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Cost and Benefit Analysis of Distributed Photovoltaic System

A Case of Beijing-Tianjin-Hebei Region

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***Abstract*—During the 13th five-year plan, China will devote great efforts to promote the development of distributed photovoltaic (PV) industry. It is conducive to energy structure optimization and ecological environment protection in important regions including Beijing-Tianjin-Hebei region, and the development of distributed PV industry depends on the economic feasibility of project investment. The paper analyzes Beijing-Tianjin-Hebei region distributed PV cost and benefit on the basis of SD simulation model and typical projects data. The results show that the development of Beijing-Tianjin-Hebei region distributed PV industry has economic feasibility of long-term investment based on current industry support policies and existing technical level. But subsidies should be more than 0.27 yuan/kWh of Beijing 0.21 yuan/kWh of Tianjin and 0.27 yuan/kWh of Hebei. The paper also shows that in order to reduce the distributed PV operation and investment risk, meanwhile improving the economic feasibility, the main task at present is still carrying out technological innovation.**

Keywords—distributed photovoltaic; Beijing-Tianjin-Hebei region; cost and benefit; system dynamic

I. INTRODUCTION

The goals of PV development in China 13th five-year plan are that PV holds 7% in the power structure, 15% in the new power structure and 2.5% to 3% in the country's total generating capacity structure. The standard coal is about 60 million tons. Distributed PV is mainly developed in PV development because of small output and less pollution. Distributed PV can satisfy electric load in local areas and it is able to generate electricity at the same time. For Beijing-Tianjin-Hebei region, distributed PV can relieve energy demand pressure and improve energy structure in local areas and speed up air pollution control. Therefor the development of distributed PV in Beijing-Tianjin-Hebei region is much significant.

To promote distributed PV development in China, the Chinese government issued policies in all aspects and pointed out improving distributed PV utilization during 2007 and 2015. The Chinese government proposed construction of large-scale grid-connected PV demonstration power plant requirements at first. It laid the foundation for the future development of distributed PV. Then the Chinese government unified the distributed PV feed-in tariff and focused on distributed PV development in 12th five-year plan. The National Energy Administration promulgate General Affairs Department of the National Energy Administration notice on PV development 13th five-year-plan planning work in 2015, where PV was mentioned as an important content. That means PV will be focused on as an important industry in the 13th five-year plan period. The notice clearly put forward to not restrict the construction scale about roof distributed PV projects and all the self-occupied ground distributed PV projects. With the introduction and implementation of policies, the Chinese PV market expands and installed capacity of PV grows fast.

The development of Beijing-Tianjin-Hebei region is highly valued by the Chinese government and there are three aspects of its necessity. First, according to the data released on February 2, 2015 by Ministry of Environment Protection of China, the air quality average standard numbers of days of Beijing-Tianjin-Hebei region are 156 days in 2014. The number is less than the average standard 85 days across the country. The air quality average standard proportion is 42.8%, radio of severe pollution and above is 17%, more than 11.4% across the country. A large amount of pollutants produced by the use of traditional fossil energy severely damaged the ecological balance of Beijing-Tianjin-Hebei region. Then, coordinated development goal of Beijing-Tianjin-Hebei region has been put forward and there are seven requirements. One of the most important requirements is strengthening the cooperation of the ecological environment protection and improving the mechanism of clean energy use areas based on the mechanism of air pollution prevention and control. In addition, International Olympic Committee announced Beijing-Zhangjiakou became 2022 World Winter Games host city on July 31st, 2015. Both initiatives have risen to national political strategic level, environmental protection and efficient use of renewable energy will make significant contributions to the Winter Olympics and the future development of Beijing-Tianjin-Hebei region. Finally, the coordinated development of Beijing-Tianjin-Hebei region allows each industry to support each other and resources can be used together. This provides feasibility conditions for Beijing-Tianjin-Hebei region taking the lead to develop the application of

distributed PV. Besides, Beijing-Tianjin-Hebei region has Yanshan, Taihang, Dam and other mountains, plateau and the vast rural plains, which have advantages in distributed PV development and meet the requirements.

Domestic and foreign scholars have done a lot of research on distributed PV economic benefits in recent years. Xingang Zhao[1] reviewed some main points of relevant policies including financial support, technology innovation and management improvement. Jiahai Yuan[2] used the levelized cost of electricity (LCOE) analytical framework to estimate the generation cost of distributed PV in China. Menglian Zheng[3] proposed an agent-based stochastic model to randomly generate appliance-level demand profiles for an average U.S. household. Su Jian[4] set up PV whole life cycle cost and benefit calculation method and model under different operating mode, and analyzed the different operating modes of two distributed PV grid-connected design. Zeng Ming[5]analyzed the uncertainties faced by the distributed power investment, focusing on the economic benefits of energy service companies, users, and other power companies in distributed energy investment.

