Research on the Economic Benefits of Roof Photovoltaic Based on the Non-Subsidy Mode of Environmental Benefits

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Abstract. Photovoltaic power generation is the main alternative to coal power generation, in order to reflect the environmental benefits of photovoltaic power generation, this paper integrates the net carbon transaction cost and environmental protection tax in the life cycle of photovoltaic power generation into the calculation of indicators of LCOE and IRR, selects eight representative regions of China's roof photovoltaic for economic benefit evaluation, and selects four indicators for sensitivity analysis of LCOE and IRR. The results show that the cost reduction range is 0.0083 - 0.0593 Yuan / kWh under the condition of measuring the net carbon dioxide, sulfur dioxide and nitrogen oxides emissions, the establishment and improvement of carbon trading market and environmental protection tax will help to improve the economic benefits of users; other regions can achieve user side parity without considering the financing cost except Chongqing; reducing the cost of photovoltaic power generation and improving the unit power generation are the main factors to improve the economic benefits.

1. Introduction

China has adopted a dual subsidy policy of state subsidies and local subsidies to add bricks to the development of the photovoltaic industry. By September 2019, the installed capacity of distributed photovoltaic power generation in China was 58.70GW, a year-on-year increase of 28%, with an increase of 8.26 million KW. However, the subsidy gap brought by the development of new energy in China is increasing, in order to reduce the subsidy pressure, the state subsidy has decreased from 0.42 yuan / kWh in 2013 to 0.32 yuan / kWh in 2019. In 2019, the national development and Reform Commission and the National Energy Administration issued the notice on actively promoting the work of non-subsidized and affordable grid access for wind power and photovoltaic power generation [1], requiring the construction of affordable grid access projects and low-cost grid access pilot projects. In order to cope with the environmental change and the decline of subsidies, the emission of carbon dioxide and air pollutants should be taken as a major advantage of clean energy to bring additional economic benefits to users. In this paper, we consider the economic value of reducing the emissions of carbon dioxide, sulfur dioxide and nitrogen oxides in the life cycle of roof photovoltaic, and analyze the economic benefits of home roof photovoltaic and industrial and commercial roof photovoltaic under the non-subsidy mode, so as to provide reference and reference for roof photovoltaic in other regions of China.

2. Literature review

LCOE (Levelized cost of energy) is a common measure used to calculate the life expectancy cost of the generated project on the basis of unit cost. The calculation method is to divide the net present value
of capital investment of a technology by the discounted energy output generated by the technology, so as to obtain the average cost per energy unit [2]. In the energy sector, LCOE is used to estimate energy costs, although other measures are also used to assess the economics of energy projects (e.g., net present value, total life cycle cost), but because of its intuitive clarity and simplicity, LCOE is attractive[3], compared with the cost of power grid energy price, it determines whether the power grid equalization has been achieved[4], pan Shanshan et al. based on the LCOE model shows that reducing the initial investment and giving preferential loans and other means can effectively reduce the cost of photovoltaic power generation[5], based on the research results of IRR analysis model under the non-subsidy mode, it shows that photovoltaic power plants in the "Three North" region of China highlight the parity of grid energy, compared with other regions, the distributed photovoltaic in the eastern and central regions is more economical[6].

Environmental benefit is the main competitive advantage of photovoltaic energy to cope with traditional power generation. Based on game theory, Lupeng Zhang et al. concluded that carbon trading market, environmental protection tax and innovation are effective tools to stimulate and promote the diffusion of green manufacturing technology among alliance enterprises[7], combining the cost learning curve, Yongxiu He et al. established a dynamic subsidy model for distributed photovoltaic power generation from the perspective of emission reduction benefits[8], research of John Eskew et al. for the environmental life cycle assessment results of Thailand's roof photovoltaic shows that the main contribution to the environmental burden occurs in the manufacturing stage and from photovoltaic modules to modules, which together constitute more than 90%[9]. Therefore, considering the net emission of carbon dioxide throughout the photovoltaic life cycle will improve the accuracy of economic benefit calculation.

