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Policy recommendations to distributed roof PV based on economic feasibility analysis: A case study in China

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Abstract—To realize the initiative of carbon peak and carbon neutral in China, the traditional energy system dominated by high-carbon fuels must be transformed to a clean and low-carbon energy system. Because of its resource potential and cleaner advantages, the development of distributed solar PV generation can significantly increase the supply of cleaner energy while offering the associated benefits. Distributed PV generation such distributed roof PV generation will be an important part of the new electrical power system dominated by new energy including solar and wind power. To attain this target, more distributed PV generation will need to be developed in China for the coming decades. However, the current incentives have not been sufficiently aggressive, and the distributed PV industry has been slow to develop. Existing policies for distributed PV generation thus need to be further improved. To provide effective support for decision makers in China, an economic feasibility analysis is performed in this study to explore the profitability of distributed roof PV production in a target area. The results show that the development of distributed roof PV production is not economically viable in China under the current conditions. Based on this analysis, some policy recommendations are presented to improve the current incentive polices aimed at promoting the development of distributed roof PV in China.

Keywords—carbon neutral, roof distributed PV, economic evaluation, discounted cash flow analysis, policy combinations

I. INTRODUCTION

Like many other countries, China is increasing its efforts to address climate change, which pledged that its carbon emissions will peak before 2030 and that it will be carbon neutral before 2060 [1,2]. To realize the initiative of carbon neutral in China, the traditional energy system dominated by high-carbon fuels must be transformed to a clean and low-carbon energy system (see Fig. 1) [3]. Currently, China is one of the world's largest consumers of energy sources and one of the world's largest contributors to greenhouse gas (GHG) emissions. Because of its resource potential and clean advantages, the development of solar PV generation can significantly increase the supply of cleaner energy while offering the associated benefits [4]. In recent years, China has issued a series of policy measures to promote the development of solar PV generation [5–7].

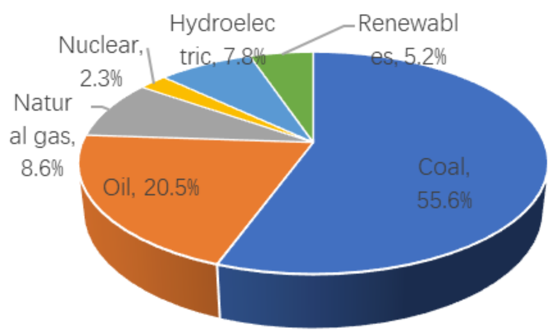

Fig.1 China's primary energy consumption mix in 2020.

With technological advances and policy support, China has achieved a series of breakthroughs in the development of solar PV generation. The installed capacity of solar PV generation in China in 2011 is only about 2.2 million kilowatt (kW), only 0.2% as share of total installed capacity in China. In 2020, the installed capacity of solar PV generation in China became approximately 25.2 million kW, accounting for 11.5% of total installed capacity in China (as illustrated in Fig. 2) [8,9]. Due to the efforts played by China, the installed capacity of total installed capacity has an approximate 113-fold increase in past ten years. The PV electricity generation has increased to 253.4 billion kW in 2020 from 0.6 billion kW in 2011, contributing a huge increase. However, the PV electricity generation is a very small percentage of total electricity generation in China, with 3.4% (see Fig.3) [8,9]. To attain the carbon neutral target, more PV will need to be developed in China for the coming decades.

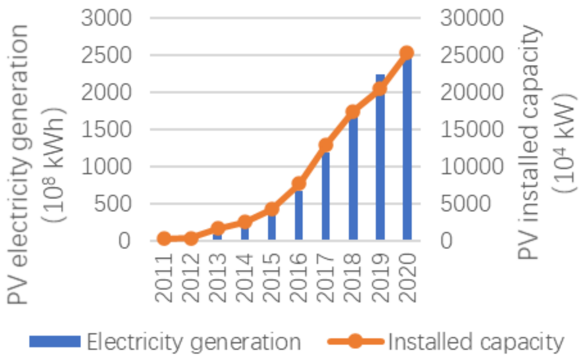

Fig.2 The PV installed capacity and electricity generation in 2011–2020.

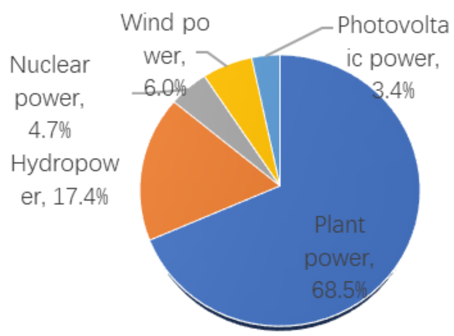

Fig.3 China's electricity production mix in 2020.

