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Effect of the use of distributed solar PV in China's tourism industry

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ABSTRACT

Given the increasing role of the tourism industry in tackling climate change and air pollution, this study attempts to develop an analysis framework to investigate the effects of promoting the green and sustainable development of tourism from the perspective of developing distributed solar PV. Three typical innovation development patterns of promoting the use of distributed PV while new tourism economic growth point also has been explored. A typical tourism and distributed PV co-development project in Shenzhen which is a typical low-carbon development city is took as an example to demonstrate the application of the framework and related methods proposed to assess the benefit. The results indicate that the energy replacement effect on high-carbon coal and emission reduction effect on CAPs and GHG of this typical case is significant. On average, it results a significant reduction in coal consumption by approximately 22 thousand tonne of coal equivalent (tce), in GHG emissions by 62.9 thousand tonnes and in CAP emissions by 0.9 thousand tonnes, respectively. As the co-development of tourism and distributed PV, the effect becomes much bigger. Based on a scenario analysis, due to the use of distributed PV, the tourism industry in Shenzhen will contribute significant reductions in coal consumption, CAP and GHG emissions, ranging from 0.8 to 3.8 million tce, ranging between 0.03 and 0.2 million tonnes and in a range from 2.2 to 10.9 million tonnes, respectively.

Keywords: climate change, carbon emission target, tourism, distributed solar PV, development pattern

1. INTRODUCTION

Given the goal of less than 2 °C warming, the whole has a short window of time to put more efforts on taking measures [1]. Today, there is a consensus among scientists that the main reason for global warming and climate change is the rapid increase in human-induced CO_2 emissions. Energy dominated by high-carbon fossil energy such as coal plays a vital role in these CO_2 emissions [2,3]. Many countries around the world, including China, are beginning to address issues of energy supply and accompanied carbon emissions from all economic sectors [4,5].

According to the World Travel and Tourism Council (WTTC), China has become one of the largest tourism tourist destination countries [6]. Tourism becomes an important industry of the economics. Economic activity at this scale has significant impacts on the energy consumption and the environment. Tourism is one of the main contributors to energy consumption and greenhouse gas (GHG) emissions [7-9]. With the rapid development of the tourism industry, these impacts will be more significant. There will be an increasing pressure and concern in development of tourism and its environment implications, requiring China to seek for low-carbon and sustainable development of tourism industry.

Among all the suppliers of tourism, a tourism area is one of the hottest topics in energy conservation, carbon reduction and subsequent sustainable development of tourism [10]. Many previous studies focus on energy issues, carbon emissions issues and sustainable development issues of the tourism industry [11-13]. However, most of these studies intend to explore the relationship between tourism, economic growth, energy

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consumption, and CO_2 emissions [14,15]. Sharif et al. (2019) adopted the Morlet Wavelet time–frequency analysis method to investigate the dynamic nexus between tourism, energy utilization, particularly renewable energy utilization, and CO_2 emissions for China using annual data from 1974 to 2016 [14]. A study conducted by Shi et al. (2019) used a series of panel models to analysis the difference of multi-relationships between tourism, economic growth, primary energy consumption and CO_2 emissions at different development stages [14]. Some research begins to study the sustainable development of tourism from the respective of energy such as renewable energy, but they usually conduct a theoretical analysis or a qualitative analysis [16,17]. He et al. (2019) established the biennial Malmquist index, considering undesirable outputs, to assess the energy efficiency of tourism industry and to decompose its changes by using a sample of 30 provinces in China from 2005 to 2013, aiming at promoting the sustainable development of tourism. Another study conducted by Michalena et al. (2010) focused on investigating specific features of thermal and photovoltaic solar systems and their contribution to the sustainable tourism development of Mediterranean islands.

Therefore, the aforementioned studies fail to highlights establishing analytical models to assess the potential contribution from the use of distributed solar photovoltaic (PV) in the tourism industry aiming at promoting the low-carbon and sustainable development of tourism industry. This study will focus on establishing an analytical framework to investigate the effect of the use of distributed solar PV in the tourism industry. It will develop a model to evaluate the effect from replacing the use of traditional high-carbon coal-fired electricity with the use of distributed solar PV. It is believed that the present paper will be of interest for policy makers and tourism managers dealing with the implementation and promotion of measures to promote the sustainable development of tourism and the rapid development of distributed solar PV.

