Prospective Estimation of the Scales and Subsidies of China's Offshore Wind Power Before 2020

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Abstract. In order to estimate the scales and subsidies of China's offshore wind power before 2020, the annual generation of China's total planned offshore wind power projects was analyzed and calculated based on existing engineering data as well as offshore wind resource data, performance parameters of wind turbines and reduction factors; generation costs based on internal rates of return of 6%, 8% and 10% of China's planned offshore wind projects were calculated by constructing capital expenditure models and using financial evaluation methods. Through the calculation of planned projects' annual power generation and generation costs, the supply curve of China's offshore wind power is constructed to calculate the development potentials and subsidies under current policy.

On the basis of further study on possible policy changes, project investment decision-making, grid integration, the feasibility of subsidies payments and other relevant factors, development scales and subsidies of China's offshore wind power before 2020 were analyzed.

It was estimated that the installed capacity of China's offshore wind power before 2020 is between 12.56 GW and 24.67 GW, the annual power generation is between 30.29 TWh and 56.03 TWh, subsidies are between 12.44 and 22.80 billion CNY, additional tariffs are between 1.88×10^{-3} and 3.45×10^{-3} CNY/kWh.

1. Introduction

The Chinese government attaches great importance to the development of renewable energy sources, including wind power. Offshore wind power is an important type of wind power. To promote the healthy and rapid development of China's offshore wind power, the Chinese government has introduced a number of policies [1~8], the policy system of offshore wind power has been preliminarily constructed. Among these policies, the basic law titled "Renewable Energy Law of People's Republic of China" came into effect in 2006 and was revised at the end of 2009. This law governs the rights and responsibilities of the main participation bodies involved in renewable energy and clarifies the basic ideas and methods applicable to the promotion of renewable energy. Other important policy documents included "the tentative measures for renewable energy tariff and cost-sharing management" and "the tentative measures for the allocation of the additional revenue for renewable energy tariffs", etc. These documents determine the characteristic of China's renewable energy policy: feed-in tariff (FIT) is taken as main policy, supplemented by concession bidding policy.

China's National Energy Administration has requested governments of coastal provinces to prepare the planning reports for offshore wind power construction [9]. These planning reports involve in more than 150 projects and were completed during the period from 2010 to 2013. In 2016, the Chinese central government issued the "13th Five-Year Plan for Wind Power Development", noting that the installed capacity of offshore wind power should reach 5 GW by 2020 [10]. However, the development of China's offshore wind power was not smooth. In 2016, the installed capacity of offshore wind power was only 1.63 GW [11], which is far from the planning target.

Under the background of the first round of offshore wind power concession bidding's stagnation, in June 2014, the Chinese government implemented a feed-in tariff (FIT) policy under which the on-grid electricity tariff for shallow-water offshore wind power is 0.85 CNY/kWh (tax included) and the on-grid electricity tariff for intertidal offshore wind power is 0.75 CNY/kWh (tax included). At the same time, the implementation of concession bidding policy is still encouraged [12]. The policy is valid until 2017. Currently, there are concerns regarding whether the current policy can effectively encourage a healthy and rapid development of China's offshore wind power. Concerns also exist regarding the future development scales and subsidies of China's offshore wind power.

Economics theory is often used to analyze industry development in the future. Through the analysis of supply and demand curve of the future markets, the future development scale can be estimated. For the development scale prediction of China's offshore wind power, the demand curve is a horizontal line because of constant on-grid electricity tariff under the FIT policy, therefore, the construction of the supply curve is the key of the development scale prediction.

In order to construct supply curve to reflect the status of market supply, wind power generation and generation costs should be calculated first. To derive the annual power generation, many researchers such as Zhang Da et al. used the Weibull distribution model and average wind velocity data provided by a meteorological department to simulate regional wind resources [15]. By combining regional wind resources with selected wind turbines' technical parameters and various power generation reduction, the power generation of wind farms can be calculated. Some researchers simulated wind resources by using computational fluid dynamics. For instance, Atsushi Yamaguchi et al. used GIS and the mesoscale model to simulate offshore wind climate along the coast of the Kanto area [22]. Generation cost is closely related to the capital expenditure (CAPEX) of a project, which is generally calculated by engineers for a specific project. In order to find the formula of generation cost applicable to all projects, M. Dicorato et al. and Mark J. Kaiser et al. considered that capital expenditure(CAPEX) was composed of several sub-items, and each sub-item was fitted from existing engineering data. [23, 24] At present, some financial software such as RETScreen has been developed to conveniently calculate annual power generation and generation costs [15, 25].

Based on calculation of the power generation and generation costs, the supply curve of wind power had been constructed by predecessors. David Kline et al. summarized methods for constructing the supply curve using GIS [13]. Combined with generation cost analysis, China's Energy Research Institute of the National Development and Reform Commission used the wind speed and terrain data provided by GIS to construct wind power supply curves for Chinese provinces and predict the development scale of China's wind power in 2050 [14]. Zhang Da et al. calculated the annual power generation and the generation costs of wind power projects in the Fujian province based on GIS and the IRPP model, constructed a supply curve with 0%, 10% and 20% cost reduction, and analyzed the development potential of wind power with different on-grid electricity tariffs [15]. Scholars at Tsinghua University in China collaborated with scholars at MIT to construct the supply curves of onshore wind power and offshore wind power in China at both national and provincial levels by using GIS [16]. Lixuan Hong et al. predicted the development scale of offshore wind power in Denmark and China [17, 18] using a similar method and also considered factors such as routes, seabird flyways, underwater cables and tropical cyclones [19~21].

