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PV integration potential with infrastructures in steel industry and its techno-economic analysis

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ABSTRACT

The high energy consumption of the steel industry has been a major challenge for the sustainability and environmental protection. Steel companies, the backbone of heavy industry in China take a vital position in climate change mitigation. To pursue sustainability and decrease emissions, an increasing number of steel companies tend to seek help from renewable energy. Integrating solar photovoltaics (PV) at steel plants is promising to reach the target. This paper investigates the potential capacity, potential output and economic performance of PV technology of 228 steel plants in China. The results indicate that the huge potential capacity and output are up to 6.96×10^6 KW and 9.71×10^9 kWh, respectively. Moreover, the ROI and profit under all self-consumption scenarios and all feed-into grid scenarios are evaluated, which shows integrating PV into the steel industry is also profitable. Among two scenarios, the all self-consumption scenario earns a higher ROI and profit compared with the all feed-into grid scenario.

Keywords: PV integration, PV potential, steel industry, techno-economic analysis.

1. INTRODUCTION

The steel industry in China has gained the momentum in development for last decades. China has become the largest country in steel production, contributing to over a half of the world's crude steel production in 2018[1]. With the rapid development, huge emissions and energy consumption from steel industry arouses the public attention. In 2013, CO_2 emissions from the iron and steel industry took up 16.2% of total CO_2 emissions in China and the energy consumption from it accounted for 16.5% of the country[2-3]. It is imperative for steel industry to find an sustainable way to produce steel. Nowadays, many technologies are integrated with the traditional steel production. Some advanced symbiotic technologies are planning to combine with the steel plant to make co-products[4]. The common method is to utilize the waste heat to provide refrigeration or heat in buildings[5]. Moreover, an increasing number of steel plants find the potential in renewable energy[6,7].

PV develops rapidly in China that the total installed capacity accounted for nearly one third of the world's and will keep growing[8]. Deploying PV technology in energy intensive industry is a promising approach which has little technical barriers. Jiang et. al. proposed the concept to deploying PV systems in coal-fired power plants using existing infrastructures, which exhibits the feasibility and the advantage in avoiding curtailment with the assistance of local power load. [9] Moreover, Qi et. al. conducted an investigation on the feasibility of integration PV systems into coal-fired power plants by installing solar panels on the surface of cooling towers with special designed trackers. The results of case studies show the proposed system exhibits better technical and economic performance. [10]

The prospect of PV technology in steel industry would be great. Firstly, construction characteristics in steel plants favor the installation of PV. The steel companies can use the current buildings for deployment which decrease the cost of PV production. Furthermore, PV electricity generation is totally eco-friendly which brings no environmental burden. This paper focuses on PV technical and economic potential for PV integration of steel industry in China. Two scenarios of different use of PV electricity are evaluated to optimize the economic benefits.

2. METHODS

2.1 Identification and estimation of available area

Google Earth™ is employed to obtain satellite images of steel plants, measurement of the available rooftops is also done by Google Earth™.

We randomly selected about 10% of the 228 steel plants, 22 steel plants, and manually measured the available roof area. Through linear regression, the relationship between the available area and the value of fixed assets was obtained based on the measurement of the 22 steel plants, and the regression result was used to estimate the PV potential of the rest plants.

2.2 PV potential Estimation

The potential capacity is calculated as:

$$capacity = \frac{area_{available}}{area_{PV}} \times P_{\max} \times \eta \quad (1)$$

where capacity is the potential capacity of the PV_{pp} system, $area_{available}$ is the available area for PV deployment, $area_{PV}$ is the area of a single PV panel, P_{max} is the peal power of a single PV panel, and η is a coefficient, which is 0.9 in this study.

According to GB 50797-2012, the annual PV generation is calculated as:

$$E_p = H_A \times \frac{P_{AZ}}{E_S} \times K \quad (2)$$

where Ep is the PV output (kWh), H_A is the local horizontal irradiance (kWh/m^2), E_S is the standard PV test condition (1000 W/m^2), P_{az} is the capacity of the potential PV system (kW), and K is the overall performance coefficient, which is 0.78 in this study.[49]

2.3 Economic metrics

Lifecycle cost is calculated as:

$$LCC = \sum_{i=1}^{25} \frac{\left(\left(C_{equipment,i} + C_{O\&M,i}\right) \times capacity\right)}{1.05^i} \quad (3)$$

where $C_{equipment,i}$ is the equipment investment and equipment replacement fee for year i, and $C_{O\&M,i}$ is the O&M price for year i. The lifetime of the PV system is set as 25 years, and the discounted value is 5%.