2. PROSPECT OF DISTRIBUTED SOLAR PV IN CHINA'S TOURISM INDUSTRY

Given the characteristics of energy supply, distributed energy such as distributed solar PV is a realistic option for the clean, low-carbon and green development of tourism [18]. Also, it is very helpful to resolve the problem of energy supply in the remote area tourism and the island tourism. Replacing coal-fired electricity with the use of distributed solar PV in tourism will be helpful for the reduction of carbon intensity and achieving the goal of total energy consumption control, particularly for fulling the commitment to achieve carbon emissions peak and carbon neutral. As the rapid development of tourism, an annual growth of 10.5% in 2018 in China [19], the energy requirement of cleaner energy such as distributed solar PV will continuously increase.

High levels of ambitious climate change mitigation plans call for a significant increase in the use of renewables representing by solar PV, while barriers to its deployment are increasing. For example, the consumption of solar PV is an important issue that perplexes its development in China. In 2015, the annual abandonment rate of solar PV in China had a value of up to 14% [20]. It means that a lot of clean energy has not been used, while the energy requirement is continuously increasing. Measures should be taken to increase the consumption of solar PV, which can promote the development of solar PV industry. Compared with centralized PV subject to many factors such as land resources and transport facilities, distributed PV has more advantages.

In addition, the potential of co-development pattern of tourism and distributed solar PV will also promote the use of distributed solar PV. Several types of new co-development patterns, including tourism combined with distributed solar PV plants (i.e., new tourist attractions based on distributed solar PV), tourism plus distributed solar PV and plus agriculture (new tourist attractions based on distributed solar PV plus agriculture), tourism plus distributed solar PV and plus architecture (new tourist attractions based on distributed solar PV plus architecture), and tourism plus distributed solar PV and plus others, have been attempt to explore in past recent years. Figures from 1 to 3 show several typical innovation patterns of the co-development of tourism and distributed solar PV. These innovations of development patterns will not only promote the development of tourism, but also significantly promote the development of distributed solar PV. The main novelty of this study includes: (1) the investigation of the prospect of the distributed PV plus tourism (plus others); (2) the adoption of a bottom-up method to quantify the effect of replacing the use of traditional high-carbon coal-fired electricity with the use of distributed PV in China, which can also be used for other regions or countries if data are available; and (3) the presentation of policy recommendations aiming at promoting the co-development of distributed PV and tourism.

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Fig 1 Distributed solar PV plus tourism (A PV station hidden in the beautiful wall painting)

Fig 2 Distributed solar PV plus agriculture plus tourism

Fig 3 Distributed solar PV plus architecture plus tourism

3. MODEL

3.1 A framework for effect evaluation

Given the status of tourism and energy sector, clean and green transition such as developing renewable energy focusing on reducing high-pollution energy consumption and increasing clean and low-carbon energy use to reduce GHG and CAPs emissions is attracting a growing concern. It is not only the government that is interested in developing renewable energy, but also some tourism companies and energy companies that are highly motivated. Especially, the company which focuses on developing novel tourism patterns is putting its efforts in providing more clean energy such as by developing distributed PV to face environmental pressure and create new economic growth points.

Based on identifying the characteristics of existing energy consumption of tourism in developing countries and reviewing the experiences of tourism in developed countries in addressing transition challenge, solutions and measures for promote the green and sustainable development of tourism such as increasing the use of distributed PV aiming at reducing GHG and CAP emissions from energy use mainly focus on two aspects. First, improving energy efficiency and reducing energy losses to reduce the consumption of energy, especially of high-pollution energy. Second, developing clean and low-carbon energy to replace high-pollution energy to optimize the energy structure. These two types of targets can been achieved with promoting the co-development of tourism and distributed PV. Three types of

development patterns have been ed to promote the use of distributed PV in tourism, including developing distributed PV to replace coal-fired electricity, developing distributed PV to provide clean electricity and establishing it as a new scenic spot, and developing distributed PV plus others such as agriculture plus tourism as a synthesis. Aim at investigating suitable countermeasures to promote the co-development of tourism and distributed PV, a multi-dimensional, multi-perspective and measurable analysis framework is established to identify the effects of the use of distributed PV in the tourism industry, as showed in Figure 4.