Development scale analysis involves a choice of China's offshore wind power policy after 2017. The characteristics of renewable energy policy tools such as the feed-in tariff(FIT) were introduced and compared in many studies[26~28]. These studies were mainly based on simple qualitative comparisons. Shrimali G et al. quantitatively analyzed the effect of incentive policies on promoting the development of renewable energy's installed capacities and power generation [29]; however, subsidies and a comparison of the policies were not considered.

In this paper, the supply curve of China's offshore wind power during the relatively short period from 2015 to 2020 was constructed by analyzing and calculating annual power generation and the generation costs of all planned offshore wind power projects, including intertidal and shallow-water offshore wind power projects. Based on the supply curve, the development potential of China's offshore wind power under the current policy was analyzed. Combined with disscusion of possible

policy changes, project investment decision-making, grid integration, the feasibility of subsidies payment and other relevant factors, the development scales and subsidies of China's offshore wind power were analyzed.

2. Methodology

In this paper, existing engineering data, including data of annual power generation and generation costs of China's planned offshore wind projects were used as much as possible [14~21] The planned projects without existing data of annual power generation and generation cost were analyzed and calculated using the constructed model. Based on annual power generation and generation cost data of all China's planned offshore wind power projects, a supply curve of China's offshore wind power was constructed to calculate the development potential and subsidy of China's offshore wind power before 2020. On the basis of further study on the other influence factors of offshore wind power, the development scales and subsidies of China's offshore wind power were presented.

2.1 Analysis and calculation of planned offshore wind projects's annual power generation

The wind speed data and technical parameters of a wind turbine are the key factors for calculating annual power generation. In this paper, the wind data were collected from online databases [38] and the website for China's meteorological departments [39]. The technical parameters of the most used 3 MW and 3.6 MW offshore wind turbines and the 5 MW offshore wind turbine which will be placed in commercial use in China in the near future were used. The annual power generation data were calculated using the Weibull distribution model and were verified with relevant researchers' results [40].

While calculating the actual power generation of the wind turbine, the following factors were considered:
    (1) Air density deviation from the standard value;
    (2) Wind power output decrease due to the control process and turbulent flow;
    (3) Utilization ratio of wind turbine influenced by malfunctions and maintenance;
    (4) Actual power curve of the wind turbine that deviated from the design power curve;
    (5) The decrease in aerodynamic efficiency due to salt fog corrosion;
    (6) The effects of an ambient temperature that is too high or too low on the unit lubrication system and blade aerodynamic performance;
    (7) Energy loss caused by auxiliary power of wind farm and line loss;
    (8) The influence of surrounding wind farms' operations.

Based on these factors, the actual power generation is reduced by 20% to 30% compared with theoretical value.

2.2 Analysis and calculation of planned offshore wind projects' generation cost

To improve the calculation accuracy of planned projects' CAPEX, the financial data of feasibility study reports [30~35] and planning reports [36, 37] were used as much as possible. The CAPEXs of projects which have no available data in the reports were calculated by the models developed in the relevant literature [23, 24], and the coefficients of the models were fitted using the fundamental engineering data from the feasibility study reports [30~35], planning reports [36, 37] and network database [38] of China's offshore wind power.

The generation cost calculation followed China's tax policies [41~43] and standard financial rules [44] and consulted the feasibility study reports of typical offshore wind power projects [30~35].

Policy system of China provides subsidies and tax incentives for offshore wind power projects. For instance, 50% exemption and fixed assets' input tax deduction of the value added tax (VAT) [41, 42], 100% exemption of enterprise income tax in the first three profit-making years and 50% exemption in the next three years [43]. These incentive policies were considered in the calculation of the generation costs of offshore wind power projects in this paper.

The internal rates of return (IRRs) were also considered when the generation costs were calculated. Consulting the benchmark yield of China's wind power industry [44], the IRRs of offshore wind power projects were determined to be 8%. To account for extreme cases, the generation costs based on IRRs of 6% and 10% were also calculated.

