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Policy Recommendations for Distributed Solar PV Aiming for a Carbon-Neutral Future

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Abstract: Distributed-solar-photovoltaic (PV) generation is a key component of a new energy system aimed at carbon peaking and carbon neutrality. This paper establishes a policy-analysis framework for distributed-solar-PV generation based on a technical- and economic-evaluation model. Given that the resource endowment is becoming lower and the raw material costs are becoming higher, the profitability of the deployment of distributed-solar-PV-generation projects in China is generally becoming much worse. Some distributed-PV-generation projects are even becoming unprofitable. This will not be helpful for the sustainable development of distributed-PV generation, which will play a vital role in attaining the goal of carbon neutrality. Based on the established model for techno-economic evaluation, a systematic policy analysis is performed to identify the effect of possible policy instruments such as financial policies on improving the economic profitability of distributed-PV-development in China. The results indicate that policy instruments related to preferential financing, green certificate, tax incentives and combinations thereof are available for priority measures aimed at optimizing incentive policies for enhancing the economic viability of distributed-PV deployment in China. Based on these findings, recommendations are proposed to optimize the currently available policy instruments for accelerating the sustainable development of the distributed-PV industry towards a carbon-neutral future.

Keywords: carbon neutrality; distributed PV; profitability; techno-economic evaluation; incentive policies

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1. Introduction

As an important contributor to carbon dioxide (CO_2) emissions in the world, China is putting more efforts into playing an increasing role in global climate governance. To demonstrate its role as a responsible major country, China pledged that it would peak its CO_2 emissions before 2030 and that it would achieve carbon neutrality before 2060. Increasing the share of renewable-energy use for establishing a new energy system is a key basis of achieving the goal of carbon peaking and carbon neutrality in China [1,2]. Renewable energy, including distributed-solar-PV-power generation is a key component of the future energy systems aiming at carbon peaking and carbon neutrality. Many countries like China are increasing their efforts to develop distributed solar PV [3].

Apart from the low resource endowment, several factors, including high raw-material cost and companies' inefficiencies explain why the profitability of developing distributed solar PV is currently not well understood [4–6]. This will not be helpful for the investment decision and the sustainable development of distributed-PV generation which contributes to playing a vital part in attaining the goal of carbon neutrality. Given its importance in establishing the future energy system, the deployment of distributed-PV-generation projects should be consistently stimulated by government departments [7,8]. In recent years, the government departments in many countries such as China usually provide policy incentives aiming at improving the profitability of the development of distributed-solar-PV generation, which contributes to the sustainable development of the distributed-solar-PV industry.

In view of the short history of developing distributed solar PV in China, very few studies focused on the comprehensive analysis with the combination of a techno-economic evaluation and a policy analysis aiming at optimizing currently available policies to promote the industry development of distributed PV in China towards carbon neutrality. Some studies such as Zhang (2016) [9], Garlet et al. (2019) [10] and Li et al. (2020) [11] present policy suggestions for supporting the development of distributed solar PV based on a qualitative analysis of the shortcomings of the existing policy system. Some studies focus on policy implications for promoting the development of distributed PV after conducting a simple economic analysis of distributed-PV projects [12–14]. For example, in their work, Zhang et al. (2015) [12] and Alhammami et al. (2021) [13] recommended policy options such as increasing education and training activities for distributed solar PV aiming at increasing public acceptance after a simple economic analysis. There are some studies highlighting an analysis of the economic viability of one type of rooftop-distributed-PV projects such as residential distributed-PV projects without considering the impact of the electricity-production-decline law, which proposed policy suggestions on the economic-evaluation model [15–17]. For instance, Zhang et al. (2021) [15] evaluated the economic benefits of residential distributed PV in rural areas of China without incorporating the effect of the law of annual electricity-production decline. In the work of Zhang et al. (2020) [16], a grid-parity analysis was conducted from the demand-side including industrial and commercial consumers and residential consumers, and from the supply-side of distributed-PV generation at the province level. They presented policy recommendations for the government and the distributed-PV industry without considering the impact of proposed policy suggestions on the economic evaluation. Moreover, these aforementioned studies usually performed an analysis on traditional incentive policies without focusing on new incentive policies such as carbon trading and green finance in the context of carbon neutrality [18–20]. In addition, there are some studies focused on the policy analysis of distributed-PV development adopting other methods including game theory, system dynamics and econometric models [21–23].

To address the questions mentioned above, this article aims at filling the gap in existing studies by (1) determining the profitability of developing distributed-solar-PV generation projects, considering the project type and the electricity-production-decline law, (2) providing more details explaining why the economic viability of the deployment of distributed-solar-PV-generation projects is generally becoming much worse, due to the new situation of carbon neutrality, and (3) conducting a policy analysis for identifying which policy instruments may have a more significant effect on enhancing the economic feasibility of deploying distributed-solar PV-generation projects. The proposed policy recommendations, which are supported by a techno-economic evaluation, may help policymakers in China to achieve carbon neutrality to address the practical obstacles to distributed-PV adoption, which may also be applicable to other countries attempting to develop distributed solar PV to achieve carbon neutrality.

The rest of this article is designed as follows. Section 2 describes a framework for policy analysis and the methods for evaluating the profitability of the deployment of distributed-PV-generation projects. In Section 3, the practical data obtained and key assumptions for this study are presented. Section 4 provides the result of the techno-economic evaluation for the typical cases. In Section 5, the effect of currently available policy instruments on enhancing the economic feasibility of deploying distributed solar PV is discussed. Finally, Section 6 concludes the article and presents policy recommendations.

2. Methods

2.1. Modelling Framework

For establishing a new energy system dominated by renewable energy towards carbon neutrality, more distributed-solar-PV projects have to be deployed, even with lower resource endowment. In light of this new situation, a more accurate evaluation of the profitability of distributed-PV-generation projects becomes more important for the investment decision. Considering current policy incentives, a techno-economic evaluation model based on a discounted-cash-flow (DCF) method is established to determine the profitability of deploying distributed-PV-generation projects. This analysis highlights the impact of the project type and the electricity-production-decline law on the profitability of developing distributed solar PV in China. The evaluation will be a key basis of the subsequent analysis for policy issues. These findings will help investigate the effect of currently available policy instruments on enhancing the economic feasibility of distributed-solar-PV projects, and provides guidance to improve current incentive policies. After a techno-economic evaluation combined with a subsequent policy analysis, possible useful ideas and suggestions aimed at optimizing policy incentives for stimulating the deployment of distributed-PV generation projects are proposed. Figure 1 illustrates the schematic diagram for the modelling framework of this paper.