In terms of solving the problem of distributed PV optimization and strategy, Ali Zangeneh[6] proposed a static fuzzy multiobjective model to determine the optimal size, location and also the proper technology of distributed generation (DG) units in distribution systems. The model can concurrently optimize a number of conflicting and competing objective functions including economic, technical and environmental attributes. Tomislav Capuder[7] introduces a comprehensive analysis framework and a relevant unified and synthetic Mixed-Integer Linear Programming optimization model suitable for evaluating the techno-economic and environmental characteristics of different Distributed Multi-Generation (DMG) options. Duong Quoc Hung[8] presented new analytical expressions to efficiently capture the optimal power factor of each Distributed Generation (DG) unit for reducing energy losses and enhancing voltage stability over a given planing horizon. Hongbo Ren[9] used multi-objective programming to analyze distributed energy optimal operation strategy considering the minimum energy cost and minimize CO2 emissions. Asim Ahmed[10] proposed strategic techno-economic assessment of heat network options for distributed energy systems in the UK. He presented a generic and comprehensive model to perform heat network design and assessment according to specified input criteria and assess operational, capital, and overall costs of multiple alternatives.

In general, the studies of distributed PV at present mainly concentrate on macro economic analysis and system optimization, and putting forward various models for distributed generation strategy analysis and evaluation. Besides, the analysis of China's major regions and distributed PV future trends predicted is less. This paper employs system dynamics (SD) simulation model to analyze current situation and future trend of Beijing-Tianjin-Hebei region distributed PV. Simultaneously, the paper calculates the subsidies threshold of Beijing-Tianjin-Hebei region distributed PV.

II. METHODOLOGY

Beijing-Tianjin-Hebei region supports distributed PV development mainly through subsidy policy and financial policy. For subsidy policy, feed-in tariff policy in accordance with generating capacity for distributed PV project was clearly put forward by China National Development and Reform Commission. Feed-in tariff standard is 0.42 yuan/kWh and subsidy standard execution period are 20 years in principle. Tariff and subsidy standards will gradually be reduced according to the scale of PV and the change of the cost in order to promote technological progress and improve PV market competitiveness. On the basis of national policy, Beijing-Tianjin-Hebei region has set up subsidy policy for local distributed PV. “Table I” is Beijing-Tianjin-Hebei region local subsidy policy. For financial policy, Beijing-Tianjin-Hebei region current green financial support for new energy industry mainly focuses on the green credit assuming the commercial banks such as Industrial Bank, Hua Xia Bank and China Merchants Bank supporting for new energy and environmental protection enterprises.

TABLE I. BEIJING-TIANJIN-HEBEI REGION LOCAL SUBSIDY POLICY

	Subsidy		**Subsidy rules**
	State	***Local***	
Beijing	0.42	0.3	Beijing government awards 0.3 yuan/kWh to distributed PV projects which are combined to the grid during the period from January 1, 2015 to December 31, 2019.
Tianjin	0.42	-	DPV follows the implement policy of state.
Hebei	0.42	0.1-0.3 (For PV plant)	DPV follows the implement policy of state. PV plant constructed before 2014 was awarded 0.3 yuan/kWh, which was constructed before 2015 was awarded 0.2 yuan/kWh and which was constructed before 2017 was awarded 0.1 yuan/kWh.

Based on the above policies, the paper employs SD simulation model to analyze cost and benefit. Research on the current situation and future trend of Beijing-Tianjin-Hebei region distributed PV. Simultaneously, the paper makes sensitivity analysis for major components of cost-benefit. “Fig. 1” is SD flow graph.