2.3 Supply curve construction, development potential analysis and subsidy calculation of China's offshore wind power

The supply curves can be constructed based on the annual power generation and the generation costs data of offshore wind power projects. For instance, the construction process of the supply curve involving five offshore wind power projects is shown in Fig. 1. A rectangle represents an offshore wind power project, as shown in Fig. 1 (a). Then, as shown in Fig. 1 (b), all five projects are sorted by generation costs and are placed in a coordinate system. Finally, the step curve formed by the tops of the rectangles is the supply curve, as shown in Fig. 1 (c).
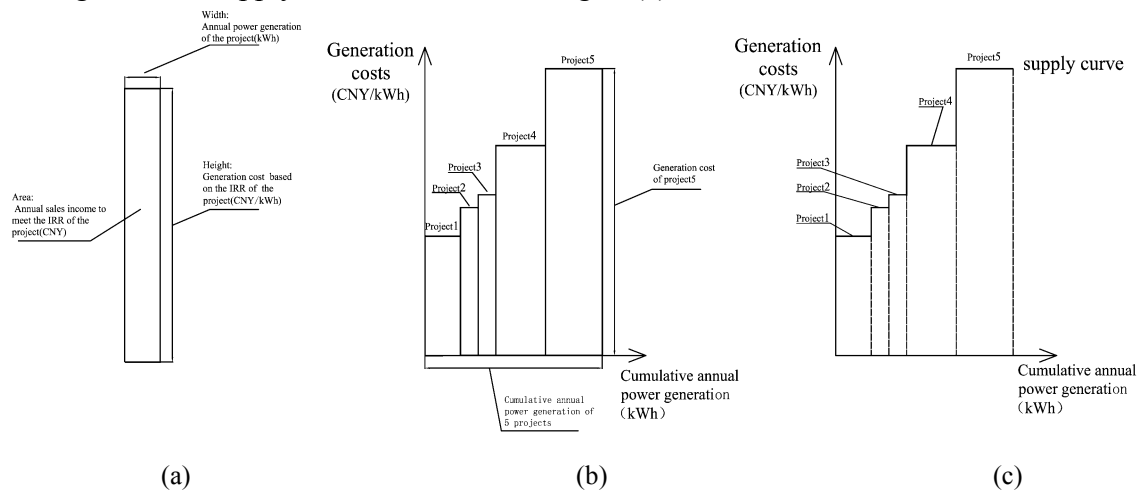

Fig. 1. The construction process of the supply curve of five offshore wind power projects

Based on the supply curve, the development potential and the required subsidy of offshore wind power can be analyzed. As shown in Fig. 2, assuming that the on-grid electricity tariff is uniform and higher than the generation costs of projects 1~4, these projects have the potential to be developed. Through investigating relative engineering data, the installed capacities and provinces of these potential projects are known.
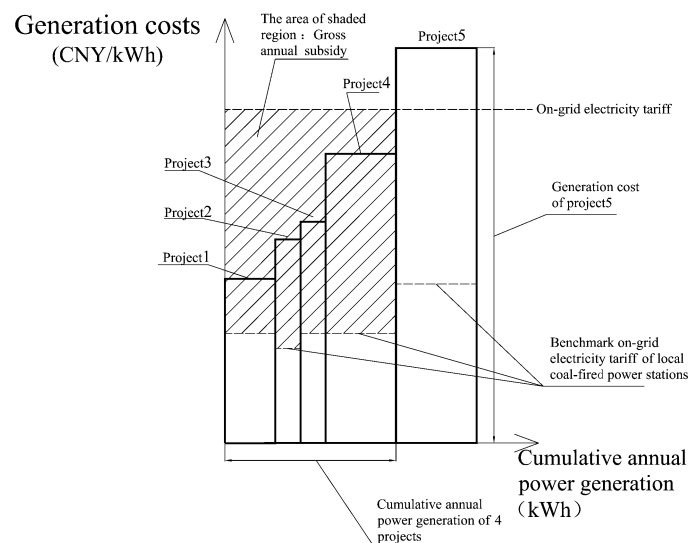

Fig. 2 The analysis and calculation method of the potential development scales and subsidies of offshore wind power

The generation costs of offshore wind power projects and other renewable energy power projects are always higher than the benchmark on-grid electricity tariff of local coal-fired power stations in China. Extra expenditures caused by a higher on-grid electricity tariff are compensated by the subsidy which is paid by power consumers through additional tariff [2]. The calculation method for the additional tariff is given in a document published by the Chinese government [2]:

$$T_{add} = S_{ann} / G_{pre}$$

$$G_{pre} = G_{total} - G_{agr} - G_{tibet}$$

where T_{add} is the additional tariff, S_{ann} is the annual subsidy for offshore wind power, G_{pre} is the annual electricity sales at a premium price, G_{total} is the total annual electricity sales, G_{agr} is the annual electricity consumption of agricultural production, and G_{tibet} is the annual electricity consumption in the Tibet area of China.

3. CAPEX, Supply Curve and Development Potential of China's Offshore Wind Power

3.1 CAPEX calculation of planned offshore wind projects

Consult previous studies [23, 24], the CAPEX is composed of equipment cost, installation cost, construction cost and other related cost as follows:

$$C_{Total} = C_{Eqs} + C_{Ins} + C_{Con} + C_{Otr}$$

Sub item C_{Eqs} (CNY/kW) is the equipment cost, including the equipment costs of the wind turbine, electricity collection and transmission, etc.

$$C_{Eqs} = C_{WT,Eqs} + C_{ArCab,Eqs} + C_{ExCab,Eqs} + C_{Otr,Eqs}$$

The calculation of sub item C_{Eqs} is shown in Table 1.