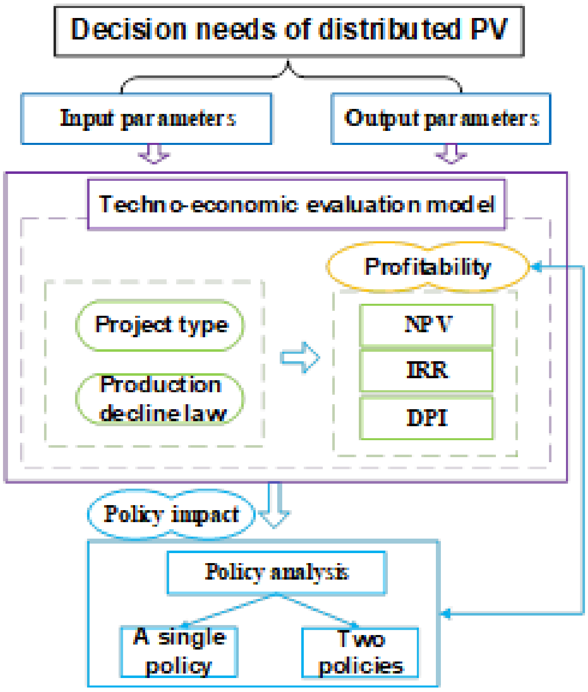


Figure 1. The model framework of policy analysis for distributed PV.

2.2. Evaluation Methods

DCF analysis [24–26], a dynamic financial-analysis method, is usually adopted for the techno-economic evaluation of energy development such as distributed-PV development. DCF analysis aims to determine the time value of an investment. This method is typically adopted to investigate a potential investment opportunity [27,28]. A financial-analysis model is established based on the DCF method and is embedded in a techno-economic evaluation, aiming to examine the economic viability of a distributed-PV project in China. This study develops a software tool with the Visual Basic language to calculate the results and to display them.

The purpose of the DCF analysis is to predict annual cash flows (CF) of investment projects for distributed-PV generation over its production life and to discount them in order to examine the current value of the development project. It offers available measures that allow us to evaluate the economic performance of deploying distributed-PV-generation projects. Several classical economic indicators, including the net present value (NPV), internal rate of return (IRR), and discounted profitability index (DPI), are typically adopted to help make the decision for investment projects [29,30].

In any operational year, the annual undiscounted net CF related to the investment in distributed-PV-generation projects is developed by the follow formula:

$$NCF_t = RDPV_t - II_0 - OC_t - ID_t - TD_t \tag{1}$$

where $RDPV_t$ is the total annual revenue of developing distributed-PV-generation projects in year t; II_0 denotes initial investments such as installation costs; OC_t is the annual operating and maintenance costs; ID_t denotes annual insurance dues; TD_t denotes annual taxes and dues. The classical economic indicators for calculating are NPV, IRR and DPI. The NPV is computed using the following equations:

$$\text{NPV} = \sum_{t=0}^{n} \frac{NCF_t}{(1+i_0)^t} \tag{2}$$

$$\text{IRR} = i,\ if\ \text{NPV} = 0 \tag{3}$$

$$\text{DPI} = \frac{\text{NPV}}{\sum_{t=0}^{k} IC_t \times (1+i_0)^{-t}} + 1 \tag{4}$$

where i_0 is the benchmark discount rate; i is the discount factor; n represents the operating time of deploying distributed-PV-generation projects; IC_t is the investment capital; k is the number of years of the capital spending. If $t \geq k$, no new capital costs are generated in year t.

3. Key Data and Assumptions

As mentioned previously, more lower-resource-endowment distributed-PV projects are necessary to be deployed, aiming at establishing a new energy dominated by renewable energy moving towards carbon neutrality. Two types of distributed-PV projects [31–33] in areas such as Jiangxi province in China, which are the third type of resource areas, are selected as the case project for the analysis. The rationality of this assessment will be ensured via the adoption of two typical distributed-PV-generation projects in lower-resource-endowment areas such as Jiangxi province in China. One is an industrial and commercial distributed-PV project, with a typical installment capacity of 3 MWp [27,29], and the other is a residential distributed-PV project with a classical installment capacity of 5 kWp [16,30]. The primary data used for the analysis are drawn from practical distributed-PV projects by conducting a detailed field investigation, and from recent studies [16,24,28], as presented in Table 1.

Table 1. Key parameters used for the evaluation.

Type	Industrial and Commercial	Residential	Unit
Initial annual generation	3,220,000	5370	kWh
Initial electricity price	0.661	0.600	CNY/kWh
Initial feed-in-tariff (FIF) price	0.4143	0.4143	CNY/kWh
Escalation rate of the price	3	3	%
Initial investment	15,840,000	26,400	CNY
Operating and maintenance costs	80,000	400	CNY/year
Insurance costs	125,000	625	CNY
Value-added-tax (VAT) rate	17	3	%
Additional-tax (AT) rate	11	5	%
Income-tax (IT) rate	25	1.5	%
Bank-loan ratio	50	30	%
Loan interest rate	8	7	%
Loan period	5	5	year
Electricity-producing life	25	25	year

The following assumptions are obtained from field investigations and recent studies on distributed PV. Due the decay of the distributed-PV-generation system, the annual degradation of the electricity yield is assigned to 2% of the initial annual generation in the first year and 0.9% annually thereafter, in this study [34,35]. Given the escalation of the electricity-payment price and the FIF price in future, the annual growth rate is assumed to be 3% in this paper [36,37]. In addition, current incentive policies such as county-wide pilot programs for distributed PV create a favorable condition for the development of this industry [38]. Moreover, to facilitate green and sustainable development, China introduced a set of guidelines on preferential tax and fee policies for stimulating the development of distributed PV [39]. For instance, regarding the industrial and commercial distributed PV project in China, the IT rate during the first three years is 0% and during the second three years it is 12.5%, and subsequently becomes 25%.

4. Results

4.1. Economic Performance of Industrial and Commercial Distributed-PV Projects

Given the difference between the electricity-payment price and the fixed-FIF price, the self-consumption ratio of electricity production will generate a distinct impact on the economics of industrial and commercial distributed-PV projects. Five typical cases are designed to explore the impact. The self-consumption ratio (SCR) is set at various rates, of 50%, 70%, 80%, 90% and 100%. According to the framework presented previously, a financial analysis is conducted to investigate the economic performance of industrial and commercial distributed-PV projects in lower-resource-endowment areas such as Jiangxi province in China. The main economic indicators of the target project at various SCR rates are elaborated in Table 2.

