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Research paper

Research on the policy route of China's distributed photovoltaic power generation

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ABSTRACT

The distributed photovoltaic power generation is an important way to make use of solar energy in cities. China issues a series of policies to support the development of distributed photovoltaics in law, electricity price, grid connection standard, project management, financial support and so on. However, there are still some defects in policies and market mechanism. China creates a competitive market with a significant number of projects of distributed photovoltaic power through the reform of the electricity market, yet substantial drawbacks of the corresponding investment subsidies prevent distributed photovoltaic power from rapidly developing. This paper summarizes the status quo of China's distributed photovoltaic power development, given its long-term plan, presents excellences and shortcomings of the existing policy system, and looks into the supporting policies and implementation paths for China's distributed photovoltaic power in different stages. Innovative business models and financial support models are conducive to the development of distributed photovoltaic power. Financial innovation methods such as crowd funding and asset securitization should be encouraged to develop a sound risk assessment mechanism for projects, involve insurance institutions, and establish a risk sharing mechanism. In the context of a series of supporting policies, the distributed photovoltaic power in China will move towards market-oriented standardization for a healthier and more stable development.

1. Introduction

As Chinese government promote clean energy development, the photovoltaic power (PV) involving centralized photovoltaic power (CPV) and distributed photovoltaic power (DPV) has been developing rapidly (Wenjing and Cheng, 2016). Due to the high land cost of the CPV (Ming, 2017), its development has been limited. However, DPV, which has a higher rate of return on investment (Hanqiao et al., 2014) and lower risk (Quansheng et al., 2016; Kirova and Velikova, 2016), is becoming the future development direction of PV. China has carried out "golden sun demonstration project" (Junhao, 2013) and "building-integrated photovoltaic" (Zhi, 2009) to promote the development of DPV.

Before 2007, the PV industry was in the initial stage of pilot. From 2009 to 2012, China implemented five phases of the "Golden Sun project" and "photovoltaic building" (Changgui and Dacheng, 2014; Xiaoxia, 2011). The policy orientation is clear, and the DPV is growing at a rapid speed. In 2011, it was first proposed to subsidize PV with electricity price (Changsong, 2014). Since 2014, China local governments have promoted DPV in subsidies provision for electricity, equipment and so on Changsong (2013).

In the early stage, the PV plants were mostly located in the west of China. However, the construction of the Western transmission channel lagged (Qiang and Ningbo, 2016), which caused the phenomenon of PV curtailment. In order to alleviate PV curtailment and promote DPV (Kunpeng, 2017; Xuehua, 2016), PV gradually developed in the middle east region of China (Xin, 2017).

Therefore, the policy is an important driving force of DPV (Fengmei and Li, 2017; Jiyang et al., 2014), the research of policy is beneficial to the DPV industry (Bi, 2017). Many countries in the world have promulgated the policy of supporting DPV. In USA, the policy includes green certificate, asset assessment for clean energy loan and grid metering mechanism (Haag et al., 2012). Its preferential policy has slowed down compared with CPV though (Stokes and Breetz, 2018). The EU promotes the marketization of PV by reducing subsidies. In 2016, the UK sharply

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reduced the price of photovoltaic subsidies by 64%. Germany's grid connected subsidy has been decreasing since 2009. Since 2017, the subsidies have no longer gained by purchasing green electricity at the government's designated price, but through market competition (Julie Yu et al., 2016). Countries such as Switzerland, Denmark, Italy and so forth also reduce or cancel subsidies.

India's photovoltaic product outlets are mainly concentrated in Asia Pacific and Africa (Ondraczek, 2014; Hansen et al., 2015), its photovoltaic industry is at the initial stage. India has launched the national solar energy plan, including renewable energy purchase obligations (RPO), financing incentives, UDAY plan and solar park (Quitzow, 2015). The Vietnamese government exempts the imported goods that constitute the fixed assets of solar energy projects, and the land occupied by solar power generation projects and transmission and transformation projects can be reduced or exempted from land and water use fees and lease fees; the price of PV integrated into the State Grid is 9.35 cents/degree; since June 30, 2019, the buyer is responsible for receiving all the electric power of photovoltaic projects, and the acquisition period is 20 years; in addition, Vietnam also stipulates preferential treatment in respect of enterprise income tax, import tariff and land use tax for PV projects. Indonesia's Ministry of Energy and Mineral Resources issued a government decree to provide appropriate support mechanisms for utility-scale photovoltaic systems, exhibitions and event management service companies, raising the subsidy of solar power tariffs to $0.25 per kWh, and adding 5.000 MWp solar photovoltaic capacity in the next two or three years. This plan will provide quotas for independent power producers (IPPs). The Indonesian government has allocated US$100 million to subsidize renewable energy sources in 2017, including PV. The Thailand government issued a lot of policies for PV on-grid price, funding, utility investment loan, and tax reduction, to support the development of PV. Briefly, the Indonesia (Fathoni et al., 2014) and Thailand (Chaianong and Pharino, 2015) PV subsidies are very high.

The DPV industry in China is in the stage of mature market. The DPV has a certain scale. The research of China's DPV policy is of great significance (Deshmukh et al., 2012). The rest of the paper is organized as follows. Section 2 describes the status of DPV in China including installed capacity, photovoltaic related industry, business model, and policy. Section 3 summarizes obstacles and issues of DPV development in short term, mid-term and long term. Section 4 analyzes the China's distributed photovoltaic grid-connected electricity price route under the influences of environmental tax. Finally, Section 5 concludes.

2. The status of DPV in China

The distributed renewable energy mainly includes PV, hydropower, biomass power generation, wind power generation and so on. In China, DPV is becoming the main way of utilizing solar energy. It is of great significance for China to solve the power limitation issues faced by the centralized renewable energy, reduce the subsidy demand of the centralized, and increase the supply of clean energy in cities.

