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# Forecasting of electricity price subsidy based on installed cost of distributed photovoltaic in China

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**Abstract**

In China, the installed cost of distributed photovoltaic (DPV) is declining rapidly. However, the level of subsidy per kWh for DPV is adjusted less frequently by the Chinese government. This paper proposed a linkage model to forecast subsidy per kWh of DPV based on net present value (NPV) method. The results show that the increase of subsidy duration, internal consumption proportion and sunshine hours will reduce subsidy level. Therefore, it is suggested that the Chinese government should take varied and targeted measures, such as reducing different subsidies for new DPV users who install DPV in different years, choosing a longer subsidy duration and setting different subsidy levels in different regions. These varied and targeted measures are beneficial to both government and users, because they can reduce the annual financial burden for the government and the surcharges of electricity purchase for users.



*Keywords:* Distributed photovoltaic; subsidy; NPV method; China

## 1. Introduction

Worldwide, photovoltaic (PV) power has become one of the most important renewable energies. In China, by the end of 2016, the cumulative installed capacity of PV was above 77GW, accounting for more than one fourth of the

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total PV installed capacity in the world. The installed capacity of distributed photovoltaic (DPV) also grew rapidly in China. By the end of 2016, the cumulative installed capacity of the DPV in China was 10.32GW with an increase of 70.3% compared with a year ago. To sum up, remarkable achievements on DPV have been made in China.

With the rapid increase of installed capacity of DPV and R&D investment, the installed cost of DPV decrease quickly [1,2]. A reasonable return can be ensured to the DPV users currently, so the government can accelerate DPV subsidy decline frequency timely. However, the DPV subsidy has been adjusted fewer only once from 2014 to 2017. Additionally, the regional differences are not considered currently in DPV subsidy level setting. In the present studies, initial investment subsidy and static subsidy are studied usually [3]. He et al. [4] used the NPV method to calculate the initial investment subsidy for DPV power generation. However, the initial investment subsidy is not in line with Chinese current policy requirements. The subsidy standard is relatively simple and do not consider more related factors [5]. Therefore, the motivations of this paper include developing a linkage model to forecast subsidy per kWh of DPV and further determine appropriate subsidy mode and level in the context of China. The contributions of this paper are as follows. A linkage model of subsidy and installed cost of DPV is proposed to forecast subsidy per kWh in China. In addition, we set varied and targeted subsidy levels with the consideration of the differences between regions, subsidy durations, internal consumption proportions and other factors.

## 2. Forecasting of DPV subsidy based on NPV method

Users analyse the cash flows of a DPV project, then calculating the NPV of the DPV project. If the NPV is less than 0, users usually do not invest in the PV project. At this time, the government will pay subsidy to users for increasing cash inflow until the NPV is more than 0.

The calculation of cash flows and NPV are as follows:

(1) Cash outflow of DPV project

As the proportion of construction cost and other expenses in the initial cash outflows is very small, only the purchase and installation expenses $C_{sys}(t)$ of DPV modules are considered in this model, and the cash outflow unrelated to the project is not considered. Therefore, the initial cash outflow $C_0$ is shown in Eq.1.

$$C_0 = (1-K_l)C_{sys}(t) \tag{1}$$

where $K_l$ is the loan ratio.

The annual operation and maintenance cost $C_{o\&m}(t)$ and interest expense $C_{fin}(t)$ are shown in Eqs.2 and 3,

$$C_{o\&m}(t) = C_{sys}(t) \times K_{o\&m} \tag{2}$$

$$C_{fin}(t) = C_{sys}(t) \times K_l \times i_l \tag{3}$$

where $K_{o\&m}$ is the estimated proportion of operating and maintenance expenses in DPV installation costs, and $i_l$ is the loan interest rate.

In summary, the total cash outflows of DPV projects $C_{out}(t)$ are shown in Eq. 4,

$$C_{out}(t) = (1-K_l)C_{sys}(t) + C_{o\&m}(t) + C_{fin}(t) + C_{loan}(t) \tag{4}$$

where $C_{loan}(t)$ is the repayments varying with time.

(2) Cash inflow of DPV project

The reduction of electricity purchase expense $I_{c-sale}(t)$ is shown in Eq. 5,

$$I_{c-sale}(t) = P_{c-sale} Q_{gen}(t) K_{use} \tag{5}$$

where $K_{use}$ is the internal consumption proportion in the DPV generation, comprehensive sales price $P_{c-sale}$ is calculated by the proportion of the peak-valley period accounting for the photovoltaic working period as a weighted coefficient, as shown in Eq.6,

$$P_{c-sale} = \frac{h_s}{h_{pv}} P_s + \frac{h_p}{h_{pv}} P_p + \frac{h_f}{h_{pv}} P_f + \frac{h_v}{h_{pv}} P_v \tag{6}$$

where $h_s$, $h_p$, $h_f$, $h_v$ denote the durations of spike, peak, flat and valley in a day respectively, $h_{pv}$ is the working hours of a DPV in a day, $P_s$, $P_p$, $P_f$, $P_v$ denote the sales price in the spike, peak, flat and valley period respectively.