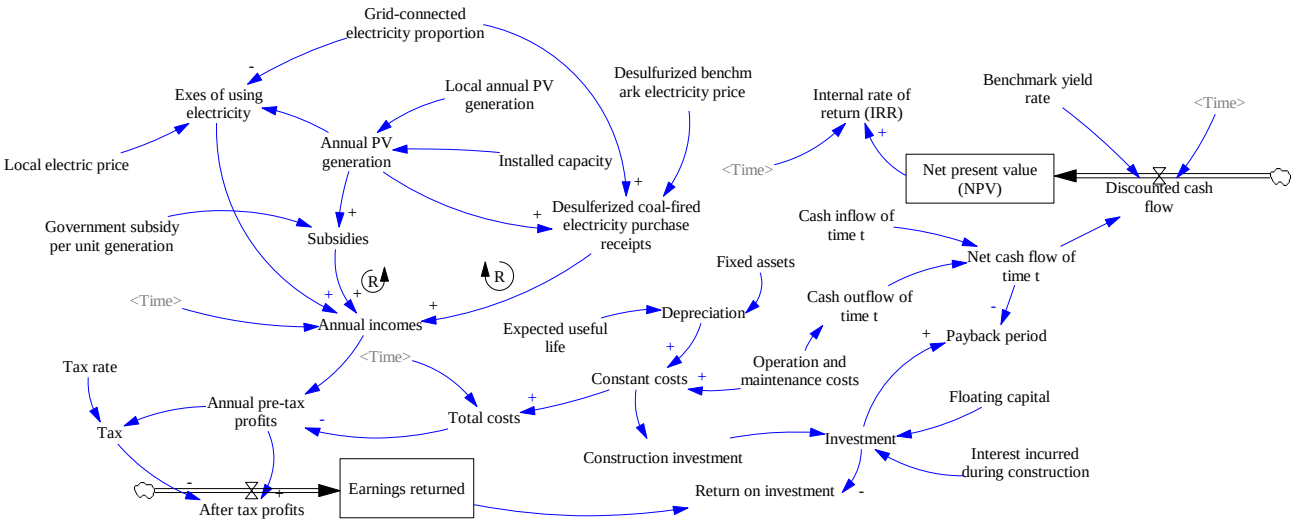

Fig. 1. SD flow graph

Where, distributed PV annual incomes are made up of three parts, which are government subsidies, exes of using electricity and desulferized coal-fired electricity purchase receipts. The three parts respectively constitute positive feedback with annual incomes. Annual incomes constitute a positive feedback with annual pre-tax profits. Total costs constitute a negative feedback with annual pre-tax profits. Distributed PV inputs are disposable, therefore the projects don't need purchase materials and fuel every year. The wages and welfare expenses are not involved. Consequently, total costs are made up mainly of constant costs including depreciation of raw materials annual operation and maintenance costs. The two parts respectively constitute positive feedback with constant costs. Project investment constitutes a negative feedback with return on investment. The more invest, the less return on investment.Net present value is the cumulative value of annual discounted cash flow and Internal rate of return is the discount rate when net present value equals zero.

III. CASE STUDY

A. Data

The state was divided into five categories in accordance with the solar energy resources. Beijing, Tianjin and southeast of Hebei are class iii, where solar energy resource is medium rich. Northwest of Hebei is class ii, where solar energy resource is rich. The National Energy Administration of China stipulates that single PV project which installed capacity is below 20MW is included into distributed PV index. In Beijing-Tianjin-Hebei region, the installed capacity of single distributed PV projects is between 15MW and 20MW except personal roof distributed PV. The paper chooses three same capacity projects which are all in class iii solar energy resource region in order to facilitate comparative analyze. They are Beijing Miyun 20MW distributed PV project, Tianjin Jingwu Town 20MW distributed PV project and Hebei Baoding 20MW distributed PV project. The paper is illustrated by the example of the three typical projects to analyze cost and benefit of Beijing-Tianjin-Hebei region distributed PV.

B. Results

SD simulation model operational process has four assumptions. First, generating capacity are all grid-connected. That means grid-connected electricity proportion is 100%. Change of grid-connected electricity proportion will be given in sensibility analysis. Second, local electricity price is calculated according to residential electricity price. Situation of industrial and commercial electricity price is also given in sensibility analysis. Third, the projects operating cycle is calculated according to solar panels expected useful life, which are twenty years. Fourth, the operational process is completely ideal state. That means no loss of electricity, all subsidies in place, adequate financing, etc.

"Fig. 2" are earnings retained results of the three projects. The earnings retained of the three projects are all greater than zero and Hebei project is the lowest. On the basis of the same fixed assets cost, tax, subsidies and operation and maintenance costs, although desulfurized benchmark electricity price of Hebei is the highest, but annual PV generation is the lowest, therefore the earnings retained of Hebei project are the lowest. It shows that annual PV generation has a great impact on distributed PV benefits.