2.1. Status of DPV installed capacity

According to China National Bureau of Statistics website data, in 2015, the number of photovoltaic households was only 20 thousand. In 2016, there were 200 thousand households. Fig. 1 introduces the development of PV station and DPV in China.

Up to 2017, the total amount of DPV installed in China reached 2966 MW. New installed units are mainly distributed in Zhejiang, Shandong and Anhui Provinces. Fig. 2 introduces the distributed photovoltaic installed capacity distribution in China.

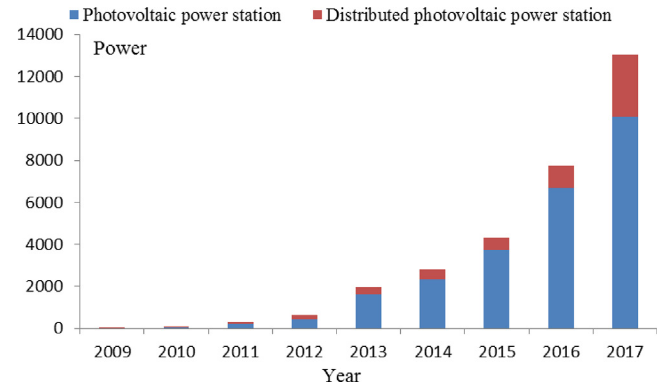

Fig. 1. The development of PV station and DPV in China (MW).

According to the statistics and evaluation report of China's solar power construction in 2017, China's DPV was 13.7 billion kWh. Its main applications include building Attached photovoltaics (BAPV), building integrated photovoltaics (BIPV) and plant site. Fig. 3 introduces the main application of DPV projects in China.

In 2017, the poly-silicon production was 242 thousand tons in China's photovoltaic equipment manufacturing industry, accounting for 56% of the global production, an increase of 24.7% and the industrial capacity utilization rate of 90%. The production of silicon chip in China was 87.6 GW, accounting for about 83% of the global production. The China's battery production was 68 GW, accounting for 68% of the global production. The production of the component was about 76 GW, accounting for about 71% of the global production. The specific production is shown in Table 1:

In 2017, the production of inverters in China was 60 GW, accounting for about 55% of global production. The inverters are promoted with the help of the China policy. Table 2 is the top ten of the China Inverter Manufacturer.

2.2. Distributed photovoltaic business model

With the promotion of China's policies on DPV projects, in terms of taxation, grid-connection, and financing, the install capacity of DPV has been increasing. However, the uncertainty and financing risk of distributed photovoltaic projects cause investors and users to be unable to form stable cooperative relationship. Therefore, the construction and operation modes of distributed photovoltaic projects need further exploration. The business models of distributed photovoltaic in China are summarized in this paper.

2.2.1. Contract energy management

In 2009–2017, China government implemented "golden sun demonstration project", introducing the contract energy management model into distributed photovoltaic projects, which solves the problems of financing, technology and management. The contract energy management model is shown in Fig. 4.

With the help of the investment subsidies, the contract energy management model shortens enterprise investment recovery period. However, there are risks in the model, such as the changes of electricity demand and willingness. This model solves the problems that most power users do not have enough funds to invest in PV projects, there is no corresponding technology and management capability, and it avoids the problem of sales qualification of PV development enterprises as the main power source.

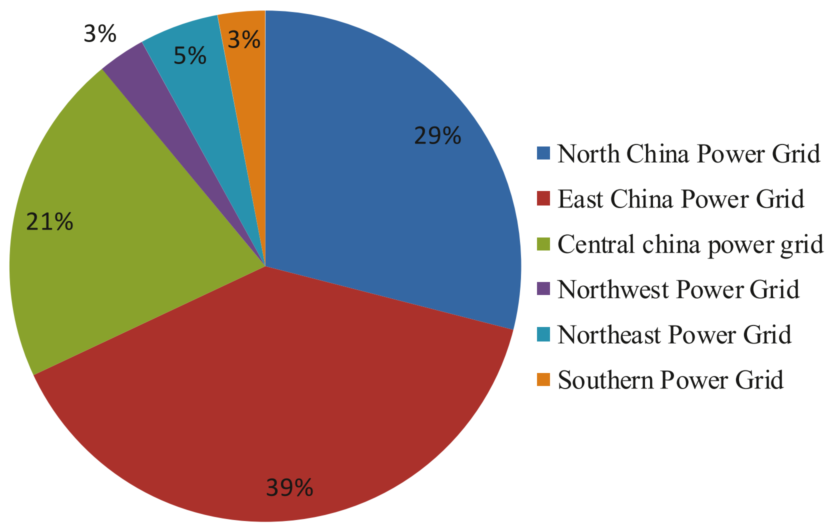

Fig. 2. Distributed photovoltaic installed capacity distribution in China.

Table 1
Production capacity and global proportion of photovoltaic industry in China.

	Capacity	Production	The share of global output	Export	Domestic digestibility
Poly-silicon	30 Million tons	24.2 Million tons	56%	14.4 Million tons	9.8 Million tons
Silicon chip	107 GW	87 GW	83%	/	/
Battery	/	68 GW	68%	4.2 GW	63.8 GW
Components	/	76 GW	71%	38.2 GW	37.8 GW

Table 2
Top ten Chinese inverter manufacturers in 2017.