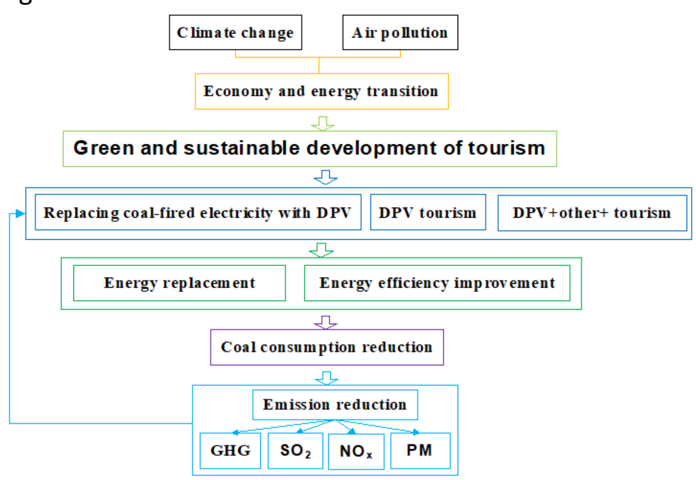

Fig 4 Proposed framework for the modelling of effect evaluation

3.2 Evaluation methods

Combined with the analysis framework above, based on a bottom-up method, a factor method and a with or without comparison method, evaluation methods aiming at quantifying comprehensive benefits of the use of distributed PV in the tourism industry are established. The coal replacement effect from the use of distributed PV in can be calculated using Equation (1):

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$$\Delta EC_t = ECR_t + ECL_t \qquad (1)$$

where $\triangle EC_t$ is the coal replacement value due to the use of distributed PV in tourism in year t; ECR_t is the coal consumed for providing energy services such as electricity replaced by distributed PV; ECL_t is the energy losses reduction by the use of distributed PV which can reduce the coal consumption for long-distance transport of electricity.

The emission reduction effect of promoting the use of distributed PV in the tourism industry on CAPs and GHG can be calculated using Equation (2) and (3):

$$\Delta GHG_t = EC_t \times EF_{gt} \qquad (2)$$

$$\Delta CAP_t = \sum_{i=1}^{m} (EC_t \times EF_{cit}) \qquad (3)$$

where $\triangle GHG_t$ is the amount of emission reduction on GHG due to developing tourism and distributed PV in year t; $\triangle CAP_t$ is the amount of emission reduction on CAPs due to developing tourism and distributed PV in year t; i is the type of CAPs such as sulfur dioxide (SO_2), nitrogen oxide (NO_x) and particulate matter (PM); EF_{gt} is GHG emission factors of different types of energy services such as electricity provision powered by traditional coal in year t; and EF_{cit} is type i CAP emission factors of different types of energy services such as electricity provision powered by traditional coal in year t.

4. A TYPICAL CASE

4.1 Case background and key data

To explore the environmental benefit of promoting the use of distributed PV in the tourism industry in China, a typical tourism and distributed PV demonstration project is chosen as the target for the evaluation. This target is a typical tourism area aiming at developing distributed PV to promote is green and sustainable development, which located in the Shenzhen City, Guangdong Province in China. The primary data that are used for the evaluation are obtained from this demonstration project via personal interviews and field investigations. Especially, the energy consumption provided by distributed PV is 660 thousand kilowatt hour (KWh), and the total energy requirement of this project is approximately 0.12 billion KWh. In addition to, other key data are obtained from literature review, personal interviews and investigations [21-23].

4.2 Results and discussion

Based on the presented framework, calculation methods and key data, the GHG and CAP emission reduction effect created by developing tourism and distributed PV is estimated. Doe to the use of distributed PV for replacing coal-fired energy, a significant energy consumption reduction effect on traditional coal as well as emission reduction effect on CAPs and GHG has been achieved. In the current circumstances, an annual reduction of coal consumption replaced by distributed PV is 201 tonne of coal equivalent (tce). An emission reduction of 4 tonnes of SO_2, 4 tonnes of NO_x, and 1 tonnes of PM has been achieved by this project in 2018. It means that the emissions reduction effect of this project in China is approximately 9 tonnes of CAPs. Meanwhile, it generated an emission reduction of 576 tonnes of GHG in 2018. It seems that the energy saving and emission reduction effect is relatively small. However, given the rapid development of distributed PV and the increasing attention on the green and sustainable development of tourism, the role of distributed PV played in the energy mix of this project will become growing bigger. Then, the greater the role of reducing energy consumption on high-carbon coal and reducing emissions on CAPs and GHG will play. Also, if more tourism areas use distributed PV, much bigger effect will be created.

Considering the development prospect of the use of distributed PV in this project, three energy mix scenarios in future have been established to investigated the significant role of distributed PV, as listed in Table 1.

Table 1. Energy mix of distributed PV accounted for.

Type	Low	Average	High
Electricity supply	40%	60%	80%

Based on the scenario assumptions, the energy replacement effect and the GHG and CAP emission reduction effect created by developing tourism and distributed PV is estimated (illustrated in **Fig. 5**).