Potential revenue is calculated as:

$$Revenue = \sum_{i=1}^{25} E_p \times \frac{(P_{LP} + S_{PV,i})}{1.05} \quad (4)$$

where E_p is the PV output (kWh), P_{LP} is the local price of coal-fired electricity (kWh/yuan), and $S_{PV,i}$ represents the PV system subsidies in different scenarios.

The return on investment (ROI) is calculated as:

$$ROI = \frac{NI}{LCC} \quad (5)$$

where NI is the net income of the system (yuan).

3. RESULTS

3.1 Technical potential

3.1.1 Available rooftop area for PV deployment

The roof surface can be placed on solar panels when it has no physical, technical or shading limitations. Steel production and processing plants usually occupy large places in rural area without tall buildings covering them, therefore rooftops of them are massive and directly exposed to the sunlight. According to data, the total area of rooftops is 4.68×10^7 m^2 which displays a great photovoltaic potential. In addition, rooftops of plants tend to be smooth and strong for placing solar panels. Hence a great number of rooftops can be availably utilized for PV deployment. We estimate the available rooftop area for PV deployment of 228 steel production and processing plants in China that the available area is 4.68×10^7 m^2 in total, averaging 2.05×10^5 m^2. Only the area of rooftops from 38 plants exceed the average number, illustrating a huge difference between large and small plants. A plant in Wuhan owns rooftops of 2.51×10^6 m^2 available for PV deployment, ranking number 1 in 228 plants.

3.1.2 Potential capacity

The potential capacity depends on the number of solar panels installed on rooftops of steel production and processing plants. When solar panels are correctly arranged with adequate distance then more solar panels they have, the more capacity they own. We estimated 1.74×10^7 solar panels for all plants in the situation that all solar panels can obtain the sufficient sunlight and do not influence the function of buildings. The number of solar panels is closely connected with the rooftop area. Thus, the plant with most solar panels is the same one which has the largest available rooftop area in Wuhan. The average number of solar panels is 7.64×10^4. One solar panel corresponds to the fixed power capacity, as a result, we can estimate the total potential capacity. The potential capacity reaches 6.96×10^6 KW in total and the average number is 3.05×10^4 KW.

3.1.2 Potential output

Solar panels can help convert the energy of light to electricity. The amount of electricity is partly decided by the local radiation intensity. The radiation intensity varies from plant to plant due to different locations but does not show much discrepancy. The highest radiation intensity is 2079.82 W/m^2 in Tibet and the lowest is 1224.11 W/m^2 in Sichuan. According to the statistic of each regions' global horizontal irradiation (GHI), Global tilted irradiation of optimum angle, Optimum tilt of PV modules and the capacity calculated before, the annual electricity production is derived. Fig 1. Displays the potential output of steel plants, the estimated electricity production of all year is up to 9.71×10^9 kWh with an average at 4.26×10^7 kWh. Again, it is the same plant in Wuhan has the biggest potential output at 4.64×10^8 kWh. The annual electricity production of 47 plants surpasses the average number. What's more, the sum of annual electricity production from only 6 plants over 108 kWh accounts for 11.72% of the total. The potential output is mainly affected by the potential capacity driven by available rooftop area for the reason that the magnitude of the potential capacity is much greater than radiation intensity.