NO.	Company name	Production (MW)
1	Huawei Technologies Co. Ltd	18 130
2	Shinepower Co., Ltd.	10 000
3	Sineng power Co., Ltd.	2700
4	Tbea Co., Ltd.	2000
5	Kstar Co., Ltd.	1681.74
6	Growatt Co., Ltd.	1612
7	KELONG Co., Ltd.	1420
8	GOODWE Co., Ltd.	775
9	EAST Co., Ltd.	572.8
10	GINLONG Co., Ltd.	563

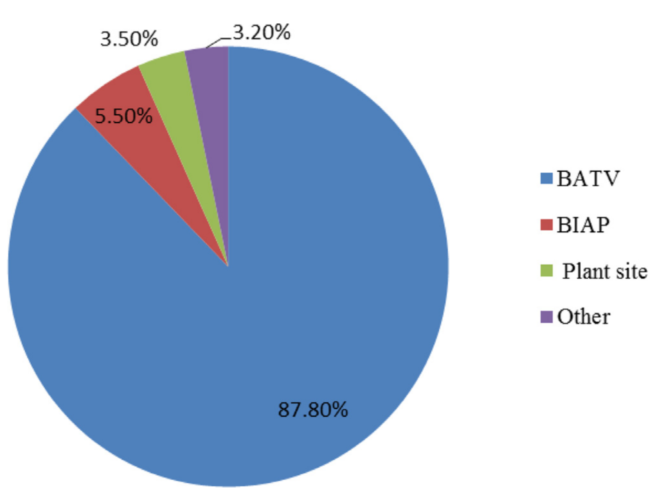

Fig. 3. The main application of DPV projects.

The contract energy management model also has risks arising from factors such as changes in the electricity demand and the willingness to use electricity. Under the economic policy environment of investment subsidies such as "Golden Sun", there are a few financings for development enterprises, the investment recovery period is short, and the risks are relatively small. In the case of economic policy conversion to electricity subsidies, the contract energy management model continues to be applied, but the above risks become greater, thus increasing the investment risk of distributed photovoltaic development enterprises.

2.2.2. Power grid enterprise charging electricity fee model

In this model, the electricity generated by the PV plant is directly connected to the local grid, and the electricity bill is settled by the power grid enterprise. Electricity customers pay electricity bills to the power grid enterprises according to the electricity price of the catalog. The specific execution process is in Fig. 5. Power grid enterprise charging electricity fee model is to coordinate the relationship between all parties, especially to give the power grid enterprise responsibility and corresponding compensation through policies. It is necessary to solve the problem of power selling qualification of distributed photovoltaic development enterprises as the main body of power supply.

2.3. Distributed photovoltaic policy

(1) Electricity price and subsidy policy
(1) Net electricity price in the division of resources

As the technological progress and cost reduction of photovoltaic industry, China reduces the net electricity prices of PV plants. after 2018, the net electricity prices of Class I, II and III resource area decrease substantially to 0.55 ¥/kW h, 0.65 ¥/kW h and 0.75 ¥/kW h, which were 0.8 ¥/kW h, 0.88 ¥/kW h and 0.98 ¥/kW h before 2018. With respect to the classes of resource area, in the light of the *Notice on Playing Price Leverage to Promote the Healthy Development of Photovoltaic Industry* in 2013, the photovoltaic resource areas of China are

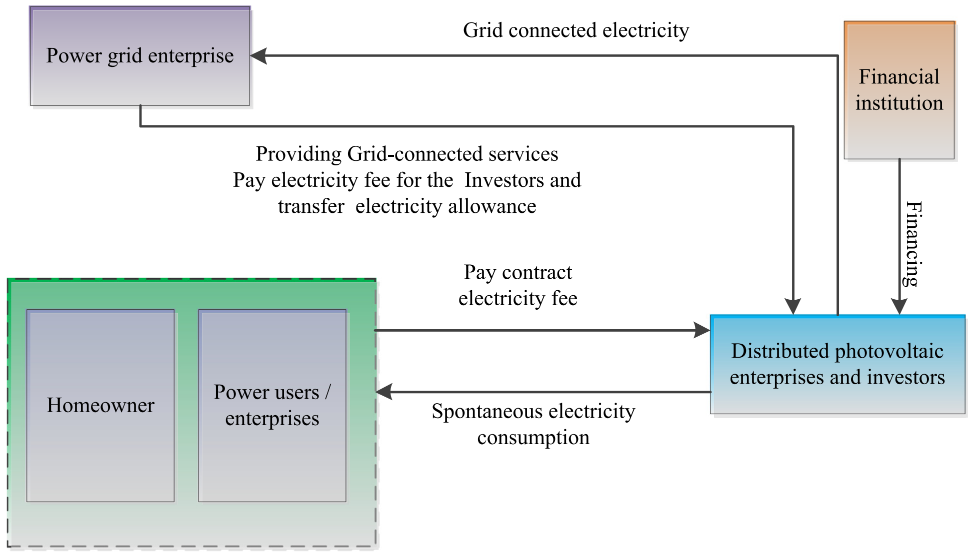

Fig. 4. Contract energy management model.