The annual DPV generation $Q_{gen}(t)$ is shown in Eq.7,

$$Q_{gen}(t) = W \times \eta \times H \times (1 - K_{dec}) \tag{7}$$

where $W$ is the installed capacity of the DPV, $\eta$ is the system efficiency of DPV, $H$ is the annual peak sunshine hours in different regions, the peak sunshine hours is more accurate than standard sunshine hours [30] ,and $K_{dec}$ is the annual DPV generation decay rate.

The cash inflow of the remaining power sales $I_{coal}(t)$ is calculated by the local desulfurization coal benchmark price $P_{coal}$, the DPV generation and the sale proportion to the grid, as shown in Eq. 8,

$$I_{coal}(t) = P_{coal} Q_{gen}(t)(1 - K_{use}) \tag{8}$$

The cash inflow of the government subsidy $I_{sub}(t)$ is calculated by subsidy per kWh $P_{sub}$ and the generation of DPV, as shown in Eq. 9,

$$I_{sub}(t) = P_{sub} Q_{gen}(t) \tag{9}$$

In summary, the total cash inflow of DPV projects $I_{in}(t)$ is shown in Eq. 10,

$$I_{in}(t) = P_{c-sale} Q_{gen}(t) K_{use} + P_{coal} Q_{gen}(t)(1 - K_{use}) + P_{sub} Q_{gen}(t) \tag{10}$$

(3) NPV of DPV project

The cash inflow and outflow calculated in step 1 and 2 are discounted at the expected rate of return to obtain the NPV of the DPV project, as shown in Eq. 11.

$$NPV = -(1 - K_l) C_{sys}(t) + \sum_{t=1}^{T} \left[ I_{in}(t) - C_{out}(t) \right] / (1 + i_0)^t \tag{11}$$

When NPV is less than 0, a linkage model is proposed as shown in Eq. 12. Eq. 12 is used to forecast the DPV dynamic subsidy per kWh $P_{sub}$ and Eq. 13 is used to calculate the DPV dynamic initial investment subsidy $P_{i-sub}$,

$$-(1 - K_l) C_{sys}(t) + \sum_{t=1}^{T} \left[ P_{sub} Q_{gen}(t) + P_{c-sale} Q_{gen}(t) K_{use} + P_{coal} Q_{gen}(t)(1 - K_{use}) - C_{out}(t) \right] / (1 + i_0)^t = 0 \tag{12}$$

$$-(1 - K_l) C_{sys}(t) + P_{i-sub} + \sum_{t=1}^{T} \left[ P_{c-sale} Q_{gen}(t) K_{use} + P_{coal} Q_{gen}(t)(1 - K_{use}) - C_{out}(t) \right] / (1 + i_0)^t = 0 \tag{13}$$

where $i_0$ is the expected return rate, $T$ is the operating life of the DPV project.

## 3. Case study

### *3.1. Data sources*

In this paper, we mainly take shopping mall rooftop DPV project in Beijing as the case. According to this project, we make the following assumptions, as shown in Table 1.

**Table 1.** Basic data in case.

| Symbol | Definition | Value |
|---|---|---|
| $V$ | The voltage level of the shopping mall | 1-10kv |
| $W$ | Installed capacity of PV | 100kw |
| $\eta$ | System efficiency of PV | 80% |
| $K_{dec}$ | Power generation decay rate of DPV | 3% for the first year, then 1% |
| $T$ | Life cycle of DPV | 25 years |
| $H_w$ | Working hours of DPV | 8: 00-18: 00 |
| $i_0$ | Expected return rate | 17% |
| $K_{use}$ | The internal consumption proportion | 75% |
| $C_{o\&m}$ | Annual operation and maintenance cost | 30,000 yuan |
| $K_l$ | Loan proportion | 20% |
| $i_l$ | Loan interest rate | 7% |
| $n_l$ | Loan period | 5 years |

Data sources: Refs. [4,6].

As this paper will calculate the subsidy of different regions in Section 3.4, we list the desulfurized coal benchmark price in 2017 and annual peak sunshine hours previously in Western Qinghai, Beijing and Hangzhou, as shown in Table 2. These three cities are the representative cities in three types of solar energy resource regions. The comprehensive sales price of the Western Qinghai, Beijing and Hangzhou and the comprehensive sales price based on Eq. 6 in 2017 are shown in Table 2.

