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AN ASSESSMENT OF PV ACCOMMODATION CAPACITY IN POWER PLANTS: A CASE STUDY OF CHINA

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ABSTRACT

As China delivering on the promise on energy transition, its photovoltaics(PV) market has become the biggest in the world, the total installed PV capacity has reached 180 GW. However, to meet the goal on 20% of total energy consumption from renewable sources, PV potential is appealing to continue release. Currently, PV deployment in China mainly focuses on residential rooftop PV systems and utility-scale PV plants, and is somehow stuck by curtailment. Distributed PV system for industrial users that has have many advantages is promising to achieve completely consumption onsite yet is still lack of investigation. Here, we present an assessment on the potential PV accommodation capacity in China's power plants by using abundant real data from power plants and geographic information system(GIS). The results show the accommodation capability of PV is 31.30 GW in power generation sector, or 3.73×10^{10} kWh for auxiliary power demand and is able to reduce 5.81×10^{7} tons of CO_2 and 9.70×10^{3} tons of $PM_{2.5}$ annually.

Keywords: PV accommodation capability, Power generation, PV potential, Emissions reduction, auxiliary power

1. INTRODUCTION

In 2018, The Intergovernmental Panel on Climate Change(IPCC) addressed their latest special report which investigates the impact of global warming of 1.5°C above pre-industrial levels, strengthens the global response to the threat of climate change, and appeals to sustainable development.[1] As the biggest developing country in the world, China is also actively taking actions on climate change mitigation and emission reduction. China have committed to achieving peak carbon dioxide emissions no later than 2030 and will decrease carbon dioxide emissions per unit of GDP to 60%-65% compared to 2005.[2] To achieve this goal, transition in energy sector should be taken place. Fossil fuels need to be substitute with low-carbon sources of energy.[3] Besides, Chinese government has set the goal to prompt renewable energy development, they have planned that the scale of solar power generation should reach 110 million kilowatts, including 60 million kilowatts of distributed photovoltaics and 45 million kilowatts of photovoltaic power stations by 2020 and non-fossil energy generation accounts for 50% of all power generation by 2030.[4; 5] Under the guidance of the related policy, by the end of the first quarter of 2019, the total installed PV capacity of the country reached 180 million kilowatts.[6] Although the installed PV capacity has exceeded the 13th five-year

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Plan, to realize real energy transition, much more efforts are needed.

The annual solar radiation in China is 1488.5 kWh/m^2.[7] The abundant solar resources have made China an ideal place for PV deployment. In the past, the most common form of PV utilization is rooftop distributed PV systems (for residential) and utility-scale PV plants. Distributed PV system for industrial users has not yet been taken seriously so far. Compared to other forms, industrial users are energy-intensive, therefore they can accept more power generation on-site without putting burdens on grids, and avoid PV curtailment effectively. Besides, infrastructures like electricity transmission devices are well equipped, so the difficulty of retrofit is lower.[8] To fully understand the value of a new proposed application, it is always suitable to start by knowing how much potential it has. To do so, many studies focused on resources and geographical constraints. Sun et al. presented a work of using DEM databases and land cover as geographical constraints, estimating PV generation potential in Fujian province.[9] Yang et al. built a GIS-based model and adopted land conversion factors to predict China's large-scale PV generation potential.[10] Hofierka et al. established a methodology for prediction of PV potential area by using a 3-D city model and solar radiation tools.[11]

This work starts from another perspective, investigating the PV accommodation capability in power generation sector. In previous works, Wang et al. assessed wind power and PV power accommodation capacity of grid and conducted a verification.[12] Liu et al. established a three stage statistical model for the accommodated electricity quantity.[13] Few study has focused on PV accommodation potential of consumer-side. our research sheds new light on PV accommodation capability study, and investigates the accommodation potential of power generation sector and assesses environmental benefits.

2. METHODOLOGY

This study adopts factual data and GIS approach to estimate the auxiliary electricity demand of power plants which can partially be supplied by PV system without energy storage device, and further investigate the PV accommodation capacity considering local solar radiation. In the last, environmental externality such like CO_2 and $PM_{2.5}$ reduction potential is calculated. The framework for the study can be seen in Fig. 1.