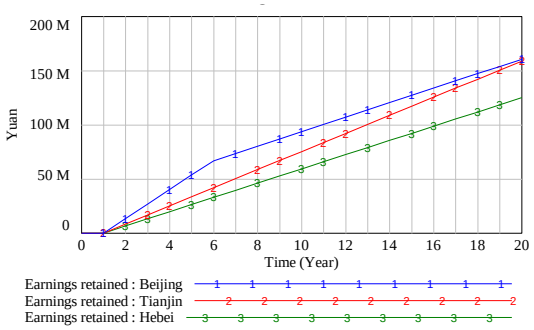

Fig. 2. Earnings retained

"Fig. 3" is return on investment results of the three projects. The return on investment of the three projects grow over time and are much higher than the power generation industry average yield of 8%. Return on investment of Tianjin is lower than that of Hebei but earnings retained of Tianjin is higher than that of Hebei. Earnings retained of Hebei is low but return on investment is high since total invest of Hebei is much lower than Tianjin . According to project data, Hebei project has no excess investment besides fixed assets investment, but Tianjin project investment is 1.7 times larger than fixed assets investment.

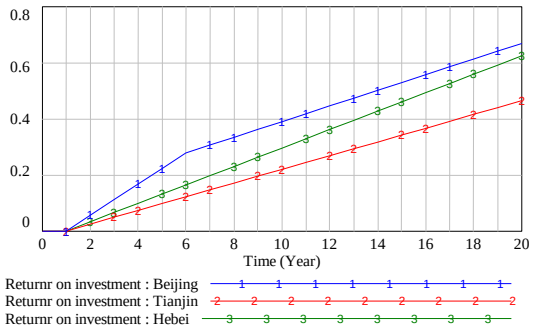

Fig. 3. Return on investment

"Fig. 4" are payback period results of the three projects. The payback period of Tianjin project is the longest, which are 17.9 years. The payback period of Beijing project is 9.7 years if the subsidy is calculated by 0.72 yuan/KWH and 13.7 years by 0.42 yuan/KWH (except Beijing excess subsidy). The payback period of Hebei project is 11.6 years. The payback periods of the three projects are all in a reasonable range which is between ten and twenty years. We compare Tianjin project with Beijing project, although the cash flow of time t of Hebei is low, but Hebei project investment is lower than the cash flow, therefor its payback period is short. Similarly, although the cash flow of time t of Tianjin is high, but Tianjin project investment is higher than the cash flow, therefor its payback period is long. It shows that the power generation cost has a greater impact on payback period compared with the cash flow of year t. Combined with the results of return on investment, we can know that return on investment can be effectively improved and payback period can also be reduced when controlling the power generation cost.

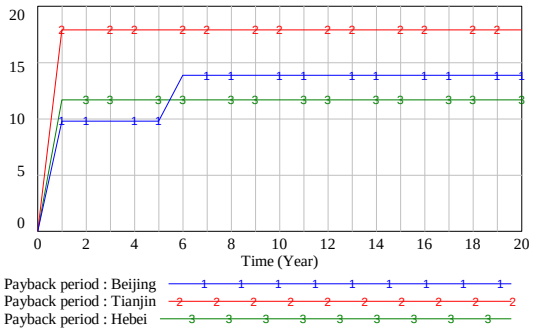

Fig. 4. Payback period

"Fig. 5" and "Fig. 6" are NPV and IRR results of the three projects. When IRR is greater than benchmark yield rate (interest rate) of 3%, NPV is greater than zero at the same time. At this point it shows that revenue is greater than the cost and the project can be operated. NPV and IRR of the three projects are all yearly increased over time. According to the results, Beijing project is defective from the beginning of eleven years and starts to profit from the 12th year. Tianjin project starts to profit from the 13th year. Hebei project is defective from the beginning of fourteen years and starts to profit from the 15th year. The beginning deficit is because annual earnings retained are used to make up the project investment and annual operation and maintenance costs. But three projects can operate and be invested in a long period. It shows that distributed PV projects are deficit in the beginning years because of high power generation costs. is still low even if projects start to profit.