In summary, the current calculation of LCOE and IRR does not fully consider the impact of environmental factors. China’s environmental tax collection has just begun, and the carbon dioxide trading market has not been opened nationwide. Therefore, this article incorporates the net carbon dioxide trading price and environmental protection tax into LCOE and IRR, considering the economic benefits under the non-subsidy mode. On the one hand, it can improve the accuracy of the economic benefits of photovoltaic power generation, and on the other hand, it can provide a certain reference for China’s future non-subsidy policy.

3. Methods and models

3.1. Net carbon transaction costs

Among them, \( C_{CO_2,t} \) is the net carbon trading cost in the photovoltaic life cycle in year of t (unit: yuan), \( P_{CO_2,t} \) is the carbon trading price in the year of t (unit: yuan/ton), \( E_{CO_2,t} \) is the CO\(_2\) emission reduction in year of t (unit: ton), \( EF_{CO_2,t} \) is the life cycle carbon emission reduction coefficient of photovoltaic alternative power generation in year of t, \( EF_{grid,base,t} \) is the life cycle carbon emission factor of the grid in year of t, which is the sum of the emission coefficient in the operation process (\( EF_{grid,CM,t} \)) and the emission coefficient before operation (\( EF_{grid,pre} \)[10]), \( EF_{PV} \) is the life cycle carbon emission coefficient of photovoltaic modules, \( EF_{grid,OM,t} \) is the marginal emission factor of electricity in year of t and \( EF_{grid,BM,t} \) is the marginal emission factor of capacity in year of t, above units are tCO\(_2\)/MWh, \( W_{OM} \) and \( W_{BM} \) are the proportion of OM and BM respectively.

\[
C_{CO_2,t} = P_C O_2 \times E_{CO_2,t} \times Q_{CO_2,t} \quad (1)
\]

\[
E_{CO_2,t} = Q_{CO_2,t} \times EF_{CO_2,t} = Q_{CO_2,t} \times (EF_{grid,base,t} - EF_{grid,CM,t}) = Q_{CO_2,t} \times (EF_{grid,CM,t} + EF_{grid,pre} - EF_{grid,CM,t}) \quad (2)
\]

3.2. Calculation of environmental protection tax

\[
TAX_{env,t} = P_{SO_2,t} \times ER_{SO_2,t} + P_{NO_x,t} \times ER_{NO_x,t} \quad (3)
\]
\[ ER_{m,t} = \frac{Q \times EF_{m,t}}{PEV_m} \]  

(4)

\[ ER_{m,t} \] is the pollution equivalent of the taxable air pollutant \( m \) in year of \( t \), and \( EF_{m,t} \) is the life cycle \( m \) emission reduction coefficient of alternative generation of photovoltaic power generation in year of \( t \), and \( EF_{SO2,t}=0.47\text{kg/MWh}, \ EF_{NOx,t}=0.43\text{kg/MWh} \[10]. \ PEV_m \] is the pollution equivalent conversion coefficient of air pollutant \( m \), it is 0.95 according to the Environmental Protection Tax Law of the People’s Republic of China.

### 3.3 LCOE

The conventional cost of electricity is the total cost of the life cycle divided by the total amount of power generated, calculated as

\[ LCOE_E = \frac{C_{\text{Total}}}{Q_{\text{Total}}} \]  

(5)

Considering the environmental benefit model in the life cycle, the life cycle cost of photovoltaic power generation includes initial investment cost \( (CI) \), which consists of two parts: equipment cost \( (C_{\text{equ}}) \) and installation cost \( (C_{\text{ins}}) \), operation and management cost \( (C_O + C_M) \), relevant taxes (only VAT is considered here), carbon emission cost \( (C_{CO2}) \) and environmental protection tax \( (TAX_{\text{env}}) \). \( Qt \) is the annual power generation, unit is kwh, \( \mu \) is the system conversion efficiency, \( G \) is the installed capacity, the unit is kw, \( H \) is the annual effective light duration, and \( \eta \) is the power generation attenuation rate, and combines formula (1-5), the LCOE is calculated as follows.

