province, which is a project area that has not been studied before. This result is of great significance for guiding the combination mode of steel plant and rooftop photovoltaic.

2.Energy-saving benefits of roof photovoltaic in Hebei Iron and Steel Plant

By deploying rooftop photovoltaic power generation to replace part of thermal power, iron and steel plants can reduce the power consumption of thermal power plants. Thermal power generation mainly depends on non-renewable resources such as coal, so deploying rooftop photovoltaic in steel plants can indirectly reduce the consumption of non-renewable resources such as coal. The results of this study show that if all the 46 iron and steel plants surveyed in Hebei use photovoltaic power generation and make full use of roof area, it is estimated that 216,700 tons of standard coal will be saved every year.

3.Emission reduction benefits of rooftop photovoltaic in iron and steel plants in Hebei Province

Hebei Iron and Steel Plant indirectly reduces the emission of some carbon dioxide, sulfur dioxide, nitrogen oxides, dust and other air pollutants caused by the production and operation activities of thermal power plants by using photovoltaic power generation. This part of the reduced emissions of carbon dioxide and air pollutants can be considered as the emission reduction benefits generated by the use of photovoltaic power generation in steel plants. If rooftop photovoltaic is deployed in 46 iron and steel plants in Hebei Province, it is estimated to reduce CO_2 emissions by 144,700 tons, SO_2 emissions by 587 tons, NO_X emissions by 667 tons and PM emissions by 133 tons every year, which will help iron and steel enterprises achieve the goal of "peak carbon dioxide emissions and carbon neutrality".

4. Economic benefits under the two business models

This paper compares the economic benefits of rooftop photovoltaic in two modes of power generation and grid feeding. The comparison between the two operation modes shows that the economic benefits brought by the self-use mode of roof photovoltaic power generation in iron and steel plants are greater than those brought by the grid-fed mode; If the iron and steel plants adopt the self-use mode of power generation, it is estimated that each iron and steel plant will make an average profit of 87 million yuan, with an average return on investment of 140% and an average payback period of 5.5 years.

This research idea is highly transportable, and can be applied to photovoltaic transformation of other high energy-consuming industries such as cement and building materials, so as to promote its energy-saving transformation and green development. At present, the state calls on all people to implement energy conservation and emission reduction measures, especially for high energy-consuming enterprises. Therefore, installing photovoltaic equipment in iron and steel plants and other high energy-consuming enterprises has a good application prospect. However, due to the flat degree of roof and the influence of surrounding environment, it is necessary to consider the feasibility of installing photovoltaic equipment on the roof of buildings when it is extended to other industries with high energy consumption. For example, areas with flat and wide roofs and not affected by high temperature of fuel are suitable for building photovoltaic equipment, while areas with narrow area or high ambient temperature are not suitable for building photovoltaic equipment.

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