Aalborg Universitet

Feasibility study of China's offshore wind target by 2020

Hong, Lixuan; Möller, Bernd

Published in:
Energy

DOI (link to publication from Publisher):
10.1016/j.energy.2012.03.016

Publication date:
2012

Document Version
Early version, also known as pre-print

Link to publication from Aalborg University

Citation for published version (APA):
Hong, L., & Möller, B. (2012). Feasibility study of China's offshore wind target by 2020. *Energy*, *48*(1), 268-277.
https://doi.org/10.1016/j.energy.2012.03.016

NOTICE: this is the author's preprint version. Changes as a result of the publishing process such as peer review, revision, correction and proofreading might not be reflected in this document. A definitive version was published in Energy, Vol. 48, No. 1, 2012, p.268-277.

Feasibility study of China's offshore wind target by 2020

Lixuan Hong*, Bernd Möller

Department of Development and Planning, Aalborg University, Fibigerstræde 13, 9220 Aalborg, Denmark

Abstract

China has an ambitious target of developing 30 GW offshore wind energy by 2020. A spatially continuous resource economic and tropical cyclone risk model is built using Geographic Information System (GIS) to evaluate the feasibility of the target from both national and provincial level. The influence of spatial constraints and tropical cyclone risk on offshore wind potential and its associated marginal levelised production costs are identified by cost-supply curves derived from the model. It is concluded that spatial constraints and tropical cyclone risk increase the marginal levelised production costs for achieving the national target by 7 €/MWh and 34 €/MWh respectively. The implications of technological progress are further investigated, which suggests the marginal levelised production costs will be in the range of 77-87 €/MWh as better tropical cyclone-resistant turbines are developed. Comparing this figure with actual winning bids from current public tender procedure, it implies that only 40-70% of the national target can be achieved even under aggressive progresses of turbine technologies in the near future. A stable provincial based feed-in-tariff system for offshore wind energy and long-term policies contributing for technological learning need to be launched in order to make the ambitious plan into reality.

Key words: offshore wind target; feasibility; GIS; China; 2020

* Corresponding author. Tel: +45 99403658 Fax: +45 98153788
E-mail address: lixuan.hong@gmail.com (L. Hong).

1. Introduction

Over the past few years, China has invested heavily in wind power to achieve its 15% non-fossil fuel obligation by 2020. In 2010, newly installed capacity was 18.9 GW, bringing the country's cumulative installed capacity to 44.7 GW as the largest market worldwide [1]. It is the fifth year in a row with the total installed capacity being doubled. However, the growth rate of onshore wind development has slowed down in 2011 due to great transmission capacity limits. It is estimated that 30% of the cumulative installed capacity has not been connected to the grid by 2010 [2,3]. On the other hand, offshore wind industry is gaining momentum for its rich resources and close proximity to electricity demand centers. The Chinese offshore wind energy marked a turning point in 2010, transitioning from research and pilot projects to commercialized operation. The 102 MW Shanghai Donghai Bridge offshore wind farm, the first large-scale offshore demonstration project outside Europe, has been in operation since June 2010. Then, the first round public tender for 1 GW of offshore wind power concession projects accomplished in October 2010 and comprised four inter-tidal/offshore wind farms in eastern Jiangsu province. The second round of offshore wind power concession projects with a total capacity of up to 2 GW is expected to be completed by June 2012. According to the National Energy Administration, China endeavors to further increase its offshore wind power installed capacity to 5 GW by 2015 and 30 GW by 2020 [4], which makes the nation emerging as the second global hotspot after Europe for offshore wind development (Fig.1).