Table 2. Economic performance of industrial and commercial distributed-PV projects for various cases.

Cases	SCR (%)	NPV (CNY)	IRR (%)	DPI
Case 1	50	−3,729,706.8	5.3	0.76
Case 2	70	−2,455,868.1	6.2	0.84
Case 3	80	−1,818,948.8	6.7	0.89
Case 4	90	−1,182,029.5	7.2	0.93
Case 5	100	−545,110.2	7.6	0.97

In view of the resource endowment, the development of industrial and commercial distributed-PV projects in Jiangxi province in China is currently not economically viable. For example, the NPV of Case 4 with the most widely used SCR [40–42] is CNY −1,182,029.5, with an IRR of 7.2% and an DPI of 0.93. These values are slightly lower than the reference values. To exclude the impact of taxes, including corporate IT and AT, pre-tax economic metrics are determined. The pre-tax NPV is CNY 2,470,953.4, the pre-tax IRR is 9.6% and the pre-tax DPI is 1.16. These values are distinctly higher than the reference values. These results suggest that if there are no taxes including corporate IT and AT, the profitability of the deployment of industrial and commercial distributed-PV projects will become better.

Table 3 presents a comparison of the economic-indicator results of similar studies focused on industrial and commercial distributed PV in China and other countries. This study presents results with economic metrics similar to that of other studies in China and other countries such as Chile and Bangladesh [18,29,40,41]. However, these studies present a result that is relatively optimistic compared to the results presented in this study because of different resource endowments [29], policy conditions (such as financial subsidies) [40,41] and calculation methods [18,40].

Table 3. Results of economic metrics of industrial and commercial distributed-PV projects presented in different studies.

Region	NPV	IRR (%)	DPI	Year	Source
Jiangxi (III type)	<0	7.2	0.93	2022	This study
Shandong (II type)	>0	14.7–19.6	N/A	2019	[29]
China	>0	13.8–27.5	N/A	2019	[40]
Chile	N/A	1–13	N/A	2017	[41]
Bangladesh	>0	N/A	1.72	2023	[18]

The net cash flow (CF), discounted cash flow (DCF) and accumulated DCF of the industrial and commercial distributed-PV project is specified in Figure 2. We can also see that this industrial and commercial distributed-PV project is not profitable. Increasing the SCR can help improve the profitability of industrial and commercial distributed-PV projects. For instance, an increase in the SCR will generate a significant improvement in profitability; i.e., the DPI increases from 0.76 to 0.97. However, the DPI of 0.97 is lower than 1, and the effect is small.

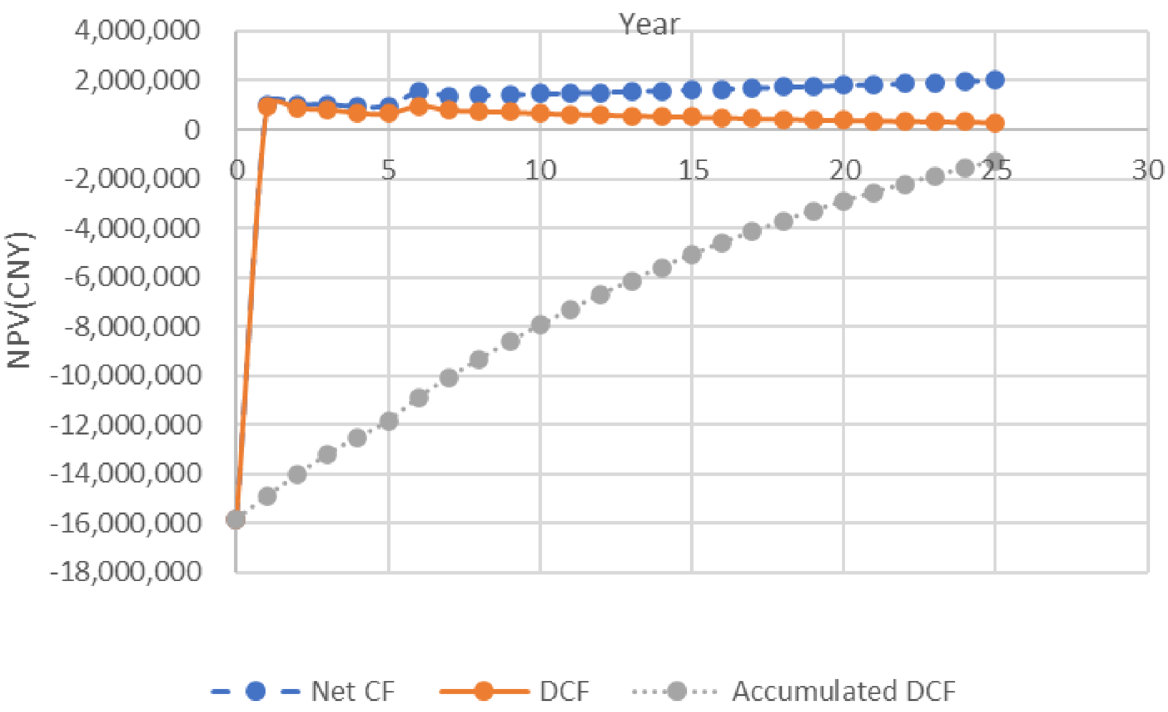


Figure 2. The annual cash flow of the industrial and commercial distributed-PV project.

To explore the effect of key factors, such as the initial annual electricity generation (IAEG), initial electricity price (IEP), feed-in tariff price (FIFP), initial investment costs (IIC), operating and maintenance costs (OMC), and insurance costs (IC), a sensitivity analysis is conducted. After carrying out calculations, the NPV of the industrial and commercial distributed-PV project in this study in relation to the changes in the key factors such as IAEG and IIC, is illustrated in Figure 3. We can see that the three most important influential factors are IIC, IAEG and IEP. Among them, IIC is the single most influential factor in the NPV. When the IIC is reduced by 10%, the NPV will increase by approximately 1430%, with an IRR of 8.4% and with a DPI of 1.04. Therefore, the measure that can decrease the IIC of the residential distributed-PV project should be adopted as a priority option.