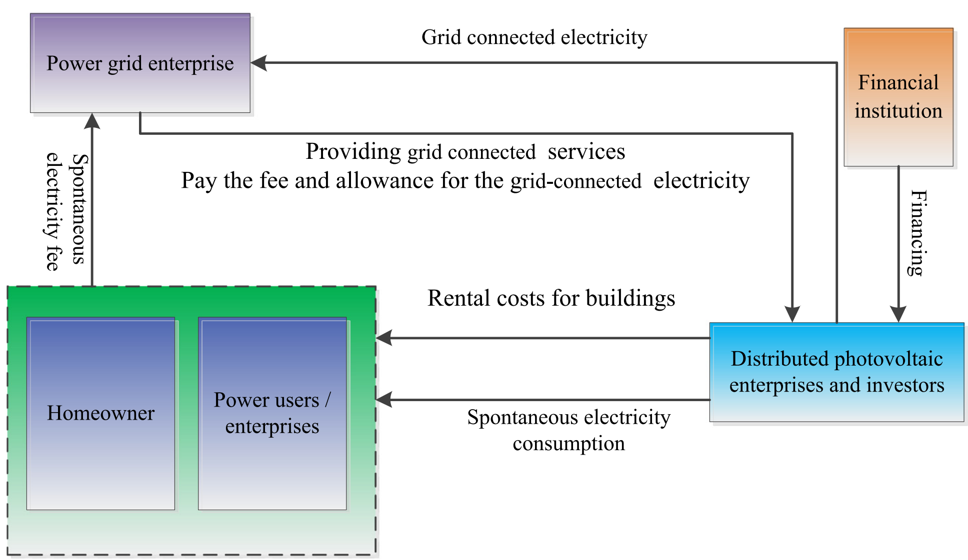

Fig. 5. Enterprise charging electricity fee model.

divided into three classes to implement different tariff policies, based on annual equivalent utilization hours. The hours of Class I exceed 1600 h, which covers Ningxia, Qinghai (western), Gansu (Jiayuguan, Wuwei, Zhangye, Jiuquan, Dunhuang, Jinchang), Xinjiang (Hami, Tacheng, Altay, Karamay), and Inner Mongolia (Hohhot, Baotou, Wuhai, Ordos, Bayannaoer, Ulanchab, Xilinguole); Between 1400 h to 1600 h is Class II, which includes Beijing, Tianjin, Heilongjiang, Jilin, Liaoning, Sichuan, Yunnan, Inner Mongolia (Chifeng, Tongliao, Xingan League, Hulunbeir), Hebei (Chengde, Zhangjiakou, Tangshan, Qinhuangdao), Shanxi (Datong, Shuozhou, Xinzhou), Shaanxi (Yulin, Yan'an), Qinghai (Xining, Haidong, Haibei, Huangnan, Hainan, Guoluo, Yushu), Gansu (Lanzhou, Tianshui, Tianshui). Silver, Pingliang, Qingyang, Dingxi, Longnan, Linxia, Gannan, and Xinjiang (Urumqi, Turpan, Kashgar, Hetian, Changji Hui, Boltala Mongolia, Iri Kazakhstan, Kizil Sukirgiz Autonomous Prefecture); the rest areas of China belong to Class III.

(2) Adjust the model of funds appropriation for PV

According to the implementation of the subsidy policy for the DPV, the PV price and the subsidy funds for the electricity price have been adjusted. The DPV enterprises can pay the electricity fee according to the allowance of the electricity price. The electricity price subsidies and bills are directly obtained from the power grid enterprises.

(3) Preferential policy of VAT for PV

In September 2013, China promulgated *the Notice on Value-Added Tax (VAT) Policy of Photovoltaic Power Generation*, clearly defining the preferential policy of 50% levy or retreat for photovoltaic power generation. (Note: VAT is a tax levied on the added value realized by units and individuals who sell or import goods or provide processing and repairing services.)

(2) Project management policy

Project management policies are the key to affect distributed photovoltaic. The relevant policies are shown in Table 3.

The document of 2013 pointed out the implementation of scale control and register management, encouraged priority to obtain the project through market competition, and simply put forward some basic requirements of DPV project management.

The biggest contribution of the 2014 document to distributed photovoltaics is that it is the first time to propose that the self-service distributed photovoltaics is not limited by the scale in the

Table 3
Distributed photovoltaic project management related policies.

No.	Policy name	Main content
1	Notice on the Issuance of Several Opinions on the Development of Distributed Generation	Implementing the general control of scale and the management mode of filing
2	Notice on the Interim Measures for the Distribution of Distributed Photovoltaic Power Projects	
3	Notice on the Scale of the Annual New Construction of Photovoltaic Power Generation in 2014	Spontaneous distributed photovoltaic is not limited by the annual plan scale,
4	Notice on Further Implementing the Related Policies of Distributed Photovoltaic Power Generation	
5	Notification of the Implementation Plan for the Construction of Photovoltaic Power Generation	
6	Guidance on Improving the Scale Management of Photovoltaic Power Generation and the Implementation of Competition Mode Configuration Project	Distributed photovoltaic projects need to be obtained by bidding
7	Notification of the Implementation Plan for the Construction of Photovoltaic Power Generation in 2016	
8	Notice on the Adjustment of the Scale of Photovoltaic Construction in 2016	
9	Notice on Further Implementing the Related Policies of Distributed Photovoltaic Power Generation	The scale PV needs the provincial power grid enterprises to build the power transmission project

annual plan. Another important point is that the surplus power for grid connection from self-service ones can be determined based on the change of load or fully be on-grid, which is a great breakthrough.

In 2016, distributed photovoltaics is managed according to two modes: unlimited and ordinary. The "unlimited" mode has four types, say building photovoltaics, local utilization, PV trading pilot, and photovoltaic poverty alleviation. Ordinary photovoltaics encourage competitive configuration of projects.

The document of 2017 emphasizes that the determination of the annual scale of centralized and distributed generation in the 13th Five-Year Plan should be based on the commitment of provincial power grid enterprises to invest in the construction of power transmission projects and the power consumption capacity.

(3) Grid-connected service policy

Compared with large PV plants, the distributed photovoltaic system has small scale, small amount of investment, and obstacles in the construction, operation and management of the project. Under the goal of scale development, the China government needs to design a special financing policy aimed at the characteristics of DPV (see Table 4).