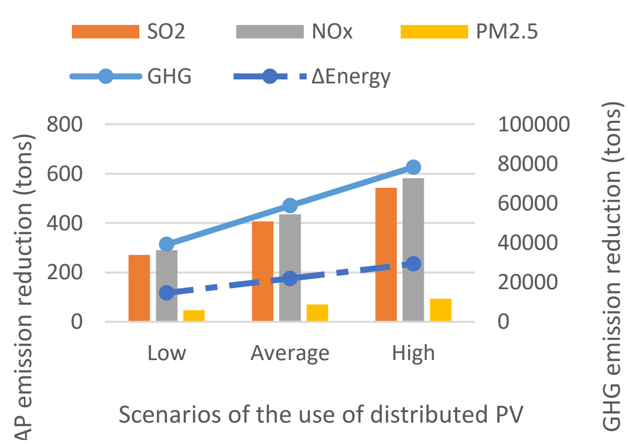

Fig 5 Effect of a tourism and distributed PV demonstration project

Fig. 5 showed that a significant energy replacement effect and emission reduction effect on CAPs and GHG

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has been achieved compared to transitional energy supply pattern. Averagely, an annual reduction of coal consumption replaced by distributed PV is 22 thousand tce. Regarding the emission reduction effect, on average, an emission reduction of 0.4 thousand tonnes of SO_2, 0.4 tonnes of NO_x, and 0.1 thousand tonnes of PM has been achieved by this project in future. It means that the emissions reduction effect of this project in China is approximately 0.9 thousand tonnes of CAPs. In addition, this project creates an average emission reduction of 62.9 thousand tonnes of GHG.

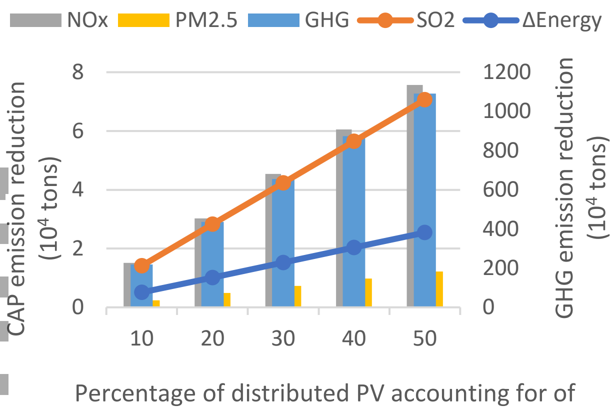

Fig 6 Effect of the increasing use of distributed PV in Shenzhen tourism industry

As illustrated in **Fig. 5**, the energy replacement effect and emission reduction effect of the increasing use of distributed PV in Shenzhen tourism industry on CAPs and GHG compared to transitional energy supply pattern are presented. With the growing use of distributed PV in Shenzhen tourism industry at various development scenarios, the potential contribution of distributed PV is increasing significant. A significant reduction in energy use such as coal consumption, in a range from 0.8 to 3.8 Million tonnes tce, can be attained in China by replacing a traditional coal-fired energy with distributed PV. A similar result has been obtained for CAPs and GHG reductions. The CAPs and GHG reductions benefit of the increasing use of distributed PV is , ranging between 0.03 and 0.2 Million tonnes and ranging from 2.2 to 10.9 Million tonnes respectively.

5. CONCLUSIONS

This paper highlights on establishing a framework for modelling the quantitative evaluation of the effect of promoting the use of distributed PV aiming at achieving the co-development of tourism and distributed PV with the targets of reducing GHG and CAP emissions for sustainable development, especially for developing countries facing these challenges. This analysis framework focuses on investigating innovation development patterns that consisted with tourism and distributed PV energy systems to achieve transitions based on the characteristics of energy consumption and related GHG and CAP emissions. As a typical developing country pursuing sustainable development, a typical project in China is took as an example to demonstrate the application of the framework proposed to analysis the effect of developing tourism and distributed PV. Based on the proposed framework, the emission reduction effect of countermeasures issued to promote the use of distributed PV in China's tourism industry to promote the co-development of tourism and distributed PV is estimated.

The results indicate that, due to the implementation of developing tourism and distributed PV, a significant energy replacement effect on high-carbon coal and emission reduction effect on CAPs and GHG has been achieved compared to transitional development pattern. There are differences in the energy replacement effect and emission reduction effect of each energy mix scenario, especially for different targets. This finding means that the proposed framework can not only effectively help China identify the effect of developing tourism and distributed PV for promoting the use of distributed PV on reducing energy consumption and GHG and CAP emissions but can also help China identify key actions and their implementation priority and order to maximize emissions reductions for different targets such as carbon emissions peak. This framework can help China generate ideas and develop programs to promote the transition aiming at the co-development of tourism and distributed PV. Moreover, this proposed framework can also help countries similar to China make decisions on suitable energy countermeasures and development pattern to promote the co-development of tourism and distributed PV for green and sustainable development.

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