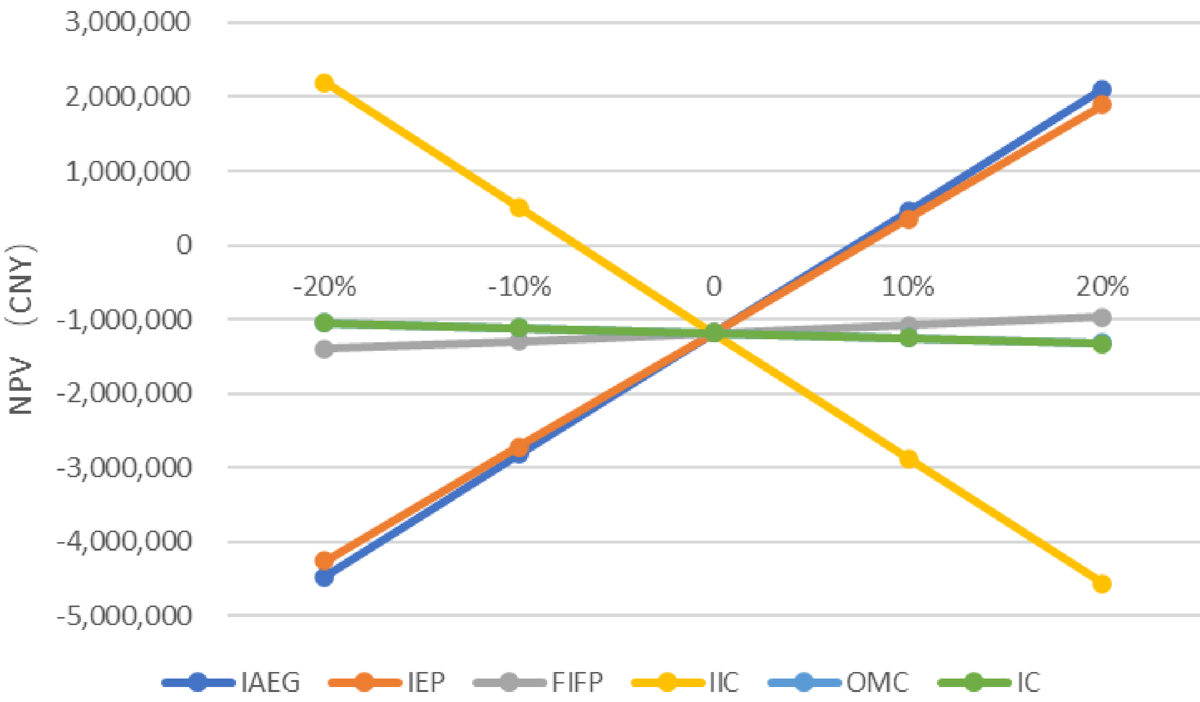


Figure 3. The sensitivity of the economic feasibility of the industrial and commercial distributed-PV project to the changes in key factors such as IAEG and IIC. Note. The effect of OMC on the NPV is almost the same as that of IC.

4.2. Economic Performance of Residential Distributed-PV Projects

Similarly to the evaluation of the development of industrial and commercial distributed-PV projects in Jiangxi province in China, this study creates five typical cases to explore the impact of SCR on the economic performance of residential distributed-PV projects. The economic indicators for the deployment of distributed-PV generation in this study is calculated for SCR rates of 20%, 30%, 50%, 90% and 100%. Table 4 presents the three economic indicators for residential distributed-PV projects for various SCR cases.

Table 4. Economic indicators for residential distributed-PV projects for various cases.

Cases	SCR (%)	NPV (CNY)	IRR (%)	DPI
Case 1	20	−1495.2	6.4	0.94
Case 2	30	−268.20	6.9	0.99
Case 3	50	2185.9	7.8	1.08
Case 4	90	7094.0	9.6	1.27
Case 5	100	8321.1	10	1.32

For an increase in the SCR of residential distributed-PV projects, the IRR increases from 6.4% to 10%, which indicates that the SCR plays a vital part in enhancing the profitability. However, given the electricity-absorption capacity of the resident, the SCR of residential distributed-PV projects cannot be too high. Usually, the SCR of most residential distributed-PV projects is lower than 30% [43–45]. Therefore, the economic viability of residential distributed-PV projects in lower-resource-endowment areas such as Jiangxi province in China is poor, under current conditions. To exclude the impact of taxes, including corporate IT and AT, pre-tax economic indicators are calculated. The pre-tax NPV is CNY 178, the pre-tax IRR is 7.1% and the pre-tax DPI is 1.01. These values are significantly higher than the reference values. These results suggest that if there are no taxes, including corporate IT and AT, the profitability of the deployment of residential distributed-PV projects will improve. However, the profitability of industrial and commercial distributed-PV projects is higher than that of residential distributed-PV projects without the impact of taxes.

A comparison of the economic-metric results of similar studies focusing on residential distributed PV in China and other countries is listed in Table 5. This study presents results with economic indicators similar to those of other studies in China and other countries such as Chile and Bangladesh [16,41,42,44]. However, these studies present results that are relatively optimistic compared to the results presented in this study, due to the differences in resource endowment [16,42], and policy conditions [41,42,44].

Table 5. Results of economic indicators of residential distributed-PV projects presented in different studies.

Region	NPV	IRR (%)	DPI	Year	Source
Jiangxi (III type)	<0	6.9	0.99	2022	This study
China	N/A	5.2–14.3	N/A	2014	[42]
China	N/A	6–18	N/A	2021	[16]
Chile	N/A	0–8	N/A	2017	[41]
EU	>0	0–19.6	N/A	2016	[44]

To investigate the effects of the key factors, including IAEG, IEP, FIFP, IIC, OMC and IC, on the NPV of the residential distributed-PV project, a sensitive analysis is performed. The effects of key factors such as IAEG, IEP and IIC on the economic value of the residential distributed-PV project in this study is demonstrated in Figure 4. We can see that the four factors with the most influence on the NPV of the residential distributed-PV project are IAEG, IIC, FIFP and IEP. Among them, IAEG is the most influential factor that can attribute to affecting the NPV. Therefore, those measures that can increase the IAEG of the residential distributed-PV project should be the target of more effort which aims to improve the economic profitability of residential distributed-PV projects in China.