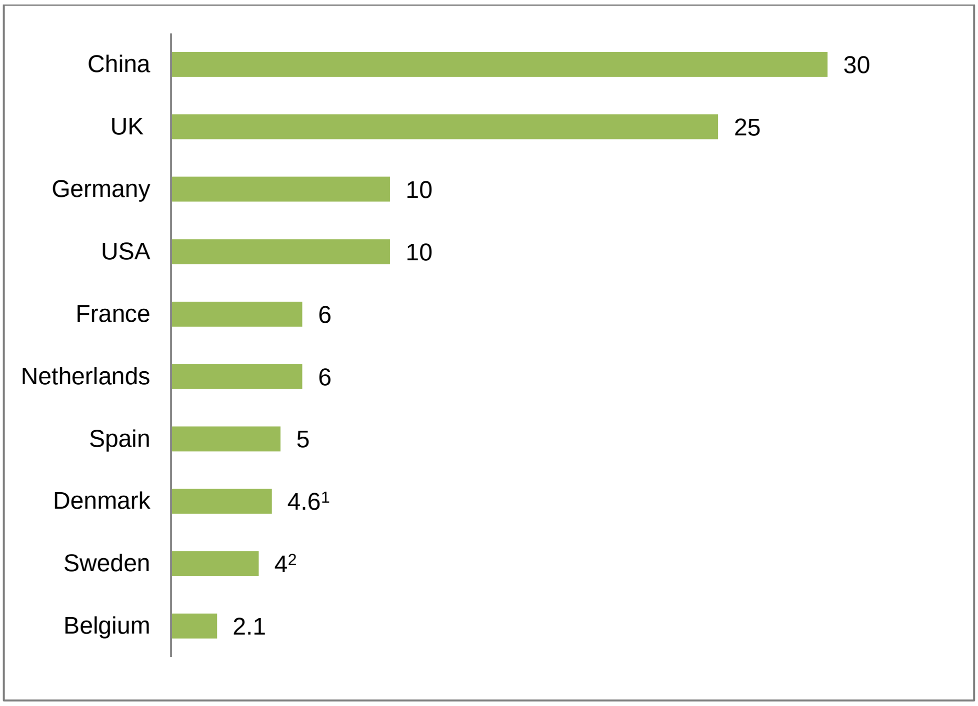

Fig. 1 National targets for offshore wind energy in 2020(GW) [14,15]

Note: 1 until 2025. 2 Based on a capacity factor of 40 percent.

However, several uncertainties cast doubts on this ambitious target by 2020. Firstly, the lack of comprehensive marine spatial planning framework would impede the progress of offshore wind development. For instance, the 1 GW of offshore wind power concession projects in the first public tender haven't started yet after more than one year, since they confront marine use conflicts with other sectors such as natural conservation zones, tourism and fishing. Second, the increase of investment cost per MW of offshore wind energy becomes an apparent phenomenon worldwide in recent years. While early studies quote investment costs of 1.2 to 2.4 M€/MW in 2007 [5,6] and then 1.8 to 2.5 M€/MW in 2008 [7,8], this figure increased to 2.7 to 3.8 M€/MW in 2010 [9,10]. The investment cost per MW of offshore wind farms in China is estimated to be 2-3 times of the same scale onshore wind farms, ranging from 1.6 to 2.4 M€/MW in average [11]. However, the successful bidding prices of the four offshore wind power concession projects are 0.6235

Yuan/kWh (66.9 €/MWh) [1], 0.737 Yuan/kWh (79.1 €/MWh), 0.7047 Yuan/kWh (75.6 €/MWh) and 0.6396 Yuan/kWh (68.6 €/MWh), which are deemed too low to make profits [12]. Thirdly, China is one of the countries that suffer most from tropical cyclones in the world, with an average of nine tropical cyclones making landfall annually in 1951-2008 [13]. Strong precipitation, extreme wind and storm surge brought by tropical cyclones might lead to fatal damages of offshore wind farms and therefore great economic losses. The focus so far has been on turbines intended for use in Europe, primarily in the North and Baltic Seas. One question that occasionally arises is how applicable offshore turbines designed for northern European conditions are to China, where tropical cyclones occur relatively frequently.

Therefore, this paper aims to investigate the implications of technology, economic cost, spatial constraints, and tropical cyclone risk on the feasibility of the 30 GW offshore wind target by 2020 and thus provide macroscopic information for policy-makers and investors. In order to answer the aforementioned issues, the structure of this paper is organized as follows: firstly a spatially continuous resource economic and tropical cyclone risk model of offshore wind energy is developed on the basis of a Geographic Information System (GIS) in Section 2; secondly the location-specific levelised production cost (LPC) and cost supply curves under spatial constraints and tropical cyclone risk are displayed in Section 3; and then the implications of different technologies on tropical cyclone-resistant offshore wind turbines on the wind potential and costs are analyzed in Section 4; the implications of pricing mechanism on the feasibility of offshore wind targets are further investigated in Section 5; and finally several conclusions are drawn in Section 6.