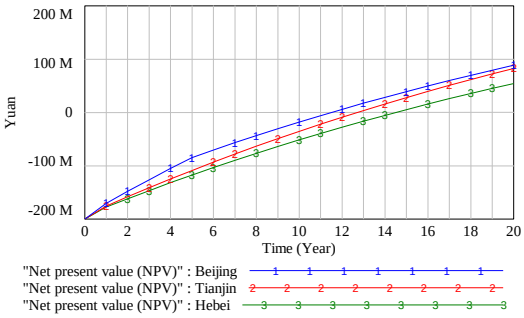

Fig. 5. NPV of projects

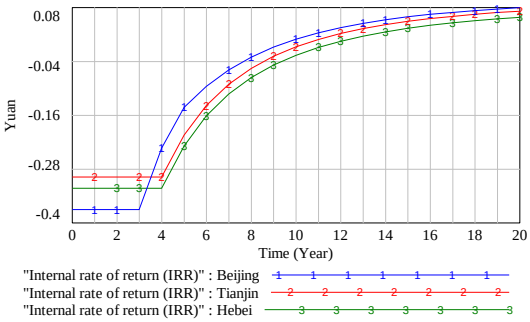

Fig. 6. IRR of projects

C. Sensibility Analysis

The results of the impact of grid-connected electricity proportion on distributed PV cost and benefit are shown as "Fig. 7". Grid-connected electricity proportion is negatively correlated with NPV, which is declining with the increase of grid-connected electricity proportion. Desulfurized benchmark electricity price is lower than local electric price. The benefit of desulferized coal-fired electricity purchase receipts is lower than that of exes of using electricity if they are calculated by the same generating capacity. It shows that distributed PV development should take self-production power for the main and dump energy is grid-connected. This can both meet electric load demand of distributed region and guarantee distributed PV economic benefits. For industrial

and commercial electricity, their prices are higher than desulfurized benchmark electricity price.

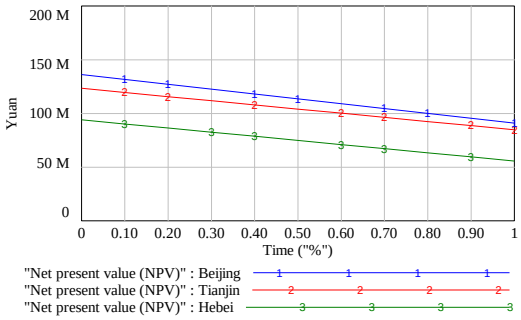

Fig. 7. Sensibility analysis of grid-connected electricity proportion

The results of the impact of costs on distributed PV cost and benefit are shown as "Fig. 8". When sensibility analyzing, the distributed PV cost was chosen in reasonable interval which is between 8 yuan/w and 12 yuan/W. It clearly shows that the distributed PV costs have a great impact on benefits. Benefits decline quickly with the increase of costs. It shows that reducing power generation costs is very important for the development of distributed PV.

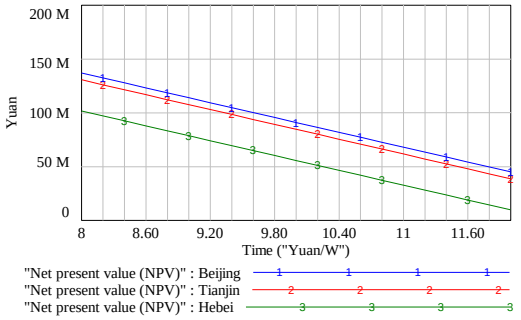

Fig. 8. Sensibility analysis of costs

The results of the impact of subsidy on distributed PV cost and benefit are shown as "Fig. 9". It shows that subsidies have great impact on benefits and subsidies growth is positively correlated with benefits growth. It also shows that, to realize economic feasibility of long-term investment, Beijing subsidies threshold is 0.27 yuan/kWh, Tianjin subsidies threshold is 0.21 yuan/kWh and Hebei subsidies threshold is 0.27 yuan/kWh.