Table 1　Calculation of the equipment cost C_{Eqs}

SN.		Variables	Fitting formula
1	$C_{WT,Eqs}$	Wind turbine cost	$C_{WT,Eqs} = 8000$
2	$C_{ArCab,Eqs}$	Collection cable cost	$C_{ArCab,Eqs} = 1.5\,P_{WT}$, P_{WT} (MW) is the installed capacity of one single offshore wind project.
3	$C_{ExCab,Eqs}$	Transmission cable cost	with offshore substation：$C_{ExCab,Eqs} = 21\,D_i + 1335$ without offshore substation：$C_{ExCab,Eqs} = 10\,D_i$ D_i (km）is the distance to shore.
4	$C_{Otr,Eqs}$	Other equipment Cost	$C_{Otr,Eqs} = 0.015\,(C_{WT,Eqs} + C_{ArCab,Eqs} + C_{ExCab,Eqs})$

Sub item C_{Ins} (CNY/kW) is the installation cost, including the installation costs of the wind turbine, electricity collection and transmission, etc.

$$C_{Ins} = C_{WT,Ins} + C_{ArCab,Ins} + C_{ExCab,Ins} + C_{Otr,Ins}$$

The calculation of sub item C_{Ins} is shown in Table 2.

Table 2　Calculation of the installation cost C_{Ins}

SN.	Variables		Fitting formula
1	$C_{WT,Ins}$	Wind turbine installation cost	$C_{WT,Ins} = (0.006D_i + 0.098)C_{WT,Eqs}$ D_i (km) is the distance to shore. $C_{WT,Eqs}$ is the wind turbine cost
2	$C_{ArCab,Ins}$	Collection cable installation cost	$C_{ArCab,Ins} = 0.42\ C_{ArCab,Eqs}$ $C_{ArCab,Eqs}$ is collection cable cost
3	$C_{ExCab,Ins}$	Transmission cable installation cost	$C_{ExCab,Ins} = 0.15\ C_{ExCab,Eqs}$ $C_{ExCab,Eqs}$ is transmission cable cost
4	$C_{Otr,Ins}$	Other equipment installation cost	$C_{Otr,Ins} = 0.26\ C_{Otr,Eqs}$ $C_{Otr,Eqs}$ is other equipment cost

Sub item C_{Con} (CNY/kW) is the construction cost, including the construction costs of the wind turbine and substation foundation and the onshore control center, etc.

$$C_{Con} = C_{WT,Con} + C_{Ex,Con} + C_{Otr,Con}$$

The calculation of sub item C_{Con} is shown in Table 3.

Table 3　Calculation of the construction cost C_{Con}

SN.	Variables		Fitting formula
1	$C_{WT,Con}$	Wind turbine foundation cost	$C_{WT,Con} = 2500\exp(0.03D_e)$ D_e (m) is water depth.
2	$C_{Ex,Con}$	Offshore substation foundation cost	$C_{Ex,Con} = 175$
3	$C_{Otr,Con}$	Other construction cost	$C_{Otr,Con} = 321$

Sub item C_{Otr} is other related cost.

$$C_{Otr} = 1551.$$

3.2 Supply curve of China's offshore wind power in the near future

When the benchmark yield of the wind power industry is 10%, 8% and 6%, the supply curve of China's offshore wind power was constructed using the annual power generation and generation costs of planned projects, as shown in Fig. 3.
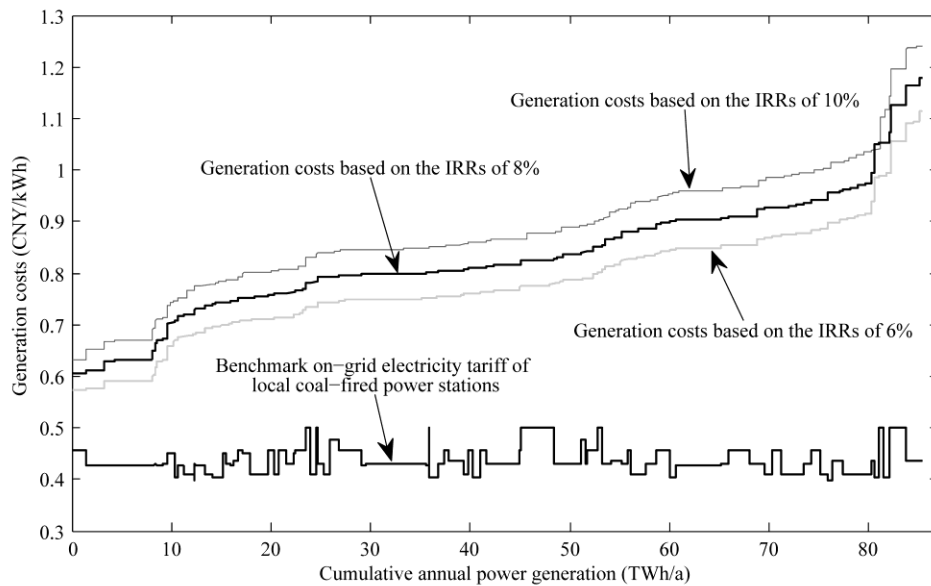
Fig. 3 Supply curve of China's offshore wind power in the near future (not including Taiwan, Hong Kong and Macao)

In Fig. 3, each step of the supply curve represents one offshore wind project. A series of steps below the supply curve indicate the benchmark on-grid electricity tariff of local coal-fired power stations. As Fig. 3 shows, the IRR of the wind power industry will have a significant influence on the gross annual subsidy of a specific policy.