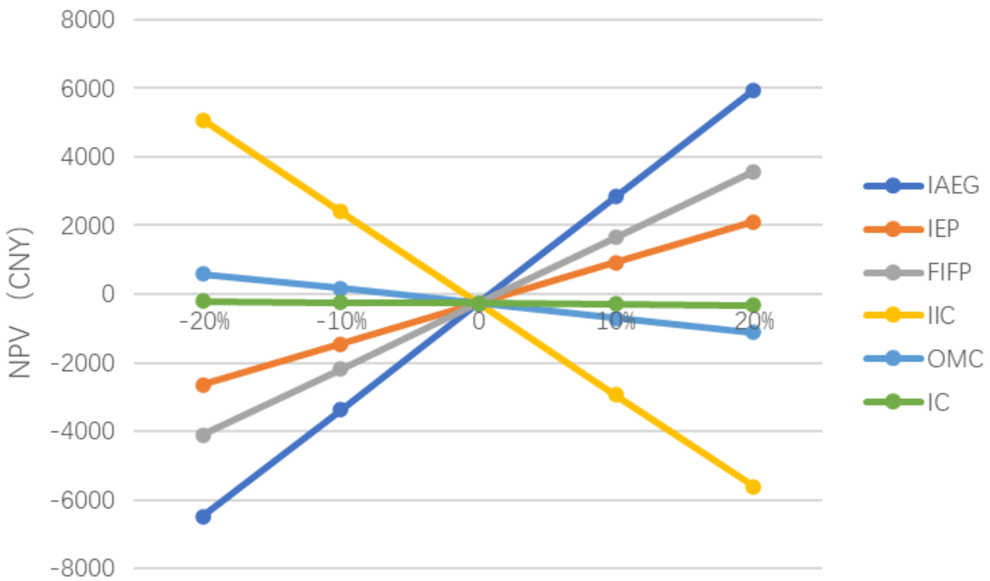


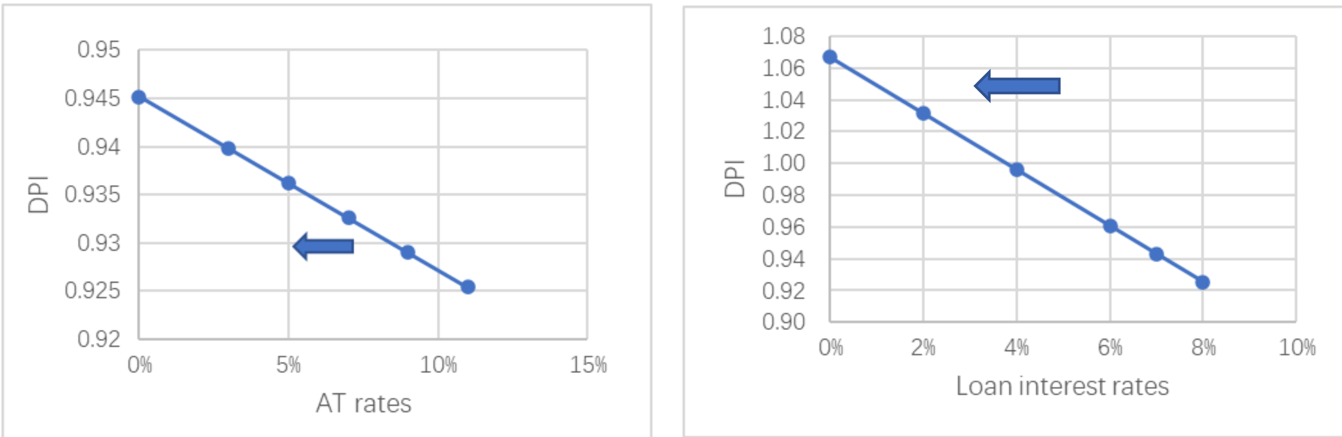
Figure 4. Key factors affecting the economic viability of the residential distributed-PV project.

5. Discussion

In view of the low profitability of distributed-PV-generation projects in China, a systematic analysis is performed to investigate the effects of the currently available policy incentives, aiming at improving the profitability. To accurately determine the validity of these possible incentive instruments, two different policy scenarios are designed, with a single policy and two policies. Considering the typicality of the SCR of distributed-PV projects, the industrial and commercial project with an SCR of 90% and the residential project with an SCR of 30% are assigned as the benchmark project for exploring the impact of policy incentives. Based on these findings, appropriate measures will be provided to give directions for optimizing current policy instruments, aiming at enhancing the economic value of distributed-PV generation projects in China.

5.1. The Impact of a Single Policy

For a benchmark industrial and commercial distributed-PV project, the impact of a single policy such as preferential AT and green finance has been investigated. For example, the DPI for the deployment of industrial and commercial distributed-PV projects in China is calculated for the AT rates of 11%, 9%, 7%, 5%, 3%, and 0, and for loan interest rates of 8%, 7%, 6%, 4%, 2%, and 0. The results are illustrated in Figure 5a,b. A preferential-AT policy measure will be helpful to increase the economic feasibility of the benchmark industrial and commercial project, as the effect is quite small. However, a green-finance policy highlighting a lower loan interest rate can render industrial and commercial distributed PV economically viable in the target area.



(**a**) (**b**)

Figure 5. (**a**) The impact of preferential-AT rate on the DPI; (**b**) The impact of green finance on the DPI.

For the preferential-VAT policy and the preferential-corporate-IT policy, the DPI for the deployment of industrial and commercial distributed-PV projects in China is calculated for VAT rates of 17%, 8.5%, 7%, 5%, 3%, and 0 and for corporate IT rates of 25%, 20%, 15%, 10%, 5%, and 0. The results show that both of them can contribute to enhancing the DPI and to making it become a profitable industrial and commercial distributed PV. If the carbon-trading policy is applied to industrial and commercial distributed-PV projects in China, profitability will be improved significantly, as shown in Figure 6. In addition, a rising initial-electricity-price policy and a rising initial-FIF-price policy can also play an important part in enhancing the economic viability of industrial and commercial distributed-PV projects.

For a benchmark residential distributed-PV project, the impact of a single policy such as preferential VAT and corporate IT has been determined. For instance, the DPI for the deployment of residential distributed-PV projects is calculated for the VAT rates of 3%, 2.5%, 2%, 1.5%, 1%, and 0 and for corporate-IT rates of 1.5%, 1.25%, 1%, 0.75%, 0.5%, and 0. The results are shown in Figure 7a,b. As a preferential-corporate-VAT policy is introduced, the DPI becomes higher, indicating improved economic value for residential distributed-PV projects. A smaller VAT rate thus leads to a bigger DPI. Therefore, preferential-VAT policies will play an important part in enhancing profitability. Although a preferential-corporate-IT policy measure can also contribute to making residential distributed-PV profitable, the effect is lower than the preferential-VAT policy.