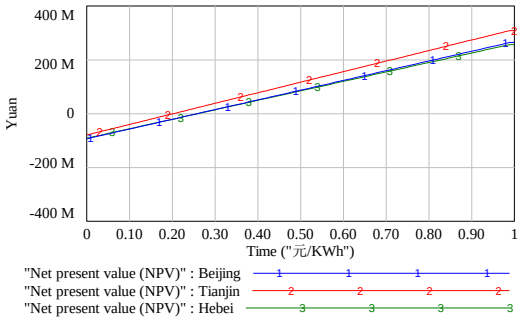

Fig. 9. Sensibility analysis of subsidy

IV. DISCUSSION

The development of Beijing-Tianjin-Hebei region distributed PV is more and more fast. In the ideal state, distributed PV development has big advantages and its long-term cost and benefit are good. It is suitable for long-term development and investment. In addition, in order to promote the coordinated development of Beijing-Tianjin-Hebei region, the proportion of receiving electric power will be greatly increased and own power generation growth will be reduced. Most power generation supply of Beijing and Tianjin are from Heibei since it is close to power consumptive land (Beijing, Tianjin and Heibe) if power stations are constructed in Hebei. Therefore power transmission losses will be much smaller. Besides, there are many mountains and plains in Hebei and solar energy resources are rich. The average of annual PV generation of northern regions in Hebei are 3000~3200 hours, which of middle and eastern regions are 2200~3000 hours. The average annual PV generation of Hebei is the highest in Beijing-Tianjin-Hebei region "Table II". According to earnings retained results, annual PV generation has a great impact on distributed PV benefits thus Hebei is most suitable for developing distributed PV in Beijing-Tianjin-Hebei region.

TABLE II. ANNUAL PV GENERATION OF BEIJING-TIANJIN-HEBEI REGION

	Beijing	**Tianjin**	**Hebei**
Annual PV generation （kwh/w）	1.214	1.318	1.427

[a.] Data source: Ref.[11]

The conclusions above are showed in completely ideal state, which are no loss of electricity, all subsidies in place, adequate financing, etc. But there are many differences between the reality and the ideal state reflecting in the following respects.

- According to sensibility analysis of subsidies, current distributed PV benefits depend on government subsidies. Subsidies are gradually reducing and changes of policies will affect the stability of distributed PV benefits in a long period. In addition, because of long-term government subsidies in arrears, fund flow is not smooth and financial costs increase in power enterprises. The first reason is insufficient renewable energy surcharge, and the second reason are complicated subsidy payment procedures. Take the fifth Published on the additional funding for renewable energy electricity price catalog for example, projects from declaration and organization to operation should last nearly a year.
- Current China distributed PV constructions exist problems of financing difficulties. PV policies require that policy banks and commercial banks implement category management to credit customers and adopt differentiated credit policy. There are two problems of current bank loans, which are credit narrow and the credit does not mean lending. Besides, the credit mainly focuses on companies and distributed PV

projects are difficult to obtain loans. According to the general experience, enterprises should assume at least 20% of the distributed PV projects start-up capital and nearly 80% of the funds need market financing support. But most banks now remain hesitant, they mainly consider risks such as uncertainly incomes, small planning and grid-connected risks of distributed PV projects. Therefore banks loans are cautious.

- Nature environment has a great impact on distributed PV. Solar panels are exposed to the open air and natural environmental factors, such as wind, water, cold and heat, ultraviolet light, natural corrosion and others have a great impact on the quality of panels. This will lead to strengthen the maintenance and replace solar panels, thereby increasing the costs and operational and investment risks are not controllable.

V. CONCLUSION AND SUGGESTION

This paper introduces background, policies and technique of Beijing-Tianjin-Hebei region distributed PV and employs SD simulation model to analyze cost and benefit. According to the simulation and sensibility analysis results, the conclusions are as follows.

- Beijing-Tianjin-Hebei region distributed PV has economic feasibility of long-term investment. Based on current industry support policies and existing technical level, net present value and internal rate of turn of Beijing-Tianjin-Hebei region distributed PV increase year by year. The government can do long period plan for Beijing-Tianjin-Hebei region distributed PV projects.
- In order to promote market development and technical innovation of Beijing-Tianjin-Hebei region distributed PV, subsidies gradually reduce is inevitable. To ensure the economic feasibility, Beijing subsidies threshold is 0.27 yuan/kWh, Tianjin subsidies threshold is 0.21 yuan/kWh and Hebei subsidies threshold is 0.27 yuan/kWh.

To better improve cost-benefit and economic feasibility of investment of distributed PV and solve the main problems of current development, this paper suggests that Beijing-Tianjin-Hebei region government should continue to strongly encourage and support technical innovation, enhance technical progress and improve research and development capabilities. The importance is embodied in three aspects.

- Technical innovation can reduce cost and increase benefits. Suppose to technology feasibility and economic feasibility before 2020 for the development of reference, as the production technology makes progress, decreased power consumption levels, reduced cutting losses and wafer thickness, raised conversion efficiency can contribute to a significant reduction in the PV solar cell components manufacturing costs. In addition, improving the level of equipment at home also reduces component manufacturing costs[12].
- When subsidies gradually reduce, the market will seek technical innovation to reduce costs.
- Technical innovation can improve the efficiency of solar panels and useful life and reduce operational risk, thereby reduce operational costs, improve the economic feasibility of investment.

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