In the light of the national policies, State Grid Corporation of China (SGCC) also issued a lot of notices to regulate grid-connection management after continuous improvements. In the standards and service opinions of grid-connected management of SGCC, there are two main types of practical power supply sources, one is 10 kV 6 mW, the other is 35 kV and below access voltage level, which corresponds to the "35 kV and below scale not exceeding 20,000 kW and mainly for self-use" stipulated by the State Energy Administration, and serves as the management of distributed power supply. In terms of service, according to the requirements of the state, there is a time-limit commitment for the grid-connected process. The natural persons will be filed by the power grid enterprises for the settlement of subsidized funds.

Table 4
Distributed photovoltaic grid-connected service policies.

No.	Policy name	Main content
1	Temporary Method of Distributed Generation Management	To complete the management of distributed energy
2	Notice on the Issuance of Several Opinions on the Development of Distributed Generation	The contract energy management model is introduced to the distributed generation project
3	Notice on the Interim Measures for the Distributed Photovoltaic Power Projects	Management programmatic documents of DPV projects
4	Notice on the Interim Measures for Photovoltaic Power Operation and Supervision	Supervision of grid connection, operation and transaction of PV projects
5	Notice on Further Implementing the Related Policies of Distributed Photovoltaic Power Generation	To solve the key constraints of DPV and further improve DPV policies
6	Opinions on Grid Connected Service for Distributed Photovoltaic Power Generation	Power grid enterprises acquire distributed photovoltaic surplus power
7	National Power Grid Corp Distributed Power Grid-Connected Service Management Rules	Providing high quality services to distributed power owners

In addition to the electricity price and the grid-connected policy, the financing policy is an important factor affecting the development of the DPV. China government issued "*Financial Services to Support Distributed Photovoltaic Opinions*", proposed that the National Development Bank will cooperate with the new energy demonstration city, green energy County and distributed photovoltaic demonstration area to carry out financial services innovation pilot. Setting up the investment and financing mechanism and repaying the loan financing platform.

3. Obstacles and issues of distributed photovoltaic development

3.1. The obstacles and issues of short-term development

What restricts the development of distributed photovoltaic are technical issues, management and policy immaturity, and imperfect business operation. It mainly includes the following 3 aspects.

(1) User subsidy issue

China implemented PV projects with the record plan management mode. Local provincial governments need to set up corresponding records management methods and start the filing procedures, so that photovoltaic projects can get the corresponding policy support. However, due to many local record plan management policies are not perfect, the DPV project is difficult to obtain electricity price subsidy.

(2) Standard issue

The establishment of standard formulation, inspection, certification and supervision is systematic. With the development of the DPV market, the standard needs to be adjusted. There are more than 20 photovoltaic standards in China, but there are still some deficiencies in implementing standards and norms for supporting distributed photovoltaic.

(3) Financing issue

Financing is a tough issue in the development of distributed photovoltaic in China. However, the issues of photovoltaic project registration policies, such as lack of implementation of grid connection program, immature business model and imperfect standard specification, increase the economic risk of distributed photovoltaic project.

3.2. The obstacles and issues of mid-term development

There are some issues in China's photovoltaic projects, such as the difficulty in grid-connection, the subsidies and the opaque approval process. The imperfect business model and investment financing system lead to the instability of the expected project income.

(1) The risk of business model with contract energy management

The business model of China's DPV projects is contract energy management. In this model, photovoltaic system developers supply electricity to the owners and grid. However, because China has not yet established an effective integrity system, the contract energy service companies face a risk of default on the residents who do not pay electricity.

(2) The risk of stable electricity demand of residents

In China current subsidy model, the residents must have larger power consumption ratio, distributed photovoltaic project revenue includes two parts: the reduction of PV purchase from the power grid electricity costs and the subsidy. If the electricity consumption demand of the residents is reduced, it will reduce the project profits; if the businesses with residents fail, the electricity generated by the distributed photovoltaic projects will be connected to the grid, and the profits of the projects will be lower than expected.

(3) Existing mechanisms limit the benefits of distributed projects

In China, the operating cycle of distributed photovoltaic project is 20 years. For the license of distributed photovoltaic project, if the users cannot consume the electricity generated by the distributed photovoltaic projects, also unable to supply the adjacent power users, the benefits of the project will be affected. However, China has not yet established a distributed photovoltaic project information database for photovoltaic products, developers and operators.

3.3. The obstacles and issues of long-term development

(1) Influence of high permeability grid connected to power grid operation

With the increase of photovoltaic generation system capacity and permeability, it will affect the operation, safety and reliability of distribution grid.

(2) The cost of long-term investment may rise

The relationship between the distributed photovoltaic and other power generation technologies is uncertain. Photovoltaic investment cost is decreasing year by year. In addition to technological progress, the most important reason is the oversupply of market, and the price does not reflect the cost completely as well. Because the margin profit of photovoltaic manufacturing industry is compressed, the price of photovoltaic cells and components will be reduced in the future, and the cost of long-term investment is high.

(3) The coordination platform needs to be innovated

DPV plants mostly rest on the corresponding facilities, distribute dispersedly, and are difficult to centralize management and control; workers cannot centralize operation and maintenance, and the volume of individual is small, both of which increases the cost of operation and maintenance accordingly. Thus, a coordinated management platform coordinating the plants, users, grids and storage, with distributed monitoring, power prediction and control, fault diagnosis, production operation management, environmental monitoring and information interaction included, is needed. The platform needs to be designed for real-time monitoring, intelligently analyzing the operation data and sharing information among the plants, grids and users, thus realizing stable operation, real-time information sharing, and timely breakdown handling.

Table 5
Benchmarking electricity price of China desulfurization coal in 2017.