3.3 Development potential of China's offshore wind power under current policy

Supply curves of intertidal and shallow-water offshore wind power projects could be constructed if these two kinds of projects were analyzed separately.

As mentioned previously, the Chinese government implemented a FIT policy, under which the on-grid electricity tariff for shallow-water offshore wind power is 0.85 CNY/kWh (tax included) and the on-grid electricity tariff for intertidal offshore wind power is 0.75 CNY/kWh (tax included) [12]. At present, installed capacities, annual power generation, subsidies and additional tariffs of shallow-water and intertidal offshore wind power based on IRRs of 6%, 8% and 10% could be determined from the supply curves, as Table 4 demonstrates.

Table 4 Development potential and subsidies of China's shallow-water and intertidal offshore wind power

Types of offshore wind power	IRR	Potential of installed capacities (GW)	Potential of annual power generation (TWh)	Corresponding subsidies（billion）	Corresponding additional tariffs（× 10^{-3}CNY/kWh）
shallow-water	6%	22.99	58.10	23. 93	3.62
	8%	18.26	46.54	19.03	2.88
	10%	12.11	31.47	13.03	1.97
intertidal	6%	1.68	4.19	1.39	0.21
	8%	0.88	2.28	0.75	0.11
	10%	0.45	1.25	0.40	0.06

4. Analysis of the influencing factors of China's offshore wind power development potential

The development potential of offshore wind power derived from the previous analysis was an ideal result, although resources of offshore wind, performance of wind turbine, all types of power generation loss, various influencing factors of wind power generation cost and different IRR levels had been considered. In fact, more factors may affect actual installed capacities, annual power generation, subsidies and additional tariffs, mainly including possible policy changes, project investment decision-making, grid integration, the feasibility of subsidies payments and other relevant factors.

4.1 Possible policy changes of China's offshore wind after 2017

China's offshore wind power policy is valid before 2017. The policy may be adjusted after 2017, which may have an important impact on the development of offshore wind power. Therefore, possible policy changes of China's offshore wind policy after 2017 was analyzed in the paper.
The incentive policies for the development of offshore wind power in the world mainly include concession bidding, feed-in tariff(FIT), renewable portfolio standard (RPS), etc.

Because of the unique power management system in China, RPS cannot be implemented in the near future. The premise of implementing RPS policy is the existence of a competitive and liberalized electricity market, in which supply and demand can directly determine the price of electricity trading. Under this policy, the extra cost caused by the compulsory quota could be passed on to end-consumers or conventional power generators automatically. However, competitive and liberalized electricity market has not yet formed in China at present, on-grid electricity tariffs and terminal sales tariff are mainly determined by National Development and Reform Commission of P.R.C, two main power grid enterprises hold a monopoly on electricity buy and sell in their jurisdictions. The Chinese government has begun to promote the reform of electricity market, and hopes to achieve significant results before 2020. There is no conclusion about whether to implement RPS policy instead of mature FIT policy after the completion of the electricity market reform. In a word, it's impossible to implement the RPS policy before 2020 in China.

Therefore, feed-in tariff(FIT) and concession bidding will be maintained, only their detail may be adjusted after 2017. For example, implement other forms of FIT policies, take the concession bidding policy as the main policy, and adjust the on-grid electricity tariffs of FIT policy. Such adjustment will still have an impact on the development of offshore wind power of China.

There are several forms of FIT [45]. The offshore wind power policy executed in China at present is a type of FIT with different on-grid electricity tariffs for intertidal and shallow-water offshore wind power (referred to as "FIT-intertidal / shallow-water"). To simplify the policy, the basic form of FIT, which does not distinguish between intertidal or shallow-water offshore wind power and has only one on-grid electricity tariff in the whole region (referred to as "FIT-basic"), is considered. It is also possible to follow China's onshore wind power policy, that is, all of the coastal provinces were divided into several large areas and given different tariffs according to the different divisions of wind resources (referred to as "FIT-areal"). Or a different tariff is executed in each province (referred to as "FIT-provincial"). It is also possible to continue to implement the concession bidding policy.

we assumed that the policy whose economy is better and risk is less will be selected as the implemented policy after 2017. In order to judge the economy of various policies, installed capacities, annual power generation, subsidies and additional tariffs of China's offshore wind power under various policies are calculated.

To be comparable and to simplify the calculation, the hypothesis conditions are as follows:

(1) When the economy of concession bidding policy is discussed, assume that the winning bid prices are equal to the generation costs.

(2) There are many schemes that divide areas according to the characteristic of offshore wind resources. When the economy of FIT-areal policy is discussed, China's coastal provinces are divided into the poor, the medium and the rich offshore wind resources area as the representative of various regional division programs in this paper.