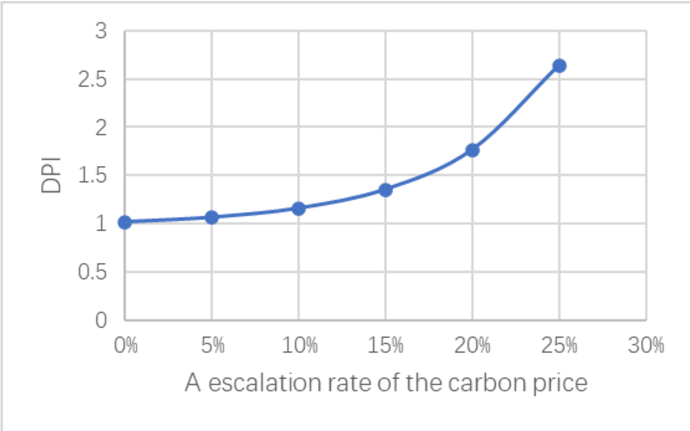
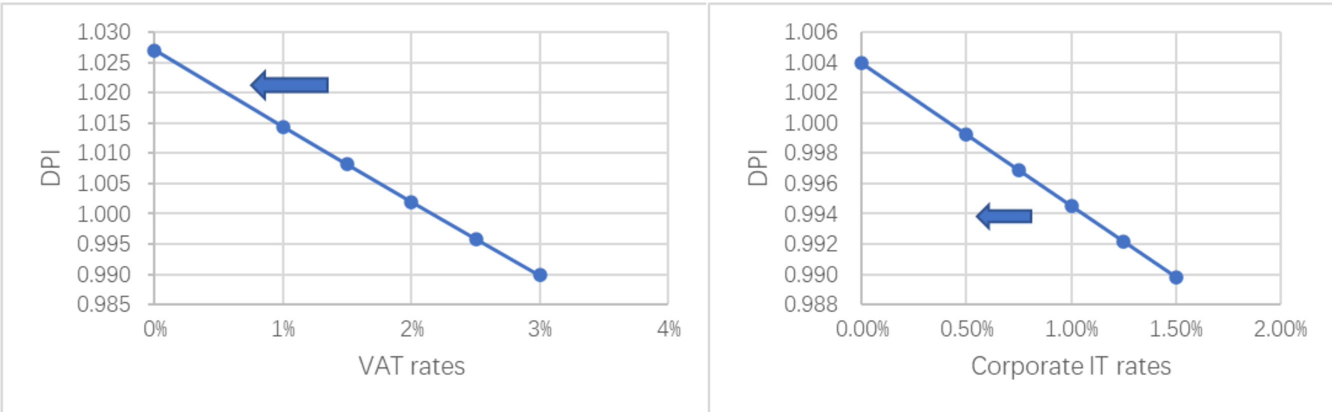


Figure 6. Effects of carbon-trading policy on the DPI of industrial and commercial distributed-PV projects.



(**a**) (**b**)

Figure 7. (**a**) Effect of preferential-VAT policies on the DPI; (**b**) Effect of preferential-corporate-IT policies on the DPI.

For the green-finance policy and the preferential-AT policy, the DPI for the deployment of residential distributed-PV projects in China is computed for various loan rates of 7%, 6%, 5%, 4%, 2%, and 0 and for AT rates of 5%, 4%, 3%, 2%, 1%, and 0. The results show that the green-finance policy will be helpful for improving the DPI and for creating a profitable residential distributed-PV project. The reduction in the AT rate can somewhat improve the economic viability of deploying residential distributed PV, but this policy instrument alone cannot make residential distributed PV become profitable. Preferential-AT policies will contribute to improving the economic feasibility of residential distributed PV. However, this policy instrument has a small effect. If the carbon-trading policy is applied to residential distributed-PV projects in China, the profitability will be improved significantly, as showed in Figure 8. In addition, a rising initial-electricity-price policy and a rising initial-FIF-price policy can also play a vital role in enhancing the profitability of residential distributed-PV projects in China.

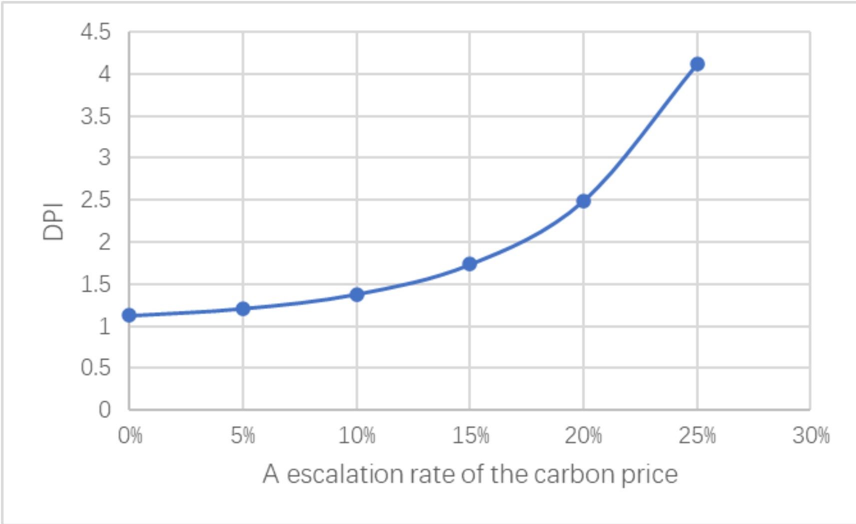


Figure 8. Effects of carbon-trading policy on the DPI of residential distributed-PV projects.

5.2. The Impact of Two Policies

After the single-policy analysis, we found in this study that not all available policy instruments can help increase the economic viability of distributed PV projects. For example, preferential-AT policies have a limited effect on improving the economic viability, which cannot render distributed PV economically viable. Profitability for distributed PV is thus poor if only one of the available policy instruments is introduced. Moreover, most of the other preferential-policy instruments, such as a preferential-corporate-IT policy, need a drastic reduction to play an important part in enhancing the economic viability of the distributed PV. Hence, the subsequent policy analysis will attempt to explore the effects of a combination of two policy instruments on the economic feasibility of distributed-PV projects.

For a benchmark industrial and commercial distributed-PV project containing a combination of two policy instruments such as the AT rate with the corporate-IT rate, the VAT rate, the green finance, the rising initial electricity price, the rising initial FIF and the DPI for distributed PV, is computed. We can see that the DPI of many policy combinations is bigger than 1. These policy instruments will have a significant impact on helping improve the profitability of industrial and commercial distributed-PV projects. For example, the effect of the combination of the AT rate and corporate-IT rate on improving economic viability is significant, as demonstrated in Table 6. However, the DPI of some combinations is lower than 1. This means that the combination of two policy incentives such as preferential-AT polices has a relatively low effect, and cannot help enhance the economic performance of industrial and commercial distributed-PV projects in the target area.