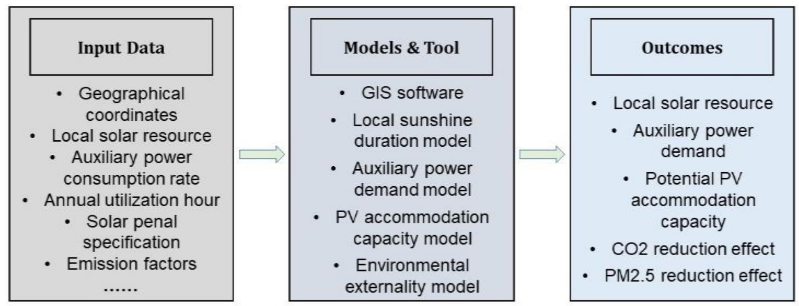

Fig 1 research framework

2.1 *Research assumption*

For the simplicity of assessing the potential PV accommodation capacity of China's power plants, we assume that:

- All power plants in china operate at non-stop run, and auxiliary electricity demand doesn't fluctuate during operation.
- No energy storage devices will be deployed to reduce the initial investment of PV system
- The outputs of PV systems will be consumed onsite and on time.

2.2 *Estimation of local sunshine duration*

To calculate the local sunshine duration of each plants, we get access to solar radiation data from WorldClim, a dataset comprises the average monthly global horizontal irradiance (GHI) value with very high spatial resolution (2.5 minutes data was used in this study).[14] Based on the GHI value, we calculate sunshine hours by the following equation:

$$\mathrm{T_{sh,i}} = \frac{\mathrm{G_i}}{\alpha_s \times 365}$$

where $T_{sh,i}$ is the average sunshine hours of power plant i, h; G_i is the annual local GHI of power plant i, kWh/m^2; α_s is the standard test condition of photovoltaics, 1000W/m^2.