(3) In order to ensure one-to-one correspondence between the annual power generation and subsidies under FIT-areal, FIT-provincial and FIT-intertidal / shallow-water policies, the following

process is performed: we choose offshore wind project portfolios from the projects with lowest generation costs to meet required total annual power generation. Then, these projects are divided into different regional groups (or type groups) according to the corresponding standards. We set the highest generation cost of the group as the on-grid electricity tariff of the group.

Based on supply curves (IRR=8%) of China's offshore wind power, the economy of the five policies is calculated, and the results are shown in Fig. 4.
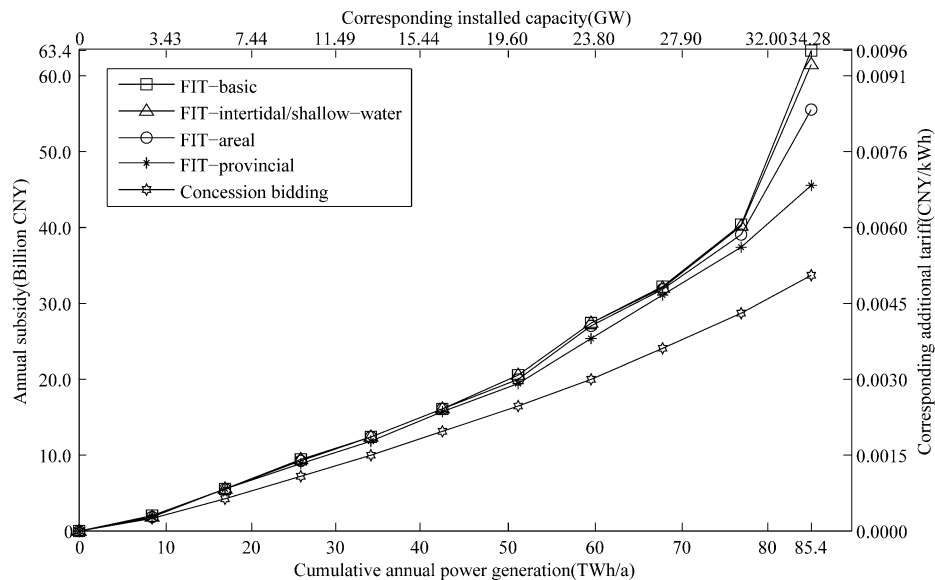

Fig. 4 The economy of five policies of China's offshore wind power

As shown in Fig. 4, the economy of the concession bidding policy is better than FIT policies. However, it is very hard to ensure that the winning bid prices are equal to the generation costs for all projects. In fact, the winning bid prices are always lower than the generation costs because of vicious competition, which leads to the refusal of winning enterprises to begin construction. The lessons of the past failures indicate that it's more likely to implement FIT policies instead of concession bidding policy.

As shown in Fig. 4, the economy of FIT-areal, FIT-provincial, FIT-intertidal / shallow-water is not much better than FIT-basic, especially in the case of smaller installed capacities or annual power generation. Because of inertia, FIT-intertidal / shallow-water may continue to be executed, that is, the present policy form is likely to be maintained in China after 2017.

Moreover, the on-grid electricity tariff level of China's offshore wind power is unlikely to change after 2017.

Firstly, it can be judged based on the supply curve that the present on-grid electricity tariff is moderate, that is, China's offshore wind power has a great development potential, while it is not too high to cause excessive subsidies.

Secondly, although the learning effect may reduce generation costs, the wind resources that can be developed are worsening. Thus, it is necessary to maintain a high on-grid electricity tariff. Refraining from arbitrarily adjusting on-grid electricity tariff is also conducive to maintaining better investment expectations.

Thirdly, based on the five rounds of concession bidding between 2003 and 2007, China began to implement FIT policy of onshore wind power in July 2009. China's onshore wind power experienced a high-speed growth period, but the on-grid electricity tariffs of onshore wind power were not reduced until the end of 2014. The offshore wind power has only experienced one round of the concession bidding, and the FIT policy of offshore wind power went to effect in June 2014. At present, China's offshore wind power is in the early development stages. Thus, it is unlikely that the on-grid electricity tariffs will be adjusted before 2020.

4.2 Project investment decision-making of China's offshore wind power

In previous sections of this paper, it was assumed that when on-grid electricity tariffs are higher than the generation costs based on IRRs of 6%, 8% and 10%, the projects have the potential to be invested. The rationality of this judgment is analyzed in this sections of the paper.

In fact, IRRs of 6%, 8% and 10%, as mentioned above, are defaults to the industry benchmark yield. The definition of the industry benchmark yield is the lowest benefit level of the investment projects that is confirmed and accepted by the investors, enterprises or industry with dynamic point of view,. The industry benchmark yield is subject to the constraints of objective conditions but also influenced by the objective conditions of investors. Factors such as sources of funding, opportunity cost of investment, project risk and inflation rates is taken into account.

The benchmark yield of China's electric power industry was determined through research and expert judgment in applicable literature [44], the benchmark yield of wind power industry is 8%, meaning that enterprise will be willing to invest in the projects when its IRR exceeds 8%.