Due to its unique advantages, distributed PV generation such as distributed roof PV generation is an important part of the new electrical power system dominated by new energy including solar and wind power. However, the deployment of distributed PV applications remains sluggish in large markets such as China and the United States [10–12]. The reason maybe that the current incentives have not been sufficiently aggressive for the deployment across the country. Existing policies thus need to be further improved.

Numerous studies have been conducted to explore the policies for promoting the development of distributed PV generation in China. However, many studies focus on presenting some suggestions after the qualitative analysis of the existing policies for distributed PV generation [13–15]. Few studies highlight the establishment of analysis model for the quantitative analysis aiming at the presentation of better policy suggestions for the development of distributed PV generation [16–18]. Especially, some studies focus on proposing some policy measures based on simple economic analysis or cost-benefit analysis norther than comprehensive economic feasibility analysis of the development of distributed roof PV generation [19–21]. None of the existing studies in the China context have examined and performed a comprehensive economic feasibility analysis of the development of distributed roof PV generation aiming at investigating key factors for propose suitable policy recommendations [22–24]. This paper aims at performing a comprehensive economic feasibility analysis of the development of distributed roof PV generation in China for presenting policy recommendations in the post-subsidy era.

The current study involves a comprehensive assessment of the economics of deploying distributed roof PV generation in China by using actual project data in a target area. These results are helpful for effectively investigating the economic feasibility of the development of distributed roof PV generation in China and particularly, realizing the targets of China such as addressing climate change and attaining carbon neutral. This paper is structured as follows: Section 2 presents the economic feasibility analysis methods adopted in this study; Section 3 presents the key data and assumptions adopted for the evaluations; Section 4 illustrates the results of this study and presents a discussion; and finally, Section 5 presents the conclusions of this study.

II. METHODS

Discounted cash flow (DCF) analysis is used to project the future annual cash flows of a distributed roof PV generation project over its power generation life and to discount them to determine the present value of this project. This calculated value is then used to evaluate the economic potential of the investment so that a decision can be made on the distributed roof PV generation project. Several popular economic metrics, such as the net present value (NPV) and internal rate of return (IRR), are frequently employed to support more rational investment decisions [25–27].

In any operational year t, the net cash flow (NCF) of a distributed roof PV generation project is the cash received less the cash spent. The annual net cash flow associated with a distributed roof PV generation project in China in year t is calculated as follows in Equation (Eq.) (1):

$$NCF_t = R_t - IC_t - OC_t - T_t \qquad (1)$$

where NCF_t is the annual net cash flow of a distributed roof PV generation project in year t, R_t is the total revenue in year t, IC_t is the capital costs in year t, OC_t is the operating costs in year t, and T_t is the taxes paid in year t. In this study, the revenues include 'savings' due to self-consumption instead of purchasing electricity, selling surplus electricity to the grid, and the financial subsidies.

The sum of the annual discounted cash flow (DCF) is equal to the NPV of this distributed roof PV generation project, which is the most widely used indicator for economic feasibility. The NPV is calculated as

$$NPV = \sum_{t=0}^{k} NCF_t / (1+i)^t \qquad (2)$$

where i is the discount rate, and k is the producing electricity life of the distributed roof PV generation project. The project life t starts at year 0 and ends in year k.

IRR is another widely used metric to measure the profitability of the distributed roof PV generation project. It calculates a discount rate when the NPV of the distributed roof PV generation project is zero. The IRR can be computed as follows in Eq. (3):

$$IRR = \{i | when\ NPV = 0\} \qquad (3)$$

III. Key Data and Assumptions

Jiangxi province is the one of the most active area for the development of distributed roof PV generation in China. To explore the prospects for distributed roof PV development in China, a typical distributed roof PV generation project with an installed capacity of 10 kilowatts in Jiangxi province is chosen as the object of this evaluation to ensure the rationality of the evaluation. The key data that are used for the evaluation of the economic feasibility are obtained via personal interviews and field investigations, as listed in Table 1.

TABLE I. KEY PARAMETERS THAT ARE USED FOR THE EVALUATION OF DISTRIBUTED ROOF PV GENERATION IN CHINA

Variable	Notation	Unit	Value
Initial annual generation	***IAG***	***kWh***	***10644.8***
Residential electricity price	***REP***	***CNY***	***0.6***
Feed-in tariff	***FIF***	***CNY***	***0.4143***
Producing electricity life	***n***	***year***	***25***
Investment cost	***IC***	***CNY***	***40000***
Operation cost	***OC***	***CNY***	***850***
Financial subsidy	***FS***	***CNY***	***0.08***
Value-added tax	***VAT***	***%***	***17***
Corporate income tax	***CIT***	***%***	***25***
Discount rate	***i***	***%***	***8***
Bank loan	***BL***	***%***	***50***
Loan interest rate	***LI***	***%***	***9***
Loan period	***LP***	***year***	***5***

[a] US$1=CNY6.55 in 2020.