[1] Based on the 30 days average exchange rate in October 2010 (www.oanda.com), 1 CNY = 0.1073 EUR.

2. Methodology

The Spatially Continuous Resource Economic Assessment Model for Offshore Wind Energy (SCREAM-offshore wind) is built using a raster-based GIS, which has the unified spatial resolution of 1 km2 within the Economic Exclusive Zone (EEZ)[2]. SCREAM was first adopted for the assessment of biomass for energy purposes [16] and then adopted for distributed wind resources and their location-specific and distance related costs. A predecessor of this idea can be found in [5,17,18], but later has been improved in [19,20], and a specific application for China can be found in [21]. In this paper, it attempts to incorporate the economic risk of tropical cyclones on offshore wind farms into the SCREAM-offshore wind model for China. It will facilitate identifying available locations, power production potential and the associated power production costs under varying spatial constraints and tropical cyclone risk; as well as to produce the resulting cost-supply curve of the cumulative available offshore wind resources and its marginal production costs for making policy suggestions. The tropical cyclone risk included LPC (RLPC) is the least cost without expected profits of one production unit produced by an offshore wind farm averaged over its entire expected lifetime under a certain degree of economic risk from tropical cyclones. It can be calculated through a minor revision of the standard discounting formula [22]:

$$RLPC = \frac{\left(I + E_L\right)}{a \cdot AUE \cdot \left(1 - r\right)} + \frac{OM}{AUE \cdot \left(1 - r\right)} \tag{2.1}$$

where I is the total investment cost per ocean area unit (€/km^2), a is the annuity factor as defined in the formula 2.2, E_L is the expected economic loss of offshore wind farms under tropical cyclones during its lifetime per ocean area unit (€/km^2) as modeled in [23]. AUE represents annual energy output per ocean area unit (MWh/km^2/y), r represents the loss ratio of annual energy generation due

[2] The boundary is gained from VLIZ (2009). As there are still a lot of disagreements on EEZ between countries worldwide, new treaties will be negotiated in the next years.

to tropical cyclones and *OM* represents annual operation and maintenance cost per ocean area unit (€/km^2/y).

$$a = \frac{1-(1+i)^{-n}}{i} \tag{2.2}$$

where *i* is the interest rate and *n* represents the expected lifetime of the project.

Costs of foundations, grid connections, installation, operation and maintenance depend on spatial factors such as sea depth, distance to shore or harbor. Hence these cost components have been modeled as input layers for the GIS model. Specifically, foundation costs are modeled by the sea depth, grid costs are calculated by the cost weighted distance from the offshore location to the nearest grid access point, and operation and maintenance costs are developed by the distance from the offshore location to the nearest harbor. Costs independent of spatial parameters such as turbine costs are converted into input layers as well. The detailed investment cost model for Chinese offshore wind farms has been elaborated in Table 1. Moreover, annual offshore wind energy generation per ocean area unit is calculated based on average wind speeds at the 90m hub height of a 5MW turbine, its associated power curves, array density of a prototype 600MW offshore wind farm, average turbine availability and average park efficiency. The layout of each offshore wind farm considers radial grid connection, with 8 turbines a row and 15 turbines a column. The distance among wind turbines is set to 8 times the rotor diameter, which is suggested as optimum array [24]. And a 20 km buffer between neighboring offshore wind farms is assumed in order to reduce wake effects [25]. Table 2 summarizes the assumptions on other non-spatial parameters. Besides, the main sectors considered as spatial constraints for offshore wind energy development include oil and gas platform, submarine cables and pipelines, shipping lanes, military training zones, natural conservation areas, fishing, visibility, and tourism and leisure zones. They are also input layers for the model. Yet, based on the availability of data, a reference scenario of spatial constraints is described in Table 3. What's more, the SeaWinds based on QuikSCAT Level 2B Ocean Wind Vectors in 12.5 km Swath Grid created by the National Aeronautics and Space Administration (NASA) [26] is applied for producing ocean wind power density map. The CMA-STI Best Track Dataset for Tropical Cyclones from 1949-2009 in the Western North Pacific [27] is utilized to produce extreme wind speed distribution. The loss ratio of annual energy generation and expected economic loss of offshore wind farms per ocean area unit is calculated by a probabilistic tropical cyclone event model and turbine damage model [23].

Table 1 Investment cost model for Chinese offshore wind farms [22].