Region	Province	Benchmarking electricity price (¥/kWh)
North China power grid	Beijing	0.3598
	Tianjin	0.3655
	Northern Hebei	0.3720
	Southern Hebei	0.3644
	Shandong	0.3949
	Shanxi	0.3320
	Western Inner Mongolia	0.2829
East China power grid	Shanghai	0.4155
	Zhejiang	0.4153
	Jiangsu	0.3910
	Anhui	0.3844
	Fujian	0.3932
Central China power grid	Hubei	0.4161
	Hunan	0.4500
	Henan	0.3779
	Jiangxi	0.4143
	Sichuan	0.4012
	Chongqing	0.3964
Northwest power grid	Shanxi	0.3545
	Gansu	0.3078
	Qinghai	0.3247
	Ningxia	0.2595
	Xinjiang	0.2500
	Tibet	0.4993
Northeast power grid	Liaoning	0.3749
	Jilin	0.3731
	Heilongjiang	0.3740
	Eastern Inner Mongolia	0.3035
Southern power grid	Guangdong	0.4530
	Guangxi	0.4207
	Yunnan	0.3358
	Guizhou	0.3515
	Hainan	0.4298

4. Analysis of China's distributed photovoltaic grid-connected electricity price route

According to the China power development plan, by 2020, solar power installed capacity will reach more than 110 GW, the DPV installed capacity will reach 60 GW, and 100 distributed photovoltaic demonstration zones are built.

4.1. Trend of desulfurization coal benchmarking electricity price

At present, the lowest benchmarking electricity price of China's desulfurization coal is 0.25 ¥/kWh (Xinjiang), the highest is 0.4993 ¥/kWh (Tibet), with an average of 0.3739 ¥/kWh. Table 5 introduces the benchmarking electricity price of desulfurization coal of China in 2017.

Table 6
Benchmarking electricity prices of coal under the influences of environmental taxes (¥/kWh).

Region	Province	No consideration of carbon tax		Low carbon tax	High carbon tax
		Desulfurization benchmarking electricity price	Desulfurization, denitrification and dedust benchmarking electricity price	Desulfurization, denitrification and dedust carbon tax benchmarking price	Desulfurization, denitrification and dedust carbon tax benchmarking price
		2017	2020	2020	2020
North China power grid	Beijing	0.3598	0.372	0.432	0.472
	Tianjin	0.3655	0.378	0.438	0.478
	Northern Hebei	0.372	0.384	0.444	0.484
	Southern Hebei	0.3644	0.376	0.436	0.476
	Shandong	0.3949	0.407	0.467	0.507
	Shanxi	0.332	0.344	0.404	0.444
	Western Inner Mongolia	0.2829	0.295	0.355	0.395
East China power grid	Shanghai	0.4155	0.428	0.488	0.528
	Zhejiang	0.4153	0.427	0.487	0.527
	Jiangsu	0.391	0.403	0.463	0.503
	Anhui	0.3844	0.396	0.456	0.496
	Fujian	0.3932	0.405	0.465	0.505
Central China power grid	Hubei	0.4161	0.428	0.488	0.528
	Hunan	0.45	0.462	0.522	0.562
	Henan	0.3779	0.390	0.450	0.490
	Jiangxi	0.4143	0.426	0.486	0.526
	Sichuan	0.4012	0.413	0.473	0.513
	Chongqing	0.3964	0.408	0.468	0.508
Northwest power grid	Shanxi	0.3545	0.367	0.427	0.467
	Gansu	0.3078	0.320	0.380	0.420
	Qinghai	0.3247	0.337	0.397	0.437
	Ningxia	0.2595	0.272	0.332	0.372
	Xinjiang	0.25	0.262	0.322	0.362
	Tibet	0.4993	0.511	0.571	0.611
Northeast power grid	Liaoning	0.3749	0.387	0.447	0.487
	Jilin	0.3731	0.385	0.445	0.485
	Heilongjiang	0.374	0.386	0.446	0.486
	Eastern Inner Mongolia	0.3035	0.316	0.376	0.416
Southern power grid	Guangdong	0.453	0.465	0.525	0.565
	Guangxi	0.4207	0.433	0.493	0.533
	Yunnan	0.3358	0.348	0.408	0.448
	Guizhou	0.3515	0.364	0.424	0.464
	Hainan	0.4298	0.442	0.502	0.542

Note: changes in the cost of coal electricity is not taken into account.

4.2. Influences of energy environmental taxes on the coal benchmarking electricity price

The power industry is the leading source of atmospheric pollutants in China. Sulfur dioxide, industrial dust, nitrogen oxides and carbon dioxide emissions rank first in all kinds of industries in the country. Since the implementation of *the Environmental Protection Tax Law of the People's Republic of China* on January 1, 2018, the environmental tax has been officially levied. it enables power producers to actively participate in energy conservation and emission reduction actions, realizes the green production and consumption of electricity, and opens up a fixed and broad channel for the government to accumulate environmental protection funds from the power industry. Before the levy of environmental tax, China had a good environmental policy basis. At the Second Conference on Environmental Protection held in 1983, environmental protection was defined as a basic national policy. China has already promulgated more than 100 national laws and administrative regulations, more than 600 local laws and regulations, and initially established the environmental resources protection law system in China. China's Agenda 21, adopted in 1994, put forward the overall strategy of sustainable development, which has become the guiding document of the medium-term plan for China's national economic and social development. Especially the *Tenth Five-Year Plan of National Environmental Protection* approved by the State Council in December 2001 clearly points out that we should actively and steadily promote the reform of fees and taxes in environmental protection; study the macro-control functions of levying environmental taxes on products that pollute the environment in the process of production and use; improve preferential policies conducive to waste recycling and utilization. Clearly, there is a good policy and legal basis for levying environmental tax in China. Coal resource tax, environmental pollution tax and carbon tax are the main influential tax in the power industry, so these three taxes are discussed here.