Table 6. Effects of combining AT and corporate-IT rates on the DPI of industrial and commercial distributed-PV projects.

AT Rates	**Corporate-IT Rates**					
	25%	20%	15%	10%	5%	0
11%	0.925	0.967	1.008	1.049	1.091	1.132
9%	0.929	0.970	1.012	1.053	1.095	1.136
7%	0.933	0.974	1.016	1.057	1.099	1.141
5%	0.936	0.978	1.020	1.062	1.103	1.145
3%	0.940	0.982	1.024	1.066	1.108	1.149
0	0.945	0.987	1.029	1.072	1.114	1.156

Note. The number with a red color is lower than 1, which demonstrates that this project is not profitable.

The calculation of the DPI for industrial and commercial distributed-PV projects containing a combination of two policy instruments including the green finance and the corporate-IT rate, the green finance and the VAT rate, the green finance and the initial electricity price, and the green finance and the initial FIF, is conducted. These results suggest that the DPI value of most preferential combinations of available policy instruments is larger than 1. These preferential policy combinations play a vital role in increasing the economic profitability of distributed-PV deployment. For instance, the combination of green finance and the corporate-IT rate play a distinct role in increasing the DPI and improving economic viability, as displayed in Figure 9. Moreover, it is obvious that the effect of these policy combinations is more powerful than that of the combinations including the preferential-AT policy.

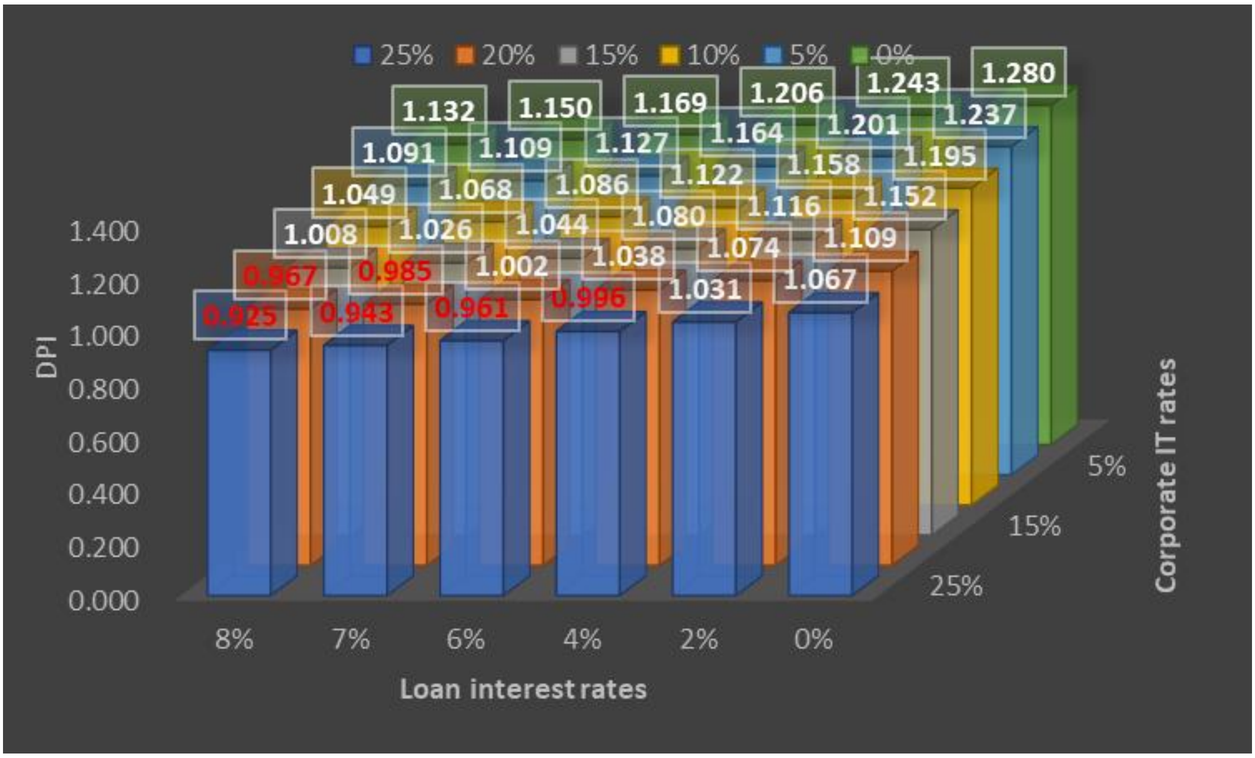


Figure 9. Effects of combinations of green finance and corporate-IT rates on the DPI of industrial and commercial distributed-PV projects.

For a benchmark residential-distributed-PV project, the DPI of the combination of two policy incentives such as the VAT rate with the AT rate, the corporate-IT rate, the green finance, the rising initial electricity price and the rising initial FIF is evaluated. We can see that the DPI of some policy combinations of the available policy instruments is higher than 1. The preferential-policy combinations play a significant part in enhancing the profitability of residential distributed-PV projects. For example, the impact of the combinations of the preferential-VAT rate and AT rate on improving the economic performance is significant, as illustrated in Figure 10. However, the DPI of another combinations is slightly lower than 1, which means that the combinations of two policies which include the preferential-VAT rate have a smaller effect, and do not effectively enhance the profitability of residential distributed-PV projects in this study.