\[
\begin{align*}
LCOE_E &= \frac{C_{\text{Total}}}{Q_{\text{Total}}} = \frac{LCOE_E \times \sum_{i=0}^{T} \left( \frac{Q_i}{1+R} \right)^i + \sum_{j=0}^{T} \frac{C_{j,0} + C_{j,f} + C_{j,M} + C_{j,F} + VAT - C_{CO2,j} - TAX_{m,t} + P_{S_j} \times \left( P_{S_{SO2,j}} + P_{S_{NOx,j}} \right) \times \left( \mu \times G \times H(1-\eta) \right)^i}{(1+R)^i}}{Q_{\text{Total}}} \\
&= \frac{\sum_{i=0}^{T} \frac{C_{j,0} + C_{j,f} + C_{j,M} + C_{j,F} + VAT - C_{CO2,j} - TAX_{m,t} + P_{S_j} \times \left( P_{S_{SO2,j}} + P_{S_{NOx,j}} \right) \times \left( \mu \times G \times H(1-\eta) \right)^i}{(1+R)^i}}{Q_{\text{Total}}} \\
&= \frac{\sum_{i=0}^{T} \left( P_i \times (1-\alpha) + P_i \times \alpha \right) \times Q_i - LCOE_E \times Q_i}{(1+R)^i} = \frac{\sum_{i=0}^{T} \bar{P} - LCOE_E \times Q_i}{Q_i (1+R)^i}
\end{align*}

(6)

(7)

Considering the cash flow generated throughout the roof PV life cycle under the non-subsidized model as follows.

\[ NPV = \sum_{i=0}^{T} \left( P_i \times (1-\alpha) + P_i \times \alpha \right) \times Q_i - LCOE_E \times Q_i = \sum_{i=0}^{T} \bar{P} - LCOE_E \times Q_i \]  

\[ (1+R)^i \]

\[ P_i \] refers to the unit price of residents or general industrial and commercial units, \( P_2 \) is the price of desulfurized coal, \( \alpha \) is self-use ratio, \( \bar{P} = P_1 \times (1-\alpha) + P_2 \times \alpha \), and \( R \) is the discount rate. From formula 8, we can know that when \( LCOE_E \leq P_1 \), the user side parity was achieved, when \( LCOE_E \leq P_2 \), the power generation side parity was achieved, and when \( LCOE_E \leq \bar{P} \), it’s financially feasible for users.

### 3.4 IRR_E

\[ \sum_{i=0}^{T} (CI_i - CO_i) (1 + IRR_E)^{-i} = 0 \]  

(8)

\( CI_i \) is the annual cash inflow, consisting of savings in electricity and sales electricity prices, \( CO_i \) is the annual cash outflow.
4. Empirical research
As of April 1, 2019, there were 28 carbon emission trading markets and 29 carbon tax mechanisms worldwide [11]. China has launched the first carbon emission trading pilot in Shenzhen since June 18, 2013, and then Shanghai, Beijing, Guangdong, Tianjin, Hubei, Chongqing, and Fujian have started trials of carbon emissions trading. As of November 22, 2016, eight carbon trading pilots in China have been successfully launched. From 2014 to the beginning of December 2019, the total volume of eight carbon trading pilots in China was 188,987,300 tons, with a total transaction price of 4,346.173 million yuan. The average price of carbon trading varies widely from place to place. The highest price is Beijing, the average price is 55.8 yuan / ton, and the lowest price is Chongqing 7.74 yuan / ton, both of them are lower than the global average price of $10 / ton and far lower than the level of $40-80 / ton in 2020 and $50-100 / ton in 2030, which is considered by the stern Stiglitz high level Committee on carbon pricing to be in line with the temperature target of the Paris Agreement[12]; each pollution equivalent of pollutants is 1.2-12 yuan, and provinces and municipalities can define their own collection quotas within the range. The specific data is shown in Table 1 below.

