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INVESTMENT VALUE ANALYSIS OF HOUSEHOLD ROOFTOP PV POWER GENERATION UNDER CARBON TRADING MODE

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ABSTRACT

This paper firstly takes Zhongshan City as an example to analyze the feasibility of investment value of household rooftop PV power generation project under carbon trading mode. The results show that the current level of carbon price in Guangdong Province is not enough to promote residents' investment in rooftop PV. Then, this paper further studies the impact of carbon price on the investment value of household rooftop PV power generation projects. The results show that the higher the carbon price level, the greater the increasing of investment value, and the level of government subsidy required is gradually declining. Finally, based on the research results, this paper puts forward two related conclusions and policy suggestions.

Keywords: household rooftop PV power generation; model of carbon trading; carbon price; subsidy

1. INTRODUCTION

The advantages of building a photovoltaic power generation system on the roof can make full use of roof resources on the one hand; on the other hand, it can be used nearby to reduce the distribution loss on the transmission and distribution lines. Especially for China, a country with a large population, family roof resources are abundant, thus rooftop PV power generation should become the main force of distributed photovoltaic development. In 2018, 10 household PV power plants in Zhongshan City, Guangdong Province successfully declared carbon trading 51t, and gained profits through carbon trading.

For the economic benefits and the environmental benefits of household rooftop PV power generation projects, Sandy Rodrigues et al. [1] calculated the net present value and internal rate of return of household rooftop PV systems in different regions of China in 2015. The results show that the investment projects can obtain higher returns in areas with better solar energy resources or in regions with higher electricity prices. Frauke Urban et al. [2] studied two cases and explored different ways to promote the development of China's solar low-carbon innovation. It was found that solar PV can make a great contribution to China's low-carbon transformation. Thanapol Tantisattayakul et al. [3] conducted a feasibility analysis on the investment value of the household rooftop PV project in Bangkok, Thailand. The article proposed several improvement measures, including appropriate on-grid tariffs, encouraging carbon trading systems and providing low-interest loans.

Therefore, based on the research of outstanding scholars, the contributions of this paper are as follows. This paper studies the impact of carbon price on the investment value of China's domestic rooftop PV power generation project from a newer carbon trading market perspective. It not only quantifies the environmental benefits of the project, but also has certain guiding significance and reference value for the development of China's carbon price and household PV.

2. MODELS AND METHODS

2.1 Net present value model of household rooftop PV power generation project

The evaluation criteria of NPV is: if the calculated NPV value is lower than 0, the user generally does not invest in the PV project; if the NPV value is higher than 0, it indicates that the investment project has investment value. The calculation method of *NPV* is as shown in equation (1).

$$NPV = \sum_{t=1}^{n} \frac{FCFE_t}{(1+r)^t} \tag{1}$$

In the expression (1): $FCFE_t$ is the annual net cash flow of the household rooftop PV power generation project; *r* is the discount rate; *n* is the system service life.

2.1.1 Annual cash outflow of rooftop PV power generation projects

At the time of initial investment, there is only cash outflow of own funds. The annual cash outflow after project investment operation mainly includes three parts: the first is the operation and maintenance expenses, the second is the annual loan repayment, and the last one is the loan interest expense, as shown in formula (2).

$$C_t = Inv_0 \times (1 - K_{loan}) + OM_t + Dept_t + Int_t \tag{2}$$

Among them, Inv_0 is the initial investment cost of the project; K_{loan} is the proportion of loans in the initial investment cost; OM_t is the annual operation and maintenance cost; $Dept_t$ is the loan repaid annually; Int_t is the annual interest expense incurred due to the loan.

2.1.2 Annual cash inflow of household rooftop PV projects

Distributed photovoltaic annual power generation EG_t is affected by factors such as installed capacity *M* of distributed PV equipment, the average annual effective solar generation hours *h* in the region, the PV power generation system efficiency PR_t and the PV reduction rate d_t, as shown in formula (3).

$$EG_t = M \times h \times PR_t \times (1 - d_t) \tag{3}$$

The cash inflow R_t mainly includes four parts, the first part is the indirect income brought by the self-use consumption part, that is, the product of the resident sales price R_{use} and the annual power generation EG_t and the self-use ratio K_{use} [4]; the second part is the direct income obtained by the surplus electricity to grid, that is, the product of the *FIT* of surplus electricity to grid and the power generation EG_t and proportion of on-grid electricity (1-K_{use}) [5]; the third part is the subsidy income given by the state according to the amount of PV power generation; the last part is the neglected carbon trading profits in the traditional model, as shown in formula (4).