Cost factor	**Variables**	**Model**
Turbine (M€/MW)	Turbine size	1.1
Foundation (€/MW)	Water depth x (m)	$(499x^2 + 6219x + 311810) \cdot 1.4$ ($0 < x < 25$) $(440x^2 - 19695x + 901691) \cdot 1.4$ ($x \geq 25$)
Grid (€/MW)	The least subsea cost distance d_s (km), the least land cost distance d_l (km)	$(0.38d_s + 0.4d_l + 76.6) \cdot 10^6 / 600$
O&M (€/MW)	The least cost distance to service harbor d (km)	$(-0.29d^2 + 159d + 50415) \cdot 0.4$
Other (%)	the percentage of investment costs	10%

Table 2 Assumptions on other non-spatial parameters.

Assumed non-spatial parameter	**Value**
Array density of turbines (MW/km^2)	0.65
Average turbine availability	0.85
Average park efficiency	0.9
Technical and economic lifetime	20
Annual discount rate	7.5%
Probability of tropical cyclone	20-year recurrence

Table 3 Spatial constraints for offshore wind farms.

Spatial constraints	**Reference**
Shipping Lanes	3km
Submarine Cables	500m
Birds	3km
Visibility	8km

3. Provincial planning for offshore wind energy

The coastal provinces see offshore wind development as a means of increasing local employment and securing energy supply. For instance, Shandong, Jiangsu, Shanghai[3], Zhejiang, Fujian and Guangdong combined contributed to 43.28% of the nation's gross domestic production in 2009 [28], yet they also consumed 31.58%, 47.98% and 30.95% of the country's total coal, oil and natural gas consumptions [29]. Contradict to their enormous appetites for primary energy, these provinces lack coal resources and become increasingly dependent upon imported fuels, either from inland Chinese

[3] Shanghai is a municipality, a higher level of city which is directly under the Chinese government, with status equal to that of the provinces. It will not be specified in the latter part.

provinces or from the international market. The import rate of primary energy supply ranges from 52.34% in Shandong to 97.68% in Zhejiang as shown in Fig.2. Besides, the country often faces severe power shortages in summers, with power generation and transmission systems unable to cope with rising demands. China faced a 30 GW power shortfall in the summer of 2011 according to China Electricity Council [30], which displays the importance and urgency of developing offshore wind energy in coastal regions. In Fig.3, it shows the electricity generation and consumption in these coastal provinces, where rely heavily on the long distance transmission of electricity from central and western China.

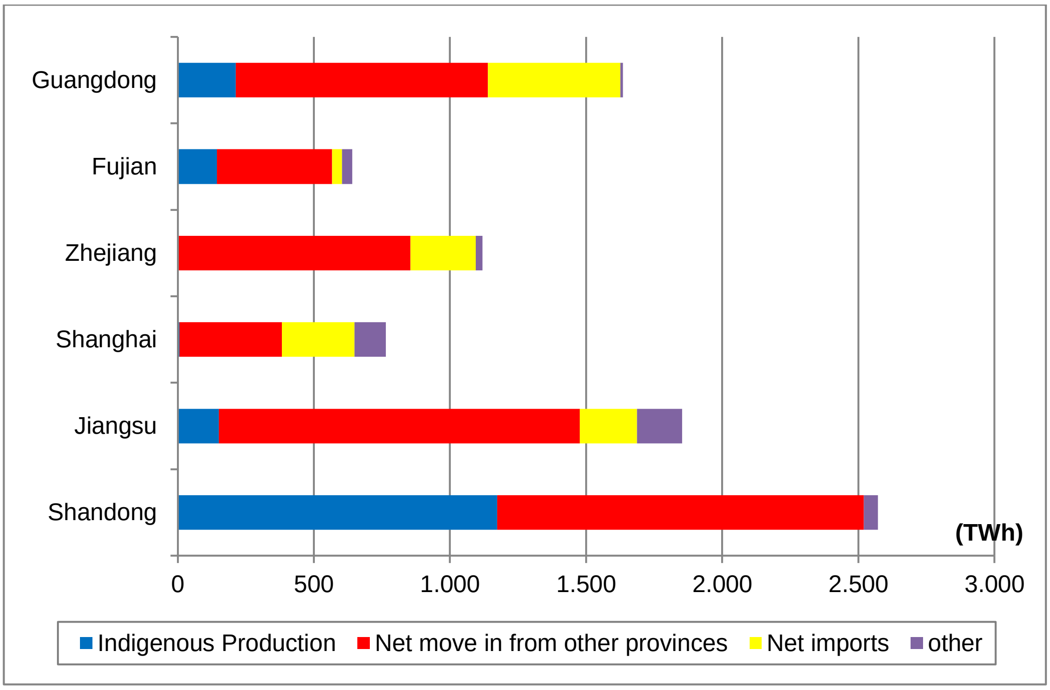

Fig. 2 Primary energy supply by source in 2009 [30].