| Carbon price (yuan / ton) | Beijing | Tianjin | Shanghai | Chongqing | Hubei | Fujian | Shenzhen | Guangdong |
|--------------------------|---------|---------|----------|-----------|-------|--------|----------|-----------|
|                           | 55.80   | 11.52   | 29.12    | 7.74      | 21.89 | 21.33  | 24.24    | 17.11     |

| EFCO2(tCO2/MWh) | Beijing | Tianjin | Shanghai | Chongqing | Hubei | Fujian | Shenzhen | Guangdong |
|-----------------|---------|---------|----------|-----------|-------|--------|----------|-----------|
| 0.8591          | 0.8591  | 0.7452  | 0.7725   | 0.7725    | 0.7452 | 0.7081 | 0.7081   |           |

| SO2 (yuan / pollution equivalent) | Beijing | Tianjin | Shanghai | Chongqing | Hubei | Fujian | Shenzhen | Guangdong |
|----------------------------------|---------|---------|----------|-----------|-------|--------|----------|-----------|
| 12                               | 12      | 10      | 7.6      | 2.4       | 2.4   | 1.2    | 1.8      | 1.8       |

| NOX (yuan / pollution equivalent) | Beijing | Tianjin | Shanghai | Chongqing | Hubei | Fujian | Shenzhen | Guangdong |
|----------------------------------|---------|---------|----------|-----------|-------|--------|----------|-----------|
| 12                               | 12      | 10      | 8.55     | 2.4       | 2.4   | 1.2    | 1.8      | 1.8       |

4.1 Economic analysis of household roof distributed photovoltaic
The operation mode of "self-use, surplus electricity on the grid" is adopted for household roof photovoltaic, with the proportion of self-use not less than 50%. As the electricity price of residents is generally higher than the electricity price of desulfurization coal, when the cost of electricity consumption of household roof photovoltaic is lower than the average electricity price of 50% of the proportion of self-use, it is economically feasible for residents. In this paper, family type distributed photovoltaic does not consider the financing cost, and the initial investment is all own capital. The results are shown in Table 2.

| LCOEN (yuan/kWh) | LCOEE (yuan/kWh) | P2 (yuan/kWh) | P1 (yuan/kWh) |  \( \bar{p} \) (yuan/kWh) | IRR_E |
|------------------|------------------|--------------|--------------|-----------------|-------|
| Beijing          | 0.3584           | 0.2991       | 0.3598       | 0.5083          | 0.4341 | 12.32% |
| Tianjin          | 0.3302           | 0.3108       | 0.3655       | 0.5100          | 0.4378 | 12.41% |
| Shanghai         | 0.3689           | 0.3396       | 0.4155       | 0.6165          | 0.5160 | 13.43% |
| Chongqing        | 0.6340           | 0.6257       | 0.3964       | 0.5150          | 0.4557 | 4.56%  |
| Hubei            | 0.4344           | 0.4152       | 0.4161       | 0.5830          | 0.4996 | 10.28% |
| Fujian           | 0.3943           | 0.4336       | 0.3932       | 0.5233          | 0.4583 | 10.41% |
| Shenzhen         | 0.3992           | 0.3803       | 0.4530       | 0.6792          | 0.5661 | 13.29% |
| Guangdong        | 0.4041           | 0.3903       | 0.4530       | 0.6258          | 0.5394 | 12.24% |

Table 2. Related indicators of household roof distributed photovoltaic in eight regions

4
When considering environmental benefits, the cost reduction of electricity consumption in the eight regions has been reduced by 16.55%, 5.87%, 7.95%, 1.30%, 3.87%, 4.32%, 4.73%, and 3.42%.