2.3 *Estimation of auxiliary power demand*

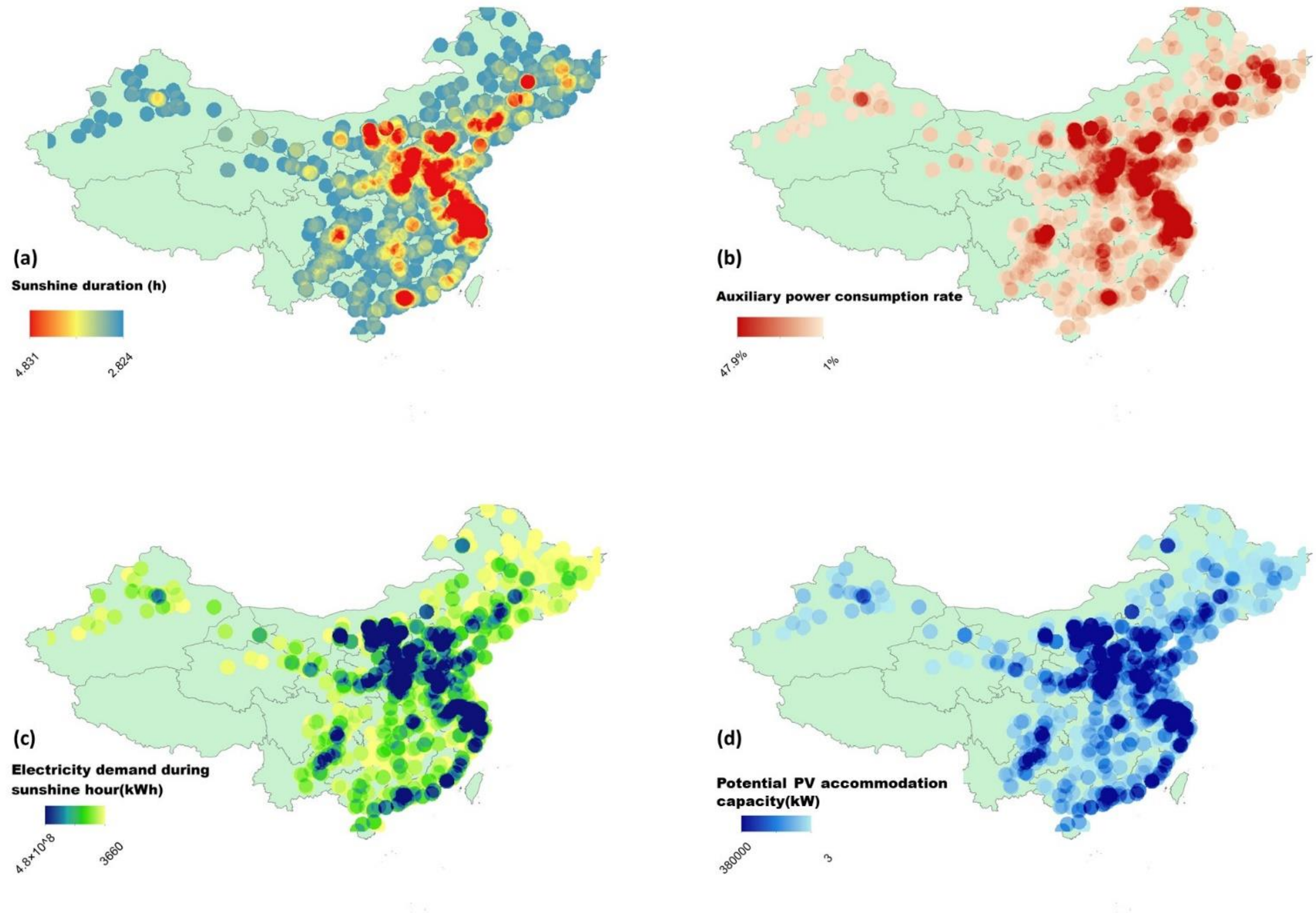

Fig 2 Spitial distribution of sunshine duration(a), auxilliary power consumption rate(b), electricity demand during sunshine hour(c) and Potential PV accommodation capacity(d).

Prior to the calculation of PV accommodation capacity, auxiliary electricity consumption (demand) should be known first. The auxiliary electricity demand is calculated by the following equations:

$$\mathrm{D_{a,i}} = \mathrm{C_i} \times \mathrm{U_i} \times \eta_{\mathrm{a,i}}$$

where $D_{a,i}$ is the auxiliary power demand of power plant *i*, kWh; C_i is the capacity of power plant *i*, kW; $\eta_{a,i}$ is the auxiliary power rate of power plant *i*, %.

PV panels only generate power during sunshine duration, and due to no energy storage devices will be deployed, PV system is able to compensate a portion of auxiliary power demand. Based on our assumption, this part of auxiliary power demand is calculated by:

$$\mathrm{D_{apv,i}} = \frac{\mathrm{D_{a,i}} \times \mathrm{T_{sh,i}}}{24}$$

where $D_{apv,i}$ refers to the partial auxiliary power demand that PV systems supply of power plant *i*, kWh.

2.4 *Estimation of PV accommodation capacity*

Once the auxiliary power demand is obtained, the PV accommodation capacity can be predicted by:

$$\mathrm{C_{ACCOM}} = \sum_{\mathrm{k=i}}^{1634} \frac{\mathrm{E_{ap,i}}}{\mathrm{G_i} \times \mathrm{k}}$$

where C_{ACCOM} refers to the PV accommodation capacity of in China's power generation sector, kW. K is the overall efficiency coefficient of PV panels, 0.78 in this study.[15]

2.5 *Estimation of environmental externality*

This study adopts emission reduction estimation of CO_2 and $PM_{2.5}$ by the following equations:

$$E_{CO_2,i} = \mathrm{D_{apv,i}} \times (\mathrm{EF_{pp}} + \mathrm{EF_{grid}}) \times 10^{-6}$$

where $E_{co2,i}$ *represents* the amount of CO_2 emission reduction of power plant *i*, T. EF_{pp} is the CO_2 emission factor of electricity generation from coal-fired power plants, 864 g/kWh.[16] EF_{grid} is the average emissions factors for China's power grids 692.5 g/kWh.[10]

$$E_{PM_{2.5},i} = \mathrm{D_{apv,i}} \times (\mathrm{EF_{PM_{2.5}}}) \times 10^{-6}$$

where $EF_{PM2.5,i}$ *represents* the amount of $PM_{2.5}$ emission reduction of power plant *i*, T, $\mathrm{EF_{PM_{2.5}}}$ is the $PM_{2.5}$ emission factor of electricity generation from coal-fired power plants, 0.26 g/kWh.[16]

3. RESULTS AND DISCUSSION

3.1 Local solar resources at power plants

In this study, we use the indicator sunshine duration (aka sunshine hours) to reflect local solar energy resource of power plants, which indicates both amount of solar radiation and working duration of PV system. Sunshine duration helps us to understand local solar resource more comprehensively.

Local solar duration is shown in Fig2(a). the average solar duration value differs from 2.82 h/day to 4.83 h/day, while the average value is 4.14 h/day. From geographical perspective, Hainan province is the region endowed with highest sunshine duration value, while Sichuan province is the weakest one. Provinces in the southwestern region (3.53 h/day) ranked bottom nationwide. Due to abundant solar radiation, northwestern region (4.35 h/day) has the longest average sunshine hours, which reveals northwestern region is superior in resource making it an ideal place to deploy solar panel in power plants in the aspect of solar resources.