IV. Results and Discussion

A. Financial analysis

Based on the method described above, a financial analysis is performed to evaluate the development of distributed roof PV generation in China's Jiangxi Province. Considering the impact of the difference of the self-consumption ratio, three cases are designed. The main economic indicators of these three cases are listed in Table 2. Taking case1 for instance, the NPV is -1649.1 CNY(US$1=CNY6.55 in 2020), and the IRR is 7.5%. Clearly, the development of distributed roof PV generation in China is currently not economically viable. Fig. 4 illustrates the annual discounted net cash flow of the distributed roof PV generation project. It suggests that this distributed roof PV generation project is not profitable.

TABLE II. THE PROFITABILITY OF THE DISTRIBUTED ROOF PV GENERATION PROJECT IN VARIOUS CASES

Case	Self-consumption ratio	Economic indicator	
		NPV(CNY)	***IRR***
Case1	*90%*	*-1649.1*	*7.5%*
Case2	*100%*	*-192.2*	*7.9%*
Case3	*50%*	*-7476.9*	*5.8%*

[b] US$1=CNY6.55 in 2020.

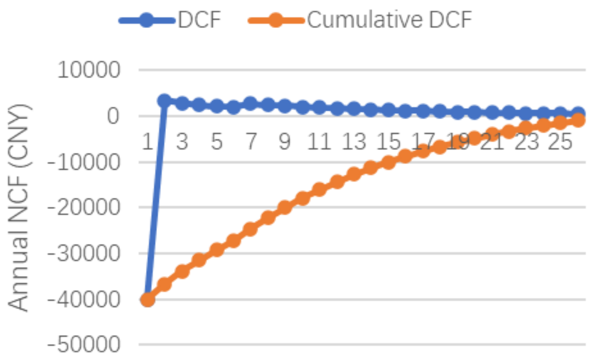

Fig.4 The annual discounted net cash flow of the distributed roof PV generation project.

B. Sensitivity analysis

There are many factors affecting the profitability of the distributed roof PV generation project. The effect of key factors, such as the initial annual generation (IAG), residential electricity price (REP), feed-in tariff (FIF), investment cost (IC), and operation cost (OC), on the NPV of the distributed roof PV generation project in the target area are plotted in Fig.5. Fig. 6 illustrates the three key factors with the most influence on the NPV of the distributed roof PV generation project: NAG, REP and IC. Among these thre uncertainty factors affecting the profitability of the distributed roof PV generation project, the IAG is the most sensitive, and it has the most significant effect on the NPV, with the highest sensitivity coefficient of 28.1. Subsequently, REP also has a very large effect on the NPV, with a sensitivity coefficient of 25.7, followed by IC, with a sensitivity coefficient of –24.9. Notably, some factors such as the IAG and REP, have a positive effect on the NPV, whereas other factors, such as IC and OC, have a negative effect.

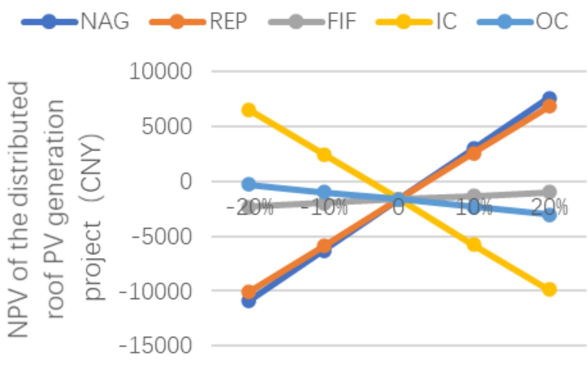

Fig.5 The effect of key factors on the NPV of the distributed roof PV generation project.

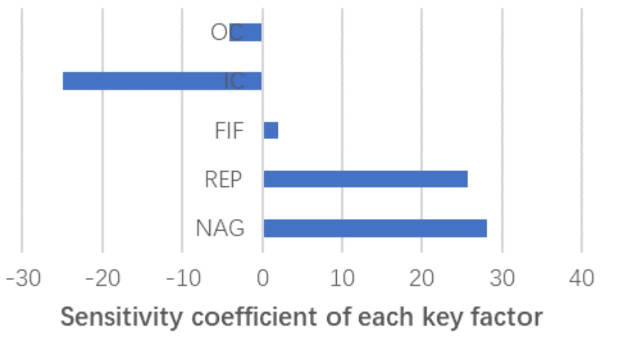

Fig.6 Sensitivity coefficient of five key uncertainty factors affecting the NPV.