Without electricity price subsidies and considering environmental benefits, the electricity cost of the other seven provinces and cities is lower than the local price of desulfurized coal except Chongqing, that is to say, user side parity has been achieved in seven provinces, and power generation side parity has been achieved in six provinces. However, Chongqing's annual effective light duration is too short, only 686.27. Hours, it is difficult to meet the feasibility requirements. Therefore, for the fourth region of solar energy resources in China. Therefore, with the implementation of the photovoltaic poverty alleviation policy, except for the fourth region, rural rooftop photovoltaic promotion in other regions in China can bring a certain amount of economic income to residents.

### 4.2 Economic analysis of industrial and commercial roof distributed photovoltaic

After the industrial and commercial roof photovoltaic is connected to the power grid, users can choose the appropriate proportion of their own power consumption between 0% and 100% according to their own power consumption. As the general industrial and commercial electricity price is higher than the desulfurization coal price, the higher the proportion of self-use, the better the economic benefits. In this paper, the installed capacity is 2WM, the proportion of self-use is 70%, the loan line is 50% of the initial investment cost, and the annual interest rate of the loan term is 5% as the basic research object [13]. E means considering environmental benefits, E-F refers considering environmental benefits without financing cost, the relevant financial indicators of the eight regions are shown in Table 3.

|                | LCOE<sub>E</sub> (yuan/kWh) | LCOE<sub>E-F</sub> (yuan/kWh) | P<sub>2</sub> (yuan/kWh) | P<sub>1</sub> (yuan/kWh) | $\overline{p}$ (yuan/kWh) |
|----------------|----------------------------|----------------------------|------------------------|------------------------|----------------------------|
| Beijing        | 0.5326                     | 0.3870                     | 0.3598                 | 0.8326                 | 0.7130                     |
| Tianjin        | 0.5267                     | 0.3831                     | 0.3655                 | 0.6639                 | 0.5961                     |
| Shanghai       | 0.5763                     | 0.4264                     | 0.4155                 | 0.7158                 | 0.6558                     |
| Chongqing      | 1.0308                     | 0.7688                     | 0.3964                 | 0.6761                 | 0.6100                     |
| Hubei          | 0.6924                     | 0.5160                     | 0.4161                 | 0.6707                 | 0.6194                     |
| Fujian         | 0.6292                     | 0.4691                     | 0.3932                 | 0.6192                 | 0.5709                     |
| Shenzhen       | 0.6364                     | 0.4743                     | 0.4530                 | 0.6419                 | 0.6192                     |
| Guangdong      | 0.6496                     | 0.4854                     | 0.4530                 | 0.6799                 | 0.6378                     |

In order to implement the target requirement of “reduce the grid link charges and transmission and distribution price, and reduce the general industrial and commercial price by 10% on average” in the government work report, all provinces and cities have started to implement the new price since April and May of 2019, and the price of electricity in all parts of the country has decreased compared with the previous one. Considering the environmental benefits, only the LCOE of Beijing, Tianjin, Shanghai and Shenzhen is lower than the general industrial and commercial price, reaching the demand side parity, and users can achieve economic feasibility by adjusting the proportion of their own use. If the initial investment is all their own capital, except Chongqing, other seven provinces and cities have reached the user side parity.

Among the eight regions, Beijing, Tianjin and Shanghai have achieved good economic performance in terms of industrial and commercial rooftop photovoltaic under basic conditions, and Chongqing has the worst economic performance, with an IRR of - 0.51%. Compared with the financing cost, the IRR of the eight regions without financing cost has increased by 4.35% on average, and the IRR of the other seven regions has exceeded 8%, except Chongqing. Therefore, for the industrial and commercial roof photovoltaic, reducing its financing cost is one of the important means to improve the income.
4.3 Sensitivity analysis

In this section, the sensitivity analysis method is used to select four indicators from the three perspectives of power generation, cost and income of roof photovoltaic. The initial investment cost, system conversion rate, loan interest rate and carbon trading price change are used to analyze the influence of photovoltaic evaluation index of industrial roof the industry and Commerce in Beijing (the second region of solar energy resources), Chongqing (the fourth region of solar energy resources) and Shenzhen (the third region of solar energy resources). The results of sensitivity analysis are shown in Figure 2.