**Table 2.** Desulfurized coal benchmark price in 2017, comprehensive sales price and annual peak sunshine hours in Western Qinghai, Beijing and Hangzhou.

| Resource area | Region | Desulfurized coal benchmark price in 2017（yuan/kWh) | Comprehensive sales price (yuan/kWh) | Annual peak sunshine hours (h) |
|---|---|---|---|---|
| I | Western Qinghai | 0.3247 | 0.72 | 1835.95 |
| II | Beijing | 0.3598 | 1.12 | 1576.80 |
| III | Hangzhou | 0.4153 | 0.92 | 1346.85 |

Data is from official website [7].

### *3.2. Calculation of subsidy with different subsidy durations*

The unit installed costs of DPV from 2006 to 2017 are based on the data from website. The unit installed costs of DPV from 2018 to 2020 are forecasted by the two-factor learning curve method mentioned by He et al. [4].

According to Eqs.12 and 13, Table 1 and 2, the results of subsidy per kWh with subsidy for 10 years, subsidy for 20 years and initial investment subsidy are shown in Table 3. Table 3 also indicates the total installed cost of 100kW roof DPV from 2006 to 2020.

**Table 3.** Subsidy per kWh with different durations in Beijing.

| | Unit installed cost of all PV(yuan/W) | Subsidy for 10 years(yuan/kWh) | Subsidy for 20 years(yuan/kWh) | Initial investment subsidy( $\times 10^4$ yuan) | Total installed cost( $\times 10^4$ yuan) |
|---|---|---|---|---|---|
| 2006 | 21.60 | 3.07 | 2.48 | 161.90 | 216.00 |
| 2007 | 19.20 | 2.65 | 2.13 | 138.92 | 192.00 |
| 2008 | 16.80 | 2.24 | 1.78 | 115.94 | 168.00 |
| 2009 | 14.40 | 1.82 | 1.43 | 92.95 | 144.00 |
| 2010 | 12.00 | 1.41 | 1.08 | 69.97 | 120.00 |
| 2011 | 10.80 | 1.20 | 0.90 | 58.48 | 108.00 |
| 2012 | 10.20 | 1.09 | 0.82 | 52.73 | 102.00 |
| 2013 | 9.60 | 0.99 | 0.73 | 46.99 | 96.00 |
| 2014 | 9.00 | 0.88 | 0.64 | 41.24 | 90.00 |
| 2015 | 8.40 | 0.78 | 0.55 | 35.49 | 84.00 |
| 2016 | 7.20 | 0.57 | 0.38 | 24.00 | 72.00 |
| 2017 | 6.19 | 0.40 | 0.23 | 14.33 | 61.92 |
| 2018 | 5.60 | 0.30 | 0.15 | 8.72 | 56.04 |
| 2019 | 5.07 | 0.20 | 0.07 | 3.62 | 50.72 |
| 2020 | 4.59 | 0.12 | 0.00 | -0.99 | 45.90 |

The initial subsidy scheme for DPV was implemented from 2006 to 2012 in China. From Table 3, with the implementation of the project “Golden Sun Project” from 2009 to 2012, the initial subsidy was closed to the half of installed cost. The large one-time initial subsidy cash flow poses a serious financial burden for the Chinese government, so the government adopt the mode of subsidy per kWh in 2013. Compared to the initial subsidy, on the one hand, the subsidy per kWh can increase the users' confidence in investing in DPV continuously, on the other hand, it can reduce annual financial burden for the government. Therefore, the mode of subsidy per kWh in DPV is adopted in our country currently. The level of subsidy for 20 years is obviously less than the level of subsidy for 10 years. Under the same expected rate of return, the policy of subsidy for 20 years will help reduce more financial burden for government. Therefore, the government can choose longer subsidy duration.

### *3.3. Calculation of subsidy with different internal consumption proportions and peak sunshine hours*

According to the Eq. 12, Table 1 and 2, based on different internal consumption proportions in the DPV generation, the results of subsidy per kWh with subsidy for 20 years in Beijing are shown in Fig. 2(a). If Beijing achieve the sunshine hours of Western Qinghai and Hangzhou, the results of subsidy per kWh in Beijing with subsidy for 20 years are shown in Fig. 2(b).