The benchmark yield of China's offshore wind power was not given in the literature individually. However, offshore wind power is a type of wind power, so an IRR of 8% is also considered as a benchmark yield of China's offshore wind power industry in the paper. At the same time, the technology of offshore wind power is more complicated, and the risk of offshore wind power is higher. Therefore, higher expected IRRs are needed, an IRR of 10% is also considered as a benchmark yield of China's offshore wind power industry in the paper. Conversely, some large enterprises may invest in some offshore wind projects with lower IRRs for layout in advance. Therefore, an IRR of 6% is also considered to be a benchmark yield of China's offshore wind power industry in this paper.

Therefore, when the on-grid electricity tariffs are higher than the projects' generation costs based on IRRs of 6%, 8%, 10%, the projects will be invested. After 3~5 years of construction, these projects will be completed and put into production.

4.3 Grid integration of China's offshore wind power

Although China's renewable energy law requires power grid enterprises to create the conditions for full access to renewable energy power, due to limits of grid integration, there is a phenomenon of wind curtailment for onshore wind power.

The factors that affect the wind curtailment are very complicated. The proportion of wind power generation to total power consumption is most important exogenous cause of wind curtailment. As we know, even for a same proportion of wind power generation to total power consumption, wind curtailment rates are different when the power load characteristics, framework and power flow of power grid, operational flexibility of conventional power and renewable energy power structure of the power systems are different. Power and energy balance simulation is necessary when wind curtailment of a power system needs to be predicted accurately. However, it is very difficult to obtain a large amount of basic data for the simulation. Thus, it is assumed that the structure of the power system of China's coastal provinces are similar, and only the proportion of wind power generation to total power consumption is discussed in this paper.

The relationship between the wind curtailment rate of some provinces (including the coastal provinces) and the proportion of wind power generation to total power consumption are shown in Fig. 5. In the figure, wind power generation equals to the on-grid wind power generation plus wind power curtailment; Every point of the figure represents a province; To eliminate the influence of solar power, the provinces with large solar installed capacities and solar power generation potential, such as Ningxia, Qinghai, Xinjiang, Gansu, Tibet and Neimeng, mainly located in the northwest of China, are excluded.
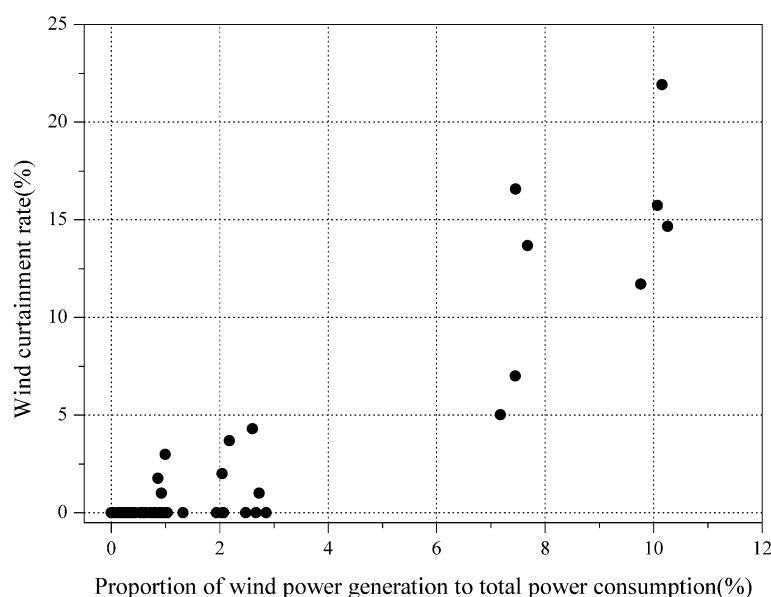
Fig. 5 The relationship between wind curtailment rate and proportion of wind power generation to total power consumption of China's Provinces

As shown in Fig. 5, wind curtailment rate and proportion of wind power generation to total power consumption are positively correlated. Thus, if the proportion of wind power generation to total power consumption of provinces in the near future is known, its wind curtailment rates can be roughly estimated.

In this paper, annual power generation potential of China's coastal provinces (municipalities) offshore wind power in 2020 has been calculated. Total power consumption and onshore wind power generation, including on-grid onshore wind power generation and onshore wind power curtailment, can be obtained from data of planning reports. Therefore, proportion of wind power generation to total power consumption of China's coastal provinces(municipalities) are known, and offshore wind curtailment rates can be roughly estimated using Fig. 5, the result is shown in Table 5.

Table 5   Estimation of wind curtailment rate of China's coastal provinces (municipalities) offshore wind power in 2020

China's coastal provinces (municipalities)	proportion of wind power generation to total power consumption	Estimated wind curtailment rate by Fig. 5
Tianjin	1.6%	0%
Hebei	9.8%	15%
Shandong	5.4%	5%
Liaoning	11.2%	15%
Shanghai	3.4%	2.5%
Jiangsu	9.9%	15%
Zhejiang	3.7%	2.5%
Fujian	7.0%	5%
Guangdong	2.7%	2.5%
Guangxi	0.2%	0%
Hainan	4.4%	5%

In fact, wind curtailment rates are rarely considered in the feasibility study reports of China's offshore wind power. Because the phenomenon of wind curtailment appears gradually only when the

proportion of wind power generation to total power consumption is higher, and it is difficult to estimate the wind curtailment rate of offshore wind projects after being put into operation at the projects investment decision stage. Therefore, compared to effect of wind curtailment rate on calculation of the annual power generation, annual subsidies and additional tariffs, it assumed that wind curtailment rate do not effect project investment decision-making, installed capacities can be obtained from supply curves directly.