(1) The influence of coal resources tax. The rate of coal tax is 5%, and coal resource tax has little influence on the rise of coal production cost, the effect on the electricity price of coal is not considered.

(2) The influence of environmental pollution tax. A clear tax standard on sulfur dioxide, nitrogen oxides and dust are proposed in the tax law on environmental pollution. The power generation enterprises of meeting the requirements can obtain the subsidies for the desulfurization, denitration and dedust. By 2020, the benchmarking electricity price of the denitration and dedust will fully increase by 0.012 ¥/kWh.

(3) The influence of carbon tax. Carbon tax rates reflect the marginal cost of carbon dioxide emission reduction. At present, the price of China's carbon trading market is 40–80 ¥/ton (see Table 6).

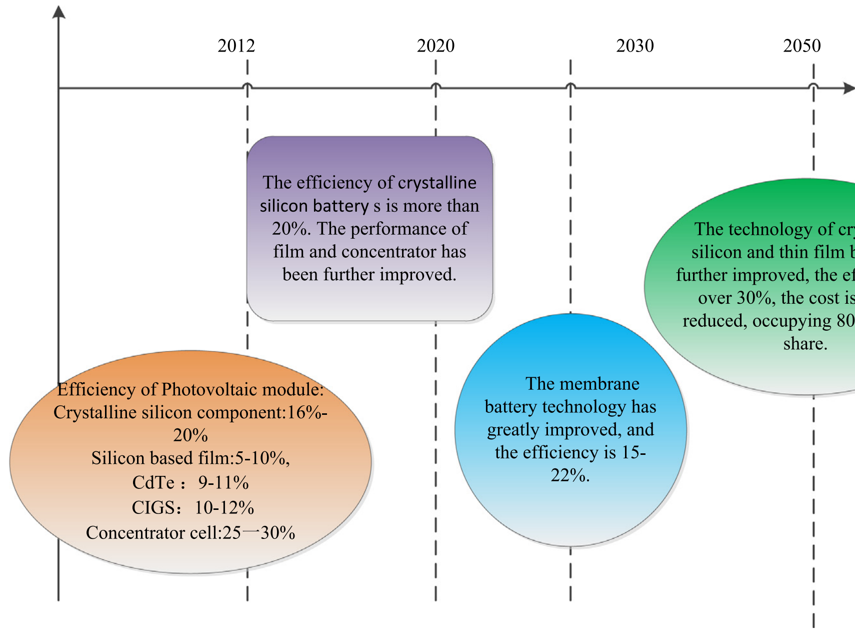

Fig. 6. Development trend of photovoltaic cell technology.

4.3. Influence of technological innovation on power generation cost of distributed photovoltaics

Technological innovation is the main driving force of the DPV cost decline. In 2020, crystalline silicon batteries will still be the leading role for China's photovoltaic, and the commercialized battery efficiency will exceed 20%. In 2030, the film battery technology will make a breakthrough. The efficiency and stability will be greatly improved, and the efficiency will be close to more than 20% of the crystal silicon battery. The trend of technology development is shown in Fig. 6.

With the progress of technology, the cost of DPV will be further reduced. In 2020, the China poly-silicon material cost will drop to 16–18 $/kg, and the battery efficiency up to 23%, the cost of the photovoltaic modules will drop to 1.52–2 ¥/W, the DPV system cost will drop to 7000 ¥/kW. By 2030, the cost of China's poly-silicon material will drop to 12–18 $/kg, and the cost of distributed photovoltaic system will be reduced to 6000 ¥ /kW.

4.4. Analysis of the distributed photovoltaic electricity price trend

After the drop of distributed photovoltaic cost, the electricity price trend of this kind of power generation is becoming the concern of the industry. The hypothetical parameters of analyzing the distributed photovoltaic price route are as follows:

(1) In 2018, the electricity price of the average desulfurization coal in China was 0.3739 ¥/kWh, and the annual rate of growth before 2020 is 1.1%, and after 2020 will be 3.5%.

(2) In 2018, the distributed photovoltaic subsidy price in China was 0.37 ¥/kWh. The distributed photovoltaic grid-connected electricity price = subsidy price + desulfurization coal benchmarking electricity price.

(3) After 2018, the reduction of the distributed photovoltaic price is 5%/year.

(4) In 2018, the average electricity price of industrial and commercial, large industry and resident users are 0.79, 0.61 and 0.53 ¥/kWh. The average annual electricity price increases by 2% before 2020, and increases by 3.5% annually after 2020.

(5) Based on the above conditions, China's photovoltaic side parity development route is shown in Table 7. In 2027, the DPV price will be equal to the desulfurization coal.

For the sale side, the change trend of the DPV price is as Table 8.

For China's industrial and commercial industries, large industries and residential electricity prices, distributed photovoltaic generation will reach parity on sale side in 2020, 2024 and 2025. By 2027, PV will have the competition with conventional fossil fuels and no longer need state financial subsidies.

On the basis of the analysis of the influence of the above energy environment tax on the electricity price of the coal benchmarks, the route of the DPV price is shown in Table 9.

As can be seen from Table 9, considering the influence of environmental tax, by 2027, distributed photovoltaic generation can achieve parity in the power generation side. If carbon tax is implemented, by 2020, the benchmarking electricity price of coal will rise by 0.055 ¥/kW h, the route of the DPV side is shown in Table 10.

From Table 10, it can be seen that considering the impact of carbon tax, China's DPV can reach parity on the generation side by 2025, and compete with coal power generation. DPV marketing route is divided into 3 parts as Fig. 7:

China's distributed photovoltaic system has established a preliminary policy system in terms of law, electricity price, grid connection standard, project management, financial and so on, which has defects in policy market environment though. In the future, China should create innovate business models, financial models and competitive electricity market through reform.