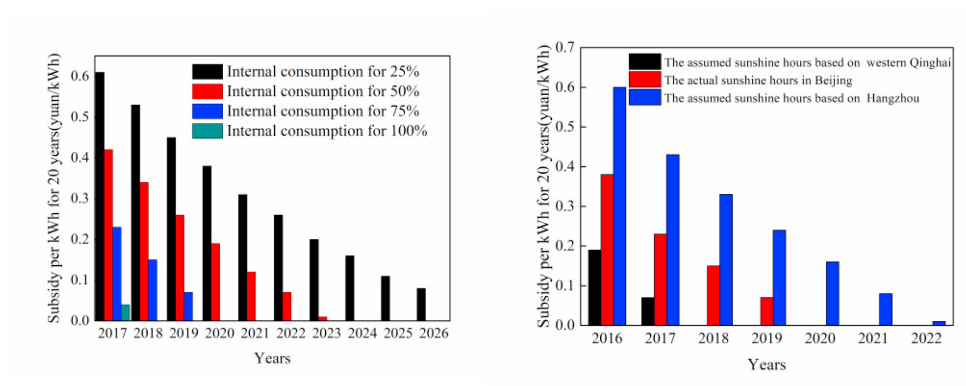


**Fig. 2(a).** Subsidy per kWh with different internal consumption proportions in Beijing;
**Fig. 2(b).** Subsidy per kWh with different peak sunshine hours in Beijing.

**Fig. 2(a)** shows that if the internal consumption proportion reaches 100%, the government will not have to pay subsidy when users invest in DPV projects in 2018. If internal consumption proportion is only 25%, it is estimated that users will get out of subsidy to achieve the expected rate of return by 2027. From the government point of view, the higher the internal consumption proportion is, the government subsidizes less. On the one hand, it can reduce the financial burden for government, on the other hand, grid parity can be achieved in advance. The government should encourage the internal consumption in the DPV generation, which can effectively reduce grid load and cut peak. It can enhance energy security and make more renewable energy connect to smart grids to achieve the upgrading of the entire power industry eventually.

**Fig. 2(b)** shows that the government needs to pay subsidy of 0.61 yuan/kWh in Beijing in 2016 if Beijing only have the sunshine hours of Hangzhou, which is above the national standard of 0.42 yuan/kWh. It indicates that the sunshine hour of Hangzhou is too short and solely relying on the subsidy per kWh paid by the central government is not enough to reach the expected rate of return. Therefore, under the current policy, no different subsidies in different regions for DPV should be adjusted. The way to set subsidy in different regions is discussed in detail in Section 3.4.

### *3.4. Calculation of subsidy in different regions*

As mentioned in Section 3.3, we should set different subsidy in terms of different regions with different sunshine hours. In this paper, with the adoption of the division standard of the three major solar resource areas in the centralized PV power plants, the DPV subsidy per kWh is also calculated in the different regions. According to Eq. 12, Table1 and 2, the results are shown in Table 4.

**Table 4.** Subsidy per kWh for 20 years in Western Qinghai, Beijing and Hangzhou.

| Year | Subsidy per kWh for 20 years in Western Qinghai (yuan/kWh) | Subsidy per kWh for 20 years in Beijing (yuan/kWh) | Subsidy per kWh for 20 years in Hangzhou (yuan/kWh) |
|---|---|---|---|
| 2018 | 0.30 | 0.15 | 0.47 |
| 2019 | 0.24 | 0.07 | 0.37 |
| 2020 | 0.18 | 0.00 | 0.29 |
| 2021 | 0.12 | 0.00 | 0.22 |
| 2022 | 0.07 | 0.00 | 0.15 |
| 2023 | 0.03 | 0.00 | 0.09 |
| 2024 | 0.00 | 0.00 | 0.03 |
| 2025 | 0.00 | 0.00 | 0.00 |

Table 4 show that there is a large difference between desulfurized coal benchmark prices, comprehensive electricity price and peak sunshine hours in different regions. The subsidy per kWh across the same year differ by more than 0.1 yuan in different regions. Although the Western Qinghai has a longer sunshine hours than Beijing, the subsidy per kWh in Western Qinghai is more than Beijing. It indicates that sunshine hours on the impact of subsidy per kWh is not the most important factor and subsidy per kWh is the result of the combination of different factors. Therefore, it is necessary for government to implement different targeted subsidy per kWh in different regions.

## 4. Conclusions

In this work, the subsidy per kWh of DPV is forecasted based on NPV method. The mechanism of subsidy per kWh rather than initial investment subsidy meets the requirements of the current policy of DPV in China. A case of shopping mall rooftop DPV project in Beijing show that the increase of subsidy duration, internal consumption proportion and sunshine hours will reduce subsidy level. Therefore, the government should choose longer subsidy duration for a period of 20 years but the subsidy contract can be signed every 5 years. Furthermore, the government should encourage the grid-connected mode of “spontaneous self-consumption, the remaining electricity grid feed” and set different subsidy levels in different regions. These varied measures can reduce the annual financial burden for the government and the surcharges of electricity purchase for users.

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