C. Policy implication anlysis

a) Financial subsidy: Currently, distributed roof PV generation projects in the target area qualify for national government financial subsidies for only two years. In this context, the small improvement cannot make distributed roof PV generation economically viable. Nonetheless, if the subsidy timeline is extended from two to twenty-five years, financial subsidies will have a more pronounced effect, which can render distributed roof PV generation almost economically feasible in the target area, with a IRR of 8% (see Fig. 7). If there is local government financial subsidies besides current two years national government financial subsidies, this distributed roof PV generation project will become economically viable. Financial subsidy is still a useful policy instrument for improvomg the economic feasibility of the distributed roof PV generation. However, the governent will be under huge financial pressure again.

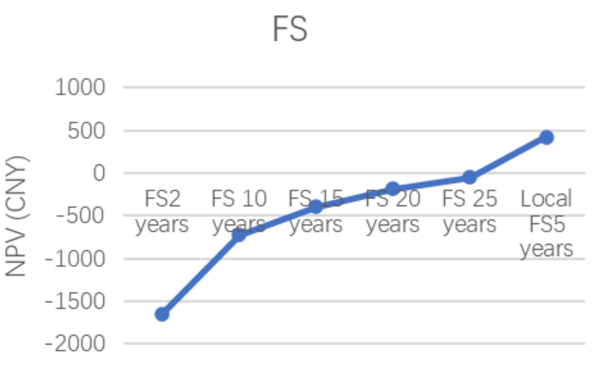

Fig.7 The effect of preferential FS policy on the NPV.

b) Higher residential electricity price: Based on the sensitivity analysis performed above, REP is one of the three key factors with the most influence on the NPV of the distributed roof PV generation project in China. The REP is assigned as a directory by the administrative department in China. It is usually under the tiered pricing rate structure. Moreover, time-of-use price has been implemented in some areas in China. Compared developed provinces, the REP of the target area is relatively lower. If a higher REP applied to the target area, the economic feasibility of the distributed roof PV generation will be better. Given this possibility, the NPV of for the production of distributed roof PV generation in the target area is calculated for various cases of REP at 0.6 CNY (base case), 0.625 CNY, 0.65 CNY, 0.675 CNY, 0.75 CNY, and 0.725 CNY (as shown in Fig. 8). The results show that higher residential electricity price play a significant role in increasing the profitability of the distributed roof PV generation project in China.

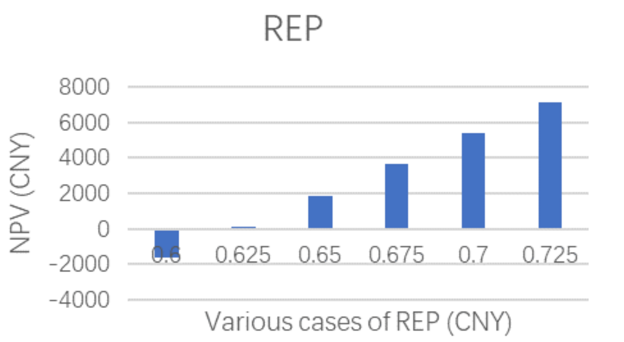

Fig.8 The effect of higher REP policy on the NPV.

c) Higher feed-in tariff: A feed-in tariff (FIT) is a typical policy designed to support the development of renewable energy sources such as distributed roof PV by providing a guaranteed, above-market price for electricity producers. Under current incentive policy, the profitability of the distributed roof PV generation project in China is low. Several cases of FIF at 0.4143 CNY, 0.45 CNY, 0.5 CNY, 0.55 CNY, 0.6 CNY, and 0.65 CNY are designed to investigate the effect of higher FIF on the NPV of the distributed roof PV generation in China (as illustrated in Fig. 9). The result suggests that higher FIF will have a more pronounced effect, which can render distributed roof PV generation economically feasible in the target area.