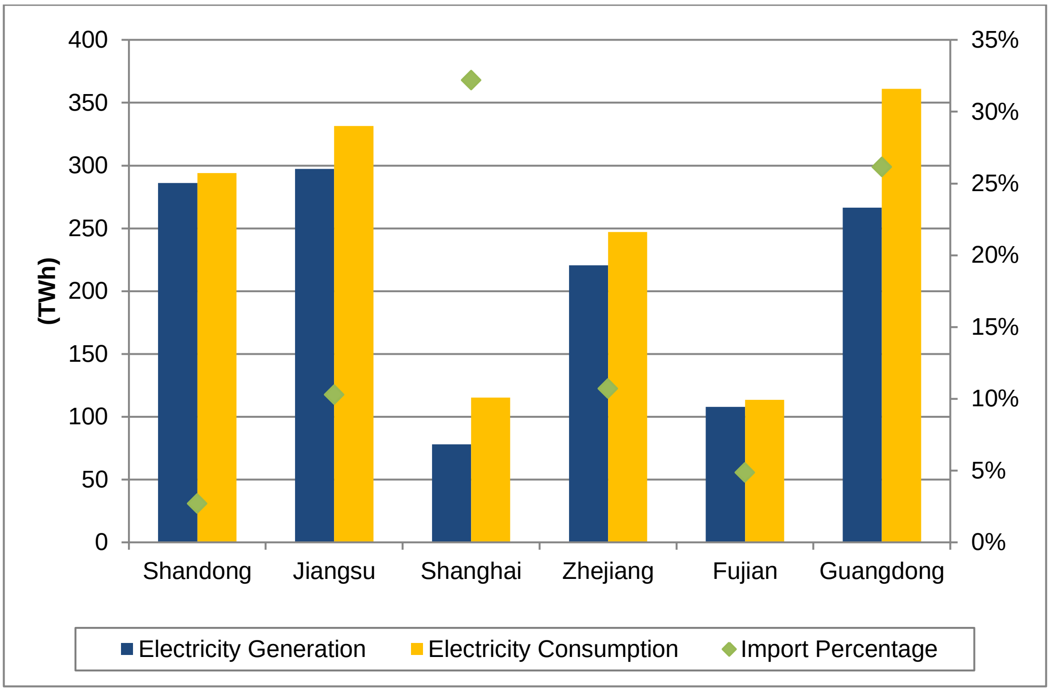

Fig. 3 Electricity generation and consumption in coastal provinces in 2009 [32,33].

In order to meet the total target of 30 GW offshore wind energy, coastal provinces of China initiate their own plans of offshore wind energy development by 2020 as displayed in Table 4. The main coastal provinces interested in developing offshore wind energy in the near future include Shandong, Jiangsu, Shanghai, Zhejiang and Fujian, whose estimated aggregate installed capacity of offshore wind energy will reach 10.1 GW in 2015 (intertidal offshore[4] 4.2 GW and near offshore[5] 5.9 GW), and 22.8 GW in 2020 (intertidal offshore 5.1 GW and near offshore 17.7 GW). The imported electricity of these provinces in 2009 is compared to the electricity generation of offshore wind energy under provincial plans (Fig.4). It shows that offshore wind energy production is expected to be 70.3 TWh by 2020, approximately 63.3% of the total imported electricity in these provinces in

[4] Intertidal offshore is in the area between high- and low-water marks (especially off the provinces north of Yangtze estuary), with wind speeds at the height of 10m roughly estimated to be in the range of 6-7m/s (mostly along the coastal provinces of Shandong, Jiangsu and Shanghai).
[5] Near offshore is in the area with sea depth between 5-25m, where are supposed higher wind speeds than intertidal areas. But this assumption is based on very limited measurements in Fujian, Jiangsu, Guangdong, Shandong, Shanghai and Zhejiang.