$$R_t = R_{use} \times EG_t \times K_{use} + FIT \times EG_t \times (1 - K_{use}) + P_{sub} \times EG_t \times K_{use} + R_{ct} \tag{4}$$

$$R_{ct} = ER_t \times P_c \tag{5}$$

$$ER_t = EG_t \times EF_{gird,CM,y} \tag{6}$$

$$EF_{gird,CM,y} = EF_{gird,OM,y} \times WOM + EF_{gird,BM,y} \times WBM \tag{7}$$

Among them, in formula (5), R_{ct} represents the carbon trading income; ER_t is the carbon reduction in the t-year of installing the household rooftop PV; P_C is the average carbon price of the carbon market. $EF_{gird,CM,y}$ in (6) represents the grid emission factor of electricity. $EF_{gird,OM,y}$ represents the marginal emission factor (t CO2/MWh) of the y year; $EF_{gird,BM,y}$ represents the marginal emission factor of capacity (t CO2/MWh) of the y year; *WOM* is the marginal emission factor weight (%) of electricity (*WOM* = 75% for PV power generation projects); WBM is the marginal emission factor weight (%) of capacity (for PV projects, *WBM* = 25%).

2.1.3 Net present value of household rooftop PV power generation projects

The cash outflows and cash inflows calculated by equations (2) and (4) are discounted at the expected rate of return to obtain the project's net present value NPV. The final detailed formula for NPV is as shown in equation (8).

$$\begin{aligned} NPV &= \sum_{t=1}^{n} \frac{FCFE_t}{(1+r)^t} = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} \\ &= \sum_{t=1}^{n} \frac{R_{use} \times EG_t \times K_{use} + FIT \times EG_t \times (1 - K_{use}) + P_{sub} \times EG_t \times K_{use} + R_{ct}}{(1+r)^t} \\ &\quad - \sum_{t=1}^{n} \frac{Inv_0 \times (1 - K_{loan}) + OM_t + Dept_t + Int_t}{(1+r)^t} \end{aligned} \tag{8}$$

2.2 Internal rate of return model for household rooftop PV power generation projects

The evaluation criteria for IRR is: when the IRR is greater than the rate of return required by the investment project, the investment project is feasible, and the higher the IRR, the higher the value of the investment project. The calculation method of IRR is as shown in equation (9).

$$\begin{aligned} 0 &= \sum_{t=1}^{n} \frac{FCFE_t}{(1+r)^t} = \sum_{t=1}^{n} \frac{R_t - C_t}{(1+r)^t} \\ &= \sum_{t=1}^{n} \frac{R_{use} \times EG_t \times K_{use} + FIT \times EG_t \times (1-K_{use}) + P_{sub} \times EG_t \times K_{use} + R_{ct}}{(1+r)^t} \\ &- \sum_{t=1}^{n} \frac{Inv_0 \times (1-K_{loan}) + OM_t + Dept_t + Int_t}{(1+r)^t} \end{aligned} \quad (9)$$

3. EMPIRICAL RESEARCH

3.1 Basic data sources

This paper takes the household rooftop PV power generation project with an average installed capacity of 5kW for most residents in Zhongshan City in 2018 as an example. The initial investment cost of the equipment is 7 yuan / W. The basic data required for the calculation is shown in Table 1.

Table 1. Basic data table

variable	unit	value	variable	unit	value
M	kW	5	K_{use}	/	50%
n	year	25	K_{loan}	/	0
h	h	1118.80	r	/	8%
PR	/	83%	P_C	yuan/t	16.35
d_1	/	3%	$EF_{gird,OM,y}$	t CO_2/MWh	0.8676
d_t	/	0.50%	$EF_{gird,BM,y}$	t CO_2/MWh	0.3071
FIT	yuan/kWh	0.823			

3.2 Analysis of investment value of household rooftop PV power generation project in Zhongshan City

Based on the model methodology and data hypotheses presented above, Table 2 shows the results of *NPV* and *IRR* studies in the case of whether Zhongshan residents participate in carbon trading. Negative values indicate that Zhongshan's family rooftop PV power generation project cannot recover the cost during the whole project cycle. The *IRR* values are lower than the expected return rate of 8% of the project. Under this circumstance, it is impossible to stimulate residents to invest in the project. However, it can be found from the results that participation in carbon trading can increase the investment value of household rooftop PV power generation projects to a certain extent. Therefore, the following article will study the impact of carbon prices on the investment value of household rooftop PV power generation projects.