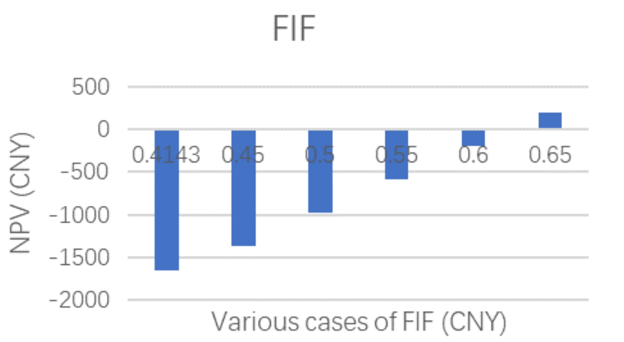

Fig.9 The effect of higher FIF policy on the NPV.

d) Preferential loan interest rate: The initial investment of this distributed roof PV generation project in the target area is approximate 40 000 CNY. For some low-income families, it may not be a affordable option. In China, the existing financing mechanisms for distributed roof PV generation projects include conventional bank loans, industry investment funds, and internet financing. Especially, bank loan is an important financing mechanism for helping the distributed PV enterprises and individuals. In this study, 50% of the initial investment of the distributed roof PV generation project are loaned from the bank at an annual interest rate of 9%, and paid off within 5 years. For investiagting the effect of preferential LIR policy on the profitability of this distributed roof PV generation project in the target area, the NPV is calculated for various loan interest rates of 9%, 7%, 5%, 3%, 1%, and 0% (as illustreated in Fig. 10). The results demonstrate that preferential LRI policy is an efffective policy instrument for improving the economics of the development of the distributed roof PV generation in China.

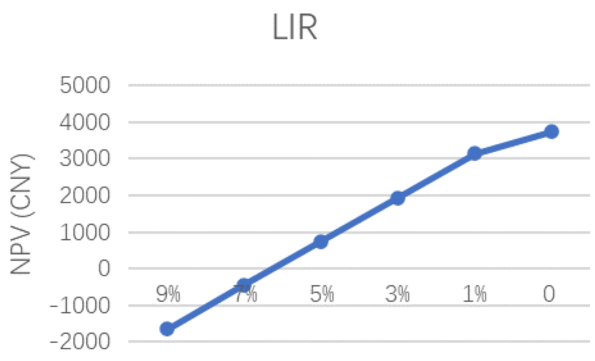

Fig.10 The effect of preferential LIR policy on the NPV.

Base on the analysis described above, the effect of various types of policy instruments including financial subsidy (FS), higher residential electricity price, higher feed-in tariff and preferential loan interest rate on the economic feasibility of the distributed roof PV generation project in China has been investigated by using DCF analysis. Some policy instruments such as higher residential electricity price policy and preferential loan interest rate policy play a vital role in increasing the profitability of the distributed roof PV generation project in the target area. However, some policy instruments such as higher feed-in tariff policy can help improve the economics of distributed roof PV generation, the effect is quite small. This means that appropriate policy instruments should be selected for better promoting the development of distributed roof PV generation based on the specific conditions of different regions in China.

V. Conclusion

To address climate change and attain carbon peak and carbon neutral in China, the traditional energy system dominated by high-carbon fuels must be transformed to a clean and low-carbon energy system. Future new energy system will be dominated by renewable energy such as solar PV generation and wind generation. Because of its resource potential and clean advantages, the development of distributed solar PV generation can significantly increase the supply of cleaner energy while offering significant environment benefits and climate benefits. The deployment of distributed PV applications remains sluggish in large markets such as China and the United States in past decades. To attain the target of carbon peak and carbon neutral, more distributed PV generation will need to be developed in China for the coming decades.

This paper aims at performing a comprehensive economic feasibility analysis of the development of distributed roof PV generation in the post-subsidy era in China. The economic profitability of the development of distributed roof PV generation in a target area in China has been investigated by adopting the discounted cash flow (DCF) analysis. The results show that the profitability of the distributed roof PV generation project in a target area in China is not economically viable under current conditions. The existing policy measures for promoting the deployment of distributed PV generation should be improved to increase the profitability and increase the enthusiasm of distributed PV development enterprises and individuals.

To explore the impact of the factors on economic profitability of the development of distributed roof PV generation in the target area, a sensitivity analysis is conducted. The results illustrate that the factors such as initial annual generation (IAG), residential electricity price (REP), feed-in tariff (FIF), investment cost (IC), and operation cost (OC) are the key factors which affect the economic profitability of the development of distributed roof PV generation in the target area. Based on this analysis, the effect of probable policy measures including financial subsidy, higher residential electricity price, higher feed-in tariff and preferential loan interest rate has been examined. Then some policy recommendations such as higher REP policy and preferential loan interest rate policy are presented. These policy instruments can play a vital role in increasing the profitability of the distributed roof PV generation project in the target area. Appropriate policy instruments should be selected for better accelerating the development of distributed roof PV generation based on the specific conditions of different regions in China.

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