5. Conclusions

Based on the research of distributed photovoltaic policy system, distributed photovoltaics will achieve parity on the power sale side around 2020, and achieve parity on the generation side around in 2025. China offers preferential treatment in terms of grid connection, site utilization, project management, tariff subsidy, etc. And relevant measures and systems are issued by the state, so as to ensure the economic benefits of distributed photovoltaic developers.

(1) We studied the development of fossil energy by internalization of external cost of fiscal and economic policies, such as fossil energy tax, carbon tax and carbon trading system. By 2020,

Table 7
The DPV price route (¥/kWh)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Coal Benchmarking electricity price	0.37	0.37	0.38	0.39	0.41	0.42	0.43	0.45	0.46	0.48
Generation electricity price	0.74	0.7	0.67	0.63	0.6	0.57	0.54	0.52	0.49	0.47

Table 8
The DPV change trend (¥/kWh)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Industrial and commercial electricity price	0.79	0.81	0.82	0.85	0.88	0.91	0.94	0.98	1.01	1.05
Industrial electricity price	0.61	0.62	0.63	0.66	0.68	0.70	0.73	0.75	0.78	0.81
Electricity price for residents	0.53	0.54	0.55	0.57	0.59	0.61	0.63	0.65	0.68	0.70
DPV price	0.89	0.85	0.81	0.77	0.73	0.69	0.66	0.62	0.59	0.56

Table 9
The route of the DPV price under environmental pollution tax (¥/kWh)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Electricity price of coal benchmarks under environmental pollution tax	0.37	0.38	0.39	0.41	0.42	0.44	0.45	0.47	0.48	0.50
DPV price	0.74	0.71	0.67	0.64	0.61	0.57	0.55	0.52	0.49	0.47

Table 10
The route of the DPV price under carbon tax (¥/kWh)

	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027
Electricity price of coal benchmarks under carbon tax	0.37	0.38	0.44	0.45	0.47	0.48	0.50	0.52	0.54	0.55
DPV price	0.74	0.71	0.67	0.64	0.61	0.57	0.55	0.52	0.49	0.47

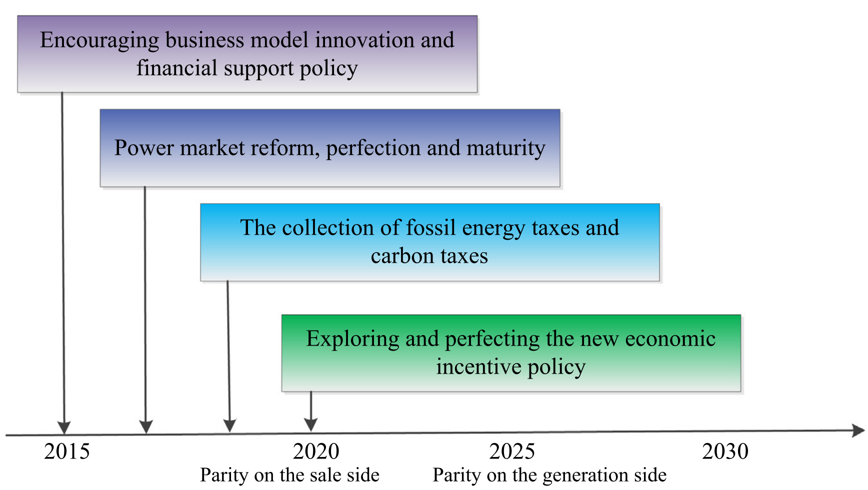

Fig. 7. A schematic map of China's distributed photovoltaic policy for 2015–2030.

the appropriate policy measures in appropriate fields to internalize the external costs of fossil energy should be selected, the competitiveness of renewable energy should be increased in the electricity market, and a fair competition environment should be provided. After 2020, the policy level of internalization of external cost of fossil energy should be making progresses gradually, the behavior of the cost of environmental pollution should be further improved, and adequate investment attraction for distributed photovoltaic development and utilization for ordinary residents should be provided.

(2) Before 2020, the current electricity price subsidy system can be maintained so as to promote and mature the distributed photovoltaic market. From 2020 to 2030, the elimination of subsidies will be carried out gradually, "net metering" can be developed to adapt the characteristic of China electricity market with the maintenance of renewable power in the electricity market incentive mechanism.

(3) In the field of renewable energy, especially distributed photovoltaics, China should carry out the pilot reform of electricity market, and start the revision of the current electricity law as soon as possible. A competitive market should be gradually established to enable distributed photovoltaic projects to commercialize.

(4) By 2025, the innovative business model and financial support model are all important measures to support the development of distributed photovoltaics. China should encourage the economic developed areas to set up the distributed photovoltaic system and assets securitization. Information disclosure system should be established with the components, product quality and so on included. The project risk assessment mechanism and risk sharing mechanism should also be established, so as to create conditions for the distributed photovoltaic project financing mechanism.

China has not yet established a policy mechanism to correct the externalities of fossil energy utilization, resulting in a lack of fair market environment for renewable energy. In the long run, we should rationalize the relationship between renewable energy power and fossil energy, and improve the competitiveness of clean energy markets such as distributed photovoltaic. Safeguard the resource tax reform policy and implement the resource tax rate gradually, introduce the environmental protection tax system as soon as possible, coordinate the implementation of the carbon tax and carbon trading policies, increase the cost of fossil energy development and utilization, form a reasonable price reflecting the external cost, and reduce the burning of coal. The price gap between power generation and distributed energy generation, such as distributed photovoltaic, reduces government subsidies and creates a fair market competition environment for non-fossil energy generation such as DPV.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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