Figure 1. Comparison of IRR in eight regions

Figure 2. Sensitivity analysis of four indicators to LCOE and IRR
As can be seen from Figure 2, when the initial investment cost changes from 3.5 yuan / W to 2 yuan / W, the LCOE of industrial and commercial rooftop photovoltaic in Beijing, Chongqing and Shenzhen decreased from 0.5326 yuan / kWh to 0.2838 yuan / kWh, 1.0308 yuan / kWh to 0.5907 yuan / kWh, 0.6364 yuan / kWh to 0.3594 yuan / kWh, respectively. IRR increased from 12.74% to 28.40%, 0.51% to 8.18%, 6.57% to 18.27%, respectively, so the advantages brought by the reduction of initial investment cost are obvious. When the initial investment cost is 3 yuan / W, LCOE of Shenzhen is lower than the average electricity price when the proportion of self-use is 70%, which is economically feasible. When the initial investment cost is 2 yuan / W, LCOE of Chongqing is lower than the average electricity price when the proportion of local industry and commerce and self-use is 70%, at this time, the advantages of economic benefits are more prominent in Beijing and Shenzhen. The system conversion efficiency indirectly affects the cost of electricity consumption through the impact on the annual effective power generation. When the system conversion rate reaches 0.9, the roof photovoltaic of Shenzhen industry and commerce can achieve economic feasibility in the non-subsidy mode, while it is difficult to achieve economic feasibility in Chongqing due to the low light duration, so the affordable grid access ability is highlighted in the solar energy rich areas. The loan interest rate is in the range of 5% to 2%. For every 1% interest rate reduction, the LCOE of the three regions will be reduced by 0.1170 yuan / kWh on average, and the IRR will be increased by 0.28% on average, the economic benefits brought by the reduction of financing cost in all regions are equivalent. The sensitivity of LCOE and IRR in different regions to the change of carbon dioxide price mainly depends on the local carbon dioxide price, when the carbon trading price in Shenzhen is 5 times of the current price (120 yuan / ton), and when Chongqing reaches 565.02 yuan / ton, it will be economically feasible.

5. Conclusion
This paper selects eight regions as the research objects to study the economic benefits of home rooftop photovoltaic and industrial and commercial rooftop photovoltaic without subsidies and considering the environmental benefits within the photovoltaic life cycle. The conclusions are as follows.

1. The reduction range of LCOE is 0.0083-0.0593 yuan / kWh, and environmental factors bring the most economic benefits in Beijing, followed by Shanghai, Tianjin, Hubei, Shenzhen, Fujian, Guangdong and Chongqing. Therefore, with the development of national carbon trading system and the improvement of carbon trading pricing and environmental protection tax, it is helpful to improve the economic benefits of photovoltaic power generation.

2. As for household roof photovoltaic, except Chongqing, other seven provinces and cities have achieved the supply side parity, among which Beijing, Tianjin, Shanghai, Hubei, Shenzhen and Guangdong have achieved the user side parity, this indicates that China's household roof photovoltaic investment still has good benefits without subsidies.

3. As for Industrial and commercial rooftop photovoltaic, in the case of no subsidy and no financing cost, all the other seven provinces and cities have achieved the demand side parity except Chongqing. Sensitivity analysis shows that the initial investment cost and annual power generation of photovoltaic are the two main factors affecting LCOE and IRR, so the economic performance of the first and second categories of regions with rich sunlight resources is better. Therefore, according to the abundance of solar energy resources in different regions, the government should choose the appropriate time to decrease subsidies in each region, and the first and second regions can firstly realize non-subsidy.

Acknowledgment
This work is supported by the National Natural Science Foundation of China Grant No.71771076

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