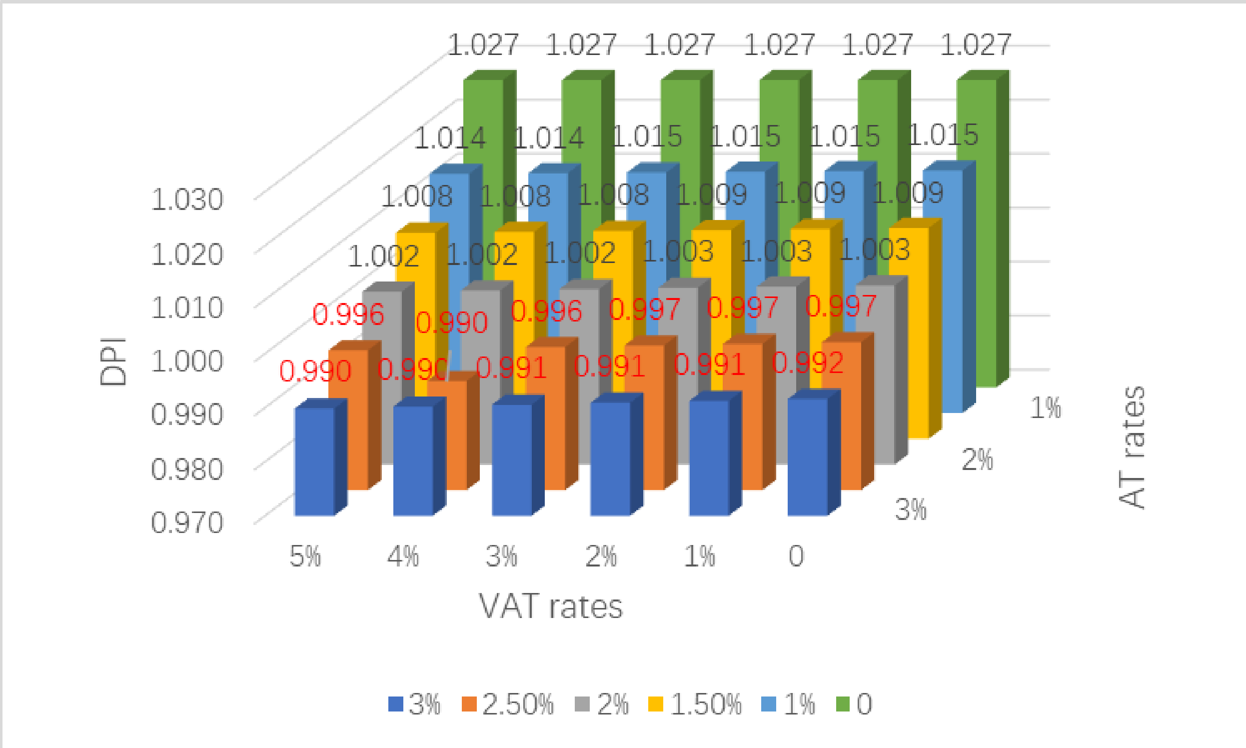


Figure 10. Effect of combining a preferential-VAT and AT rate on the DPI of residential distributed-PV projects.

The DPI for residential distributed-PV projects containing a combination of two policy instruments including the green finance with the VAT rate, the corporate-IT rate, the initial electricity price and the initial FIF, is determined. We obtained results showing that the DPI of most preferential-policy combinations is bigger than 1. The combination of the available policy instruments plays a vital part in enhancing the economic profitability of residential distributed-PV projects. For instance, the combination of green finance and the VAT rate on improving the economic viability is significant, as summarized in Table 7. Moreover, we can obtain results showing that the incentive combination has a more pronounced effect than the combinations which include the preferential-AT policy, and will help increase the DPI and render residential distributed-PV economically feasible.

Table 7. Effects of the combination of green finance and a preferential-VAT rate on the economic indicator.

VAT Rates	Loan Interest Rates					
	7%	6%	5%	4%	2%	0
3%	0.990	1.001	1.012	1.024	1.046	1.069
2.5%	0.996	1.007	1.019	1.030	1.052	1.075
2%	1.002	1.013	1.025	1.036	1.059	1.081
1.5%	1.008	1.019	1.031	1.042	1.065	1.087
1%	1.014	1.026	1.037	1.048	1.071	1.094
0	1.027	1.038	1.050	1.061	1.084	1.106

Note. The value with a red color is lower than 1, which demonstrates that this project is not profitable.

6. Conclusions

Aiming at achieving their carbon neutrality goals, many countries such as China, moving towards carbon neutrality, need to establish renewable-dominated energy systems, including distributed-PV generation. With the continuous development of distributed solar PV, increasing lower-resource-endowment distributed-PV projects are necessary. In addition to the permanently changing market environment, such as the rising raw-material cost, the economic feasibility of the distributed-solar-PV generation project becomes less certain. It will be not helpful for the high-quality development of distributed-PV generation, which will play an important part in attaining the goal of carbon neutrality.

This paper establishes a policy-analysis framework for distributed solar PV, based on a techno-economic-evaluation model and considering the impact of the project type and the electricity-production-decline law on the profitability of developing distributed solar PV. The results show that the profitability of the deployment of two types of distributed-solar-PV projects in low-resource-endowment areas in China is generally becoming much worse. Some distributed-PV projects are even becoming unprofitable under current policy conditions. Based on the techno-economic evaluation, a policy analysis is performed to determine the effects of the currently available policy incentives on improving the profitability of distributed-solar-PV projects. The findings in this study indicate that not all available policy instruments can help enhance the economic viability of distributed-PV projects. The combination of two policy instruments should be considered for policy formulation to better optimize the profitability of distributed-PV projects.

Based on these findings, some policy recommendations are proposed for distributed solar PV, aiming at carbon neutrality. First, from the perspective of a single policy: (a) for industrial and commercial distributed-PV projects, an incentive policy instrument such as preferential-corporate-IT rate, rising initial electricity price and carbon-trading participation can be adopted to improve economic feasibility; (b) for a residential distributed-PV project, an incentive policy instrument such as green finance, rising initial-FIF price and carbon-trading participation can be adopted for enhancing profitability. Second, from the perspective of two policies: (a) for industrial and commercial distributed-PV projects, a combination of two available policy incentives such as the AT rate with the corporate-IT rate, the VAT rate and the green finance can be adopted as policy instruments to improve economic viability; (b) for a residential distributed-PV project, a combination of two available incentive policies such as the VAT rate with the corporate-IT rate and the green finance can be adopted to increase the economic performance. Considering the specific characteristics of distributed-PV projects in different regions, a dynamic evaluation and analysis is the base for the selection of suitable policy incentives aimed at promoting the deployment of the distributed-PV industry.

The systematic analysis in this article will be helpful for decision-makers to determine the issues of current incentive policies applied to distributed PV. It is anticipated that these findings of the paper are a valuable resource for decision-makers in many countries such as China who are working towards carbon neutrality. The policy recommendations proposed in this paper will also be helpful for decision-makers to implement suitable approaches aimed at optimizing current policy incentives in their nations. Lastly, we anticipate that these findings in the article will provide a useful reference for the researchers aiming at further optimizing policy incentives for stimulating the sustainable development of distributed solar PV, aiming for a carbon-neutral future.

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