Table 2. The results of the study

Do not participate in carbon trading		Participate in carbon trading	
index	value	index	value
IRR	7.42%	*IRR*	7.6%
NPV	-1598.25	*NPV*	-1050.65

3.3 Impact of carbon price on the investment value of household rooftop PV power generation projects

Table 2 shows that the increase in the *IRR* value of participating in carbon trading under the carbon price level in Guangdong Province is not significant. Because China's current carbon price is at a low level internationally, there is still a large gap compared to other countries with mature carbon markets (such as California-Quebec carbon emissions trading stand is 97.79 yuan/t, EU emissions trading stand is 104.31 yuan/t, South Korea emissions trading stand is 136.91 yuan/t). However, China's carbon price still has a large room for growth. Therefore, this paper further studies the *IRR* values of Zhongshan's family rooftop PV power generation project in different international carbon price levels. The results of the study are shown in Figure 1. As the carbon price level increases, the *IRR* value of the rooftop PV projects continues to rise. If Zhongshan's carbon price comes to 47.72 yuan/t, the *IRR* value of Zhongshan's family rooftop PV power generation project will reach the expected rate of return. If Zhongshan's carbon price reaches the highest carbon price level in the eight carbon trading pilots of China, that is, Beijing's carbon price is 52.72 yuan/t, the *IRR* value will come to 8.06%. If China's carbon price rises to the current carbon price level of 136.91 yuan/t in South Korea, the *IRR* value will easily come to 9.07%, thus providing a good opportunity to stimulate residents to invest in the project effectively on this occasion. Therefore, it can be seen that encouraging carbon trading mode is a more effective measure.

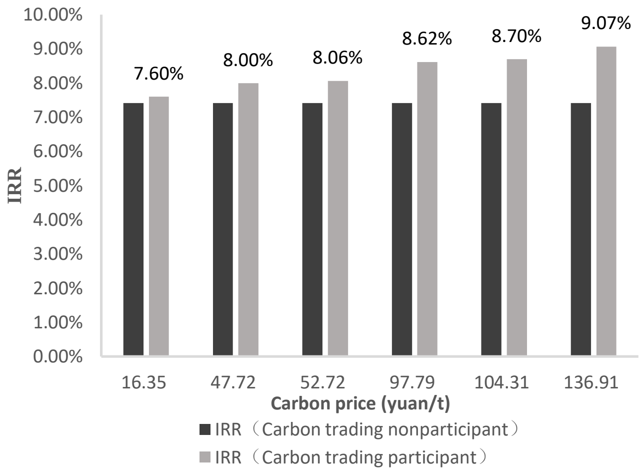
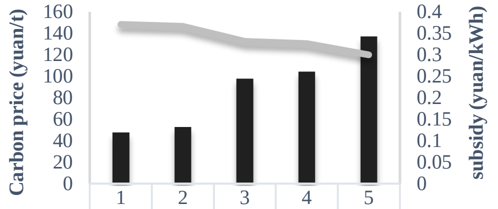


Fig. 1. IRR values at different carbon price levels

In addition, since carbon trading can be carried out between companies, other institutions and individuals, this measure does not require additional government subsidies, which in turn helps to reduce the government's financial burden. Figure 2 shows that with the IRR value at the expected rate of return of 8%, as the carbon price level increases, the level of government subsidies required for the project shows a downward trend. If the carbon price in Zhongshan City of Guangdong Province rises to the current carbon price level of 136.91 yuan/t in South Korea, the government subsidies can be adjusted downward to 0.2999 yuan/kWh, and residents can reach the expected rate of return of 8%. This shows that encouraging PV users to participate in carbon trading is conducive to reducing the level of government subsidies and reducing the burden on the government, and thereby to achieve household rooftop PV grid parity.



	1	2	3	4	5
Carbon price (yuan/t)	47.72	52.72	97.79	104.31	136.91
Required subsidy (yuan/kWh)	0.37	0.3661	0.3306	0.3255	0.2999

Carbon price (yuan/t)
Required subsidy (yuan/kWh)

Fig.2. Subsidy standards required under different carbon price levels

4. CONCLUSIONS

Based on the above research contents and discussion results, this paper proposes the following two conclusions and policy recommendations to promote the development of household PV in China.

Carbon trading mode is an effective measure to increase the investment value of household rooftop PV power generation projects. Currently for Zhongshan, it is recommended to increase the carbon price to at least 42.72 yuan/t. For the whole China, the Chinese government should further improve the carbon market trading system, clarify the specific policies for PV users to participate in carbon trading.

The carbon trading model is conducive to reducing the level of subsidies for the government's rooftop PV power generation projects. Therefore, by encouraging and guiding residents to participate in carbon trading, household rooftop power generation projects can be promoted to market development through carbon trading without state subsidies, and thus realize the grid parity for household rooftop PV in China.

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