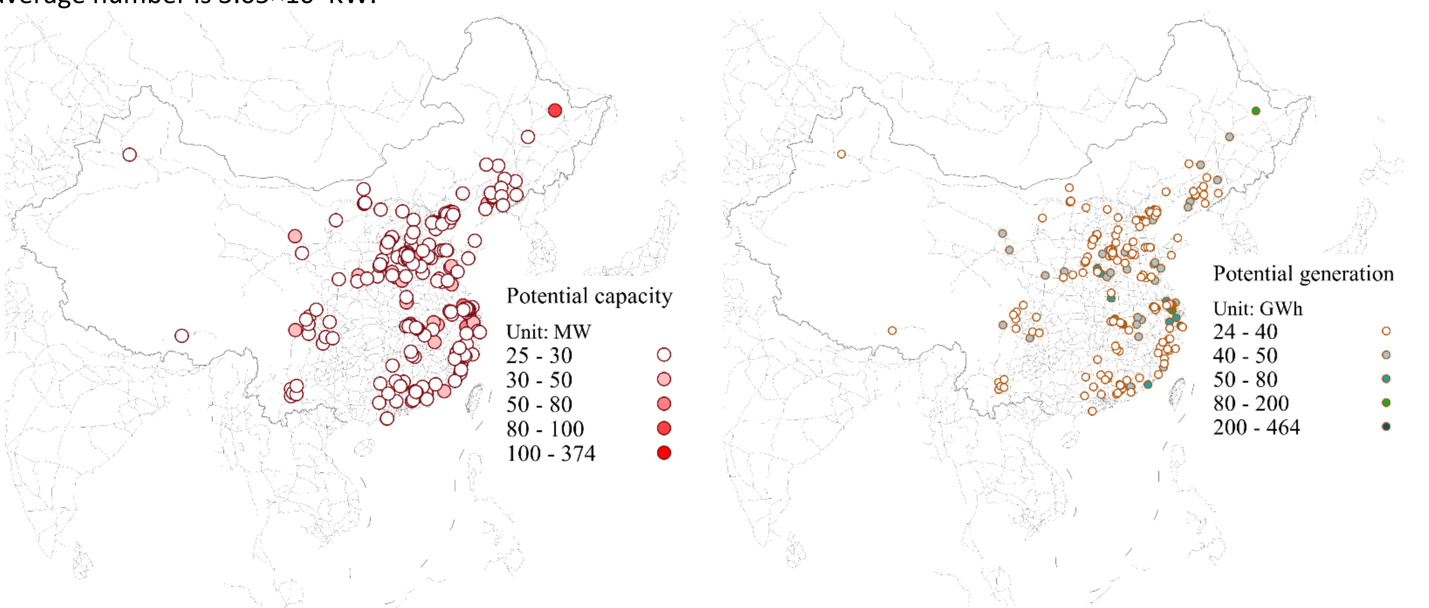

Fig. 1. The technical PV potential of 228 Chinese steel power plants. Left, potential capacity. Right, potential generation.

3.2 Economic performance

3.2.1 scenario I: all self-consumption

In all self-consumption scenario, the electricity generated by photovoltaics is all supplied to steel plants. The cost of industrial electricity used for steel production is terribly high. The electricity generated by photovoltaics could cover a small part of it and earns the profit from less industrial electricity use. All steel plants investigated could gain the profit in 25 years. As shown in fig. 2, the average profit of 228 steel plants reaches 2.45×10^{8} CNY and the maximum achieves 3.04×10^{8} CNY. The ROI varies from 86.18% to 234.84%, averaging 170.55%. Except for the ROI of a steel plant in Xinjiang province, the ROI of other steel plants surpasses 100%. For most power plants, a high profit represents a high ROI. However, the ROI of the steel plant with the highest profit is just 173.64%, slightly above the average number.

3.2.2 scenario II: all feed-into grid

In the all feed-into grid scenario, steel plants can get economic benefits from selling PV solar electricity to the grid. As shown in fig. 2, the profit that can be high as 1.52×10^{9} CNY and low as 2.05×10^{7} CNY is 1.35×10^{8} CNY in average. The same with ROI, it also has the wide range which is from 17.51% to 144.03%. The highest ROI of the steel plant located in Tibet is 13.81% larger than second highest ROI. If we number these steel plants by their ROI from the highest to the lowest, it can be easily founded that the ROI drops urgently from the number 211 with 55.69% to the number 222 with 31.96%. In this scenario, the ROI of steel plants with the top 4 profit is all below the average. The ROI of Wuhan steel plant which earns the highest profit is merely 86.94%.