4.4 The feasibility of subsidies payments

In some countries with high renewable energy penetration, the subsidies of renewable energy powers are so high that finances and the public become overwhelmed. This leads to the reduction of renewable energy power's on-grid electricity tariffs, or even the cancellation of the subsidies directly. Thus, it is necessary to discuss the feasibility of subsidies payments of China's offshore wind power.

According to our analysis, it is feasible for China to pay subsidies for offshore wind power at current tariff levels. Because the subsidies of China's offshore wind power are not paid by financial revenues, but by additional tariffs that are shared by power consumers. Even if all power generation of China's planning offshore wind power projects is consumed, the additional tariff is only 0.0096 CNY/kWh, as shown in Fig. 4. Because of this subsidy sharing mechanism, a single user does not need to pay much money.

4.5 Other factors affecting the development of China's offshore wind power

Worse sea and weather conditions than expected may affect China's offshore wind power development scales and subsidies. China's offshore wind power planning reports and feasibility research reports are the basis of the study in this paper. It was not possible to investigate the sea and weather conditions in detail when the planning reports and feasibility research reports were prepared. In the actual construction process, worse sea and weather conditions than expected may appear, which could result in a dramatic increase in the investments and generation costs of offshore wind projects, and the construction of the project may be denied directly.

Complicated preparatory work and lack of the construction experience may also affect China's offshore wind power development scales and subsidies. The construction of offshore wind power involves electric power sector, maritime sector, shipping sector, fishery breeding sector, military sector and other departments. As a result, the progress of the preparatory work is relatively slow. In addition, because of the lack of the construction experience of offshore wind power project in China, the schedule of construction may be affected, which may influence installed capacities and power generation in specific year.

4.6 Prospective estimation of the scales and subsidies of China's offshore wind power before 2020

After a comprehensive consideration of the factors mentioned above, the scales and subsidies of China's offshore wind power before 2020 were estimated and shown in Table 6.

Table 6 Prospective estimation of the development scales and subsidies of China's offshore wind power before 2020

Types of offshore wind power	IRR	Installed capacities(GW)	Annual power generation(TWh)	Corresponding subsidies（billion CNY）	Corresponding additional tariffs(CNY/kWh）
shallow-water	6%	22.99	52.45	21.62	3.27
	8%	18.26	42.03	17.20	2.60
	10%	12.11	29.22	12.09	1.83
intertidal	6%	1.68	3.58	1.18	0.18
	8%	0.88	1.95	0.65	0.10
	10%	0.45	1.07	0.35	0.05

5. Conclusion

Due to a preliminarily constructed policy system of offshore wind power and other renewable energy power, China's offshore wind power has achieved initial development in recent years. At present, the feed-in tariff(FIT) is the main incentive policy for offshore wind power in China, supplemented by the concession bidding policy. Concerns exist as to whether the current policies can effectively encourage a healthy and rapid development of China's offshore wind power. There are also concerns regarding the development scales and subsidies of China's offshore wind power in the near future.

In this paper, existing engineering data, including data on annual power generation and generation costs of China's planned offshore wind projects were used as much as possible. The annual power generation of the planned projects without existing data were analyzed and calculated based on offshore wind resource data, performance parameters of wind turbine, and several types of power generation reduction factors. Generation costs based on internal rates of return (IRRs) of 6%, 8% and 10% of China's planned offshore wind projects were calculated by constructing capital expenditure(CAPEX) models and using financial evaluation methods. Through the calculation of planned projects' annual power generation and generation costs, the supply curves of China's offshore wind power was constructed. Based on the supply curves, the development potential and subsidy of China's offshore wind power before 2020 were calculated.

In further analysis, possible policy changes, project investment decision-making, grid integration, the feasibility of subsidies payments and other relevant factors were considered to estimate development scales and subsidies of China's offshore wind power before 2020.

The study shows that there is a large possibility for sustaining the present policy of offshore wind power in China, that is, the feed-in tariff(FIT) policy will continue to be executed and the on-grid electricity tariff will remain unchanged; Investors would construct the planning offshore wind projects with the IRR range of 6% to 10%; Amounts of on-grid generation of offshore wind power will cause wind curtailment, especially in the Hebei, Liaoning, Jiangsu provinces of China; The subsidies of offshore wind power can be paid normally; Challenges such as worse wind and sea conditions than expected, complicated preliminary work and lack of construction experience will enable the development of offshore wind power in China to face more uncertainty.

It was estimated that the installed capacities of China's offshore wind power before 2020 is between 12.56 GW and 24.67 GW, the annual power generation is between 30.29 TWh and 56.03 TWh, subsidies are between 12.44 and 22.80 billion CNY, additional tariffs are between 1.88×10^{-3} and 3.45×10^{-3} CNY/kWh.

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