3.2 Auxiliary power consumption rate and auxiliary power consumption

Fig2(b) depicts the auxiliary power consumption rates of power plants in China. The auxiliary power consumption rate is the ratio of the auxiliary power consumption to the total power generation, and it is one of the main economic and technical indicators of power plants.[17] the average auxiliary power consumption rate of china's power plants is 7.91%. the auxiliary power consumption rates are greatly affected by the type of power generation. For example, the auxiliary power consumption rate of gas power plants is generally lower than 2.5%. the auxiliary power consumption rates of captive power plants and waste-to-energy plants are usually higher than other types. Auxiliary power consumption rates also show an inverse trend with a decrease trend from small generator units to large generator units. The average capacity for plants whose auxiliary power consumption rate is higher than 20% is 36.85MW. In contrast, the average capacity for plants whose auxiliary power consumption rate is lower than 20% is 557.56MW.

When power generation of each power plant is considered, we can easily get the auxiliary power consumption of plants. Multiply auxiliary power consumption and local sunshine hours then divide by 24, we can estimate auxiliary power demand during sunshine hours.

3.3 Auxiliary power demand during sunshine hours

Auxiliary power demand during sunshine hours has close relations with generation capacity, auxiliary power consumption and local sunshine hours. The estimation of auxiliary power demand during sunshine hours is up to 3.73×10^{10} kWh, which is 20.01% of national PV power generation in 2018 and is the 6.8 times of curtailed PV generation in 2018. As shown in fig2(c). The higher demand is found in Shanxi province, Inner Mongolia, Jiangsu and Shandong province. The demand in Sichuan, Hainan, Jiangxi, Beijing and Qinghai is relatively low mainly due to small cumulative power plant capacity.

3.4 Potential PV accommodation capacity

Based on auxiliary power demand and local solar radiation, the estimation for PV accommodation capacity is 31.30 GW. Which is equivalent to 71% of new installed PV capacity in 2018. The Chinese government plans to deploy 150 GW PV power during "13th five-year" period, and our result show that just power generation sector can fulfill 21% of the objective. Fig 2(d) shows the spatial distribution of PV potential accommodation capability. Shanxi and Inner Mongolia is capable to accommodate over 2.9 GW PV capacity separately, which are largest, almost 20 time higher than Qinghai, the smallest one among the country. China's eastern and central regions have stronger accommodation capability to than the western region. Provinces like Shanxi, Shandong, Jiangsu where have already been front-runners in PV installation still exhibit great potential for further development.

3.5 Environmental externality

PV generation produces less emission than other power generation technology. In this work, we use emission factors (EFs) to evaluate the effect of CO_2 and $PM_{2.5}$ reductions. According to our estimation, the PV system of corresponding capacity is promising to reduce 5.81×10^7 tons of CO_2 and 9.70×10^3 tons of $PM_{2.5}$ annually.

A more inspiring observation is that although we know that strong imbalance exists between large-scale PV allocation and electricity consumption, the large-scale PV generation center is in the northwestern region, yet east China is the electricity consumption center, however, the emission reduction potential matches the local pollutant emission intensity. Shanxi province where the CO_2 emission from auxiliary power generation is the maximum has the greatest emission reduction amount. Although they don't stand out in terms of the total CO_2 reduction amount, potential PV deployment can offset 1.33% and 1.09% CO_2 emission in Tianjin and Henan, getting them holding a lead in proportion aspect.

CONCLUSION

This paper uses 1634 real power plants data to estimate auxiliary power demand and corresponding PV accommodation capability. With the assistance of GIS software and EFs, the relevant geographical characteristics and environmental externality are investigated. The results demonstrate that there is a great PV accommodation capability exists in power generation sector. the estimation for PV accommodation capability is up to 31.30 GW. If PV system are installed to supply auxiliary power consumption in power plants, 3.73×10^{10} kWh electricity demand can be fulfilled, reducing 5.81×10^{7} tons of CO_2 and 9.70×10^{3} tons of $PM_{2.5}$ emission annually. From geographical perspective, it is encouraging to find that PV generation potential matches local auxiliary power demand, and the emission reduction potential is consistent with emission intensity in principle.

The research reveals great PV potential in power generation sector. Deploying PV system which can be consumed onsite and on time in power plants is able to further unleash China's PV development without putting burdens on grid, and bring environmental benevolent for our society.

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