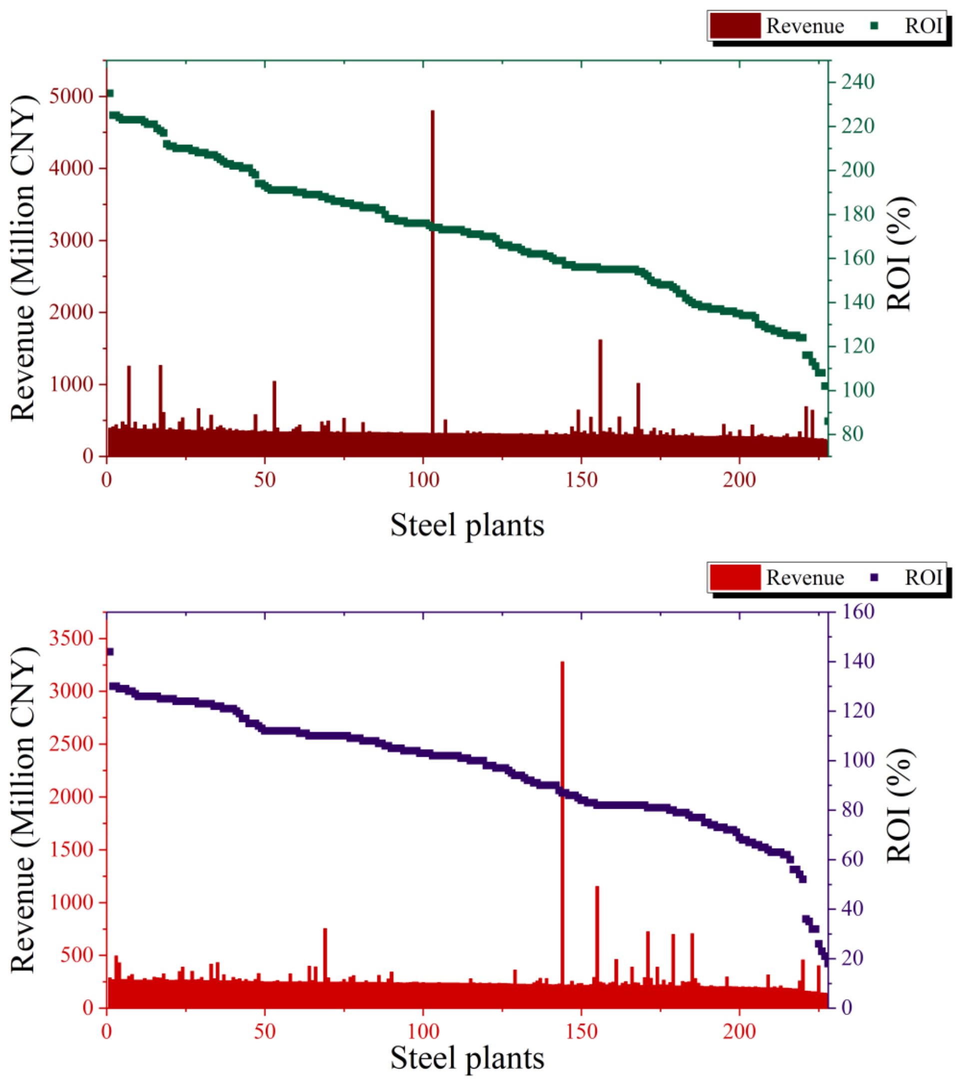

Fig. 2. The lifetime revenue and ROI of PV systems under 2 scenarios. Top, scenario I: all self-consumption; Bottom, scenario II: all feed-into grid.

3.2.3 Scenarios comparison

It is obviously found that economic performance of scenario I is greater than scenario II. Averagely, the profit of the same steel plant in scenario I is closely twice of that in scenario II. The multiple between them increases as the profit decreases. The profit of the steel plant in Chengdu with the lowest profit in scenario I and second lowest in scenario II shows the largest difference. In scenario I, the profit is only 2.05×10^7 CNY but turns out to be 1.20×10^8 CNY in scenario II which is nearly 5 times larger. In two scenarios, the LCC of each steel plant is fixed so the profit difference only originated from different price of electricity. The price of industrial electricity in scenario I is higher than the benchmark price of PV.

The ROI of the same steel plant in scenario II is 74.97% higher than in scenario II in average. Two scenarios do not share the same ranking of steel plants from the highest ROI to the lowest. Steel plants with highest profit tend to have a lower ranking of ROI in scenario II than scenario I. For example, the ROI of the steel plant with the highest profit ranked 104 in scenario I but only 144 in scenario II.

4. CONCLUSION

Technical and economic potentials of PV technology implementation for steel industry are shown in this paper. The technical potential illustrates that 228 steel plants in China would obtain the potential capacity which reaches 6.96×10^6 KW in total and 9.71×10^9 kWh PV electricity annually. The economic performance is evaluated by all self-consumption scenarios and all feed-into grid scenarios. In two scenarios, the LCC is a fixed number but the gap of profit cannot be neglected.

The recommended way of utilizing PV electricity is all self-consumption. In this scenario, the steel plant saves the electricity of steel production from PV technology and it will be able to get the profit at 2.45×10^8 CNY and ROI at 170.55%. The scenario with PV electricity all feed-into grid displays a lower profit and ROI, mainly due to relatively lower benchmark price of PV. However, adding PV technology also bring benefits to steel plants in this scenario.

Future work will focus on other indicators and assess the performance under new scenarios of PV technology in steel industry. The advantages and disadvantages of PV deployment will also be presented.

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