2009. What's more, the CO_2 emission reductions are estimated to be 56.05 Mt due to the replacement of coal by offshore wind[6], which is almost equivalent to the observed emissions from greenhouse gases in Denmark in 2009.

Table 4 Provincial plan for offshore wind energy [1].

Province	**Capacity(GW)**		**Plan Stage**
	2015	**2020**	
Shanghai	0.7	1.55	Approved
Jiangsu	4.6	9.45	Being examined
Zhejiang	1.5	3.7	Waiting for investigation
Shandong	3	7	Original draft
Fujian	0.3	1.1	Original draft
Other	5	10	Compiling plan
Total	15.1	32.8	

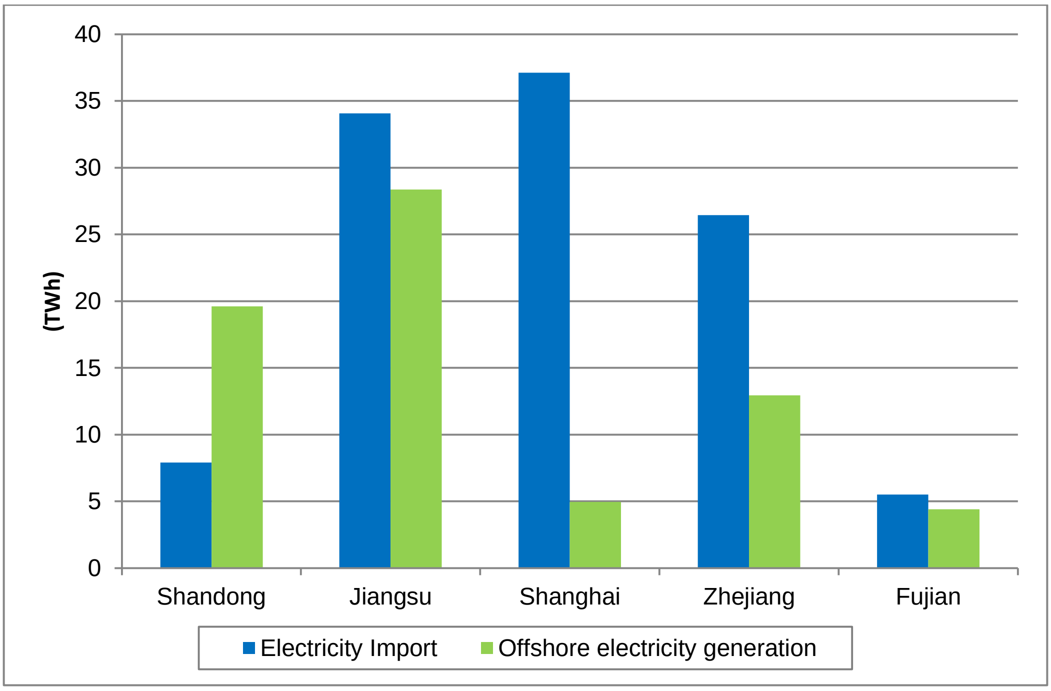

Fig.4 Imported electricity in 2009 compared to offshore wind generation in 2020.

[6] The average consumption of standard coal per kWh electricity production is expected to be 320g/kWh in 2020 in China. The observed emissions from greenhouse gases from Denmark were 62.098 Mt in 2009.

Offshore wind plans in various coastal provinces are at different stages, but generally speaking, Shanghai and Jiangsu are pioneers of developing offshore wind energy in China. The offshore wind plan of Shanghai has already been approved by National Energy Administration, which propose to develop offshore wind farms firstly in Donghai Bridge, Fengxian and Nanhui with an installed capacity of 600 MW by 2015 [33]. And a final target of 6 GW offshore wind energy will be reached and distributed in eight available locations of Shanghai by 2030 [33]. Though Jiangsu's offshore wind plan remains to be examined; four offshore concession projects with a total installed capacity of 1 GW have already been fully commissioned. Two are offshore wind farms, located in Binhai and Sheyang, with an installed capacity of 300 MW each. Another two intertidal projects locates in Dongtai and Dafeng, sizing 200 MW each. Other provincial plans are at the initial stage, and the spatial distribution of offshore wind projects by development stage in coastal provinces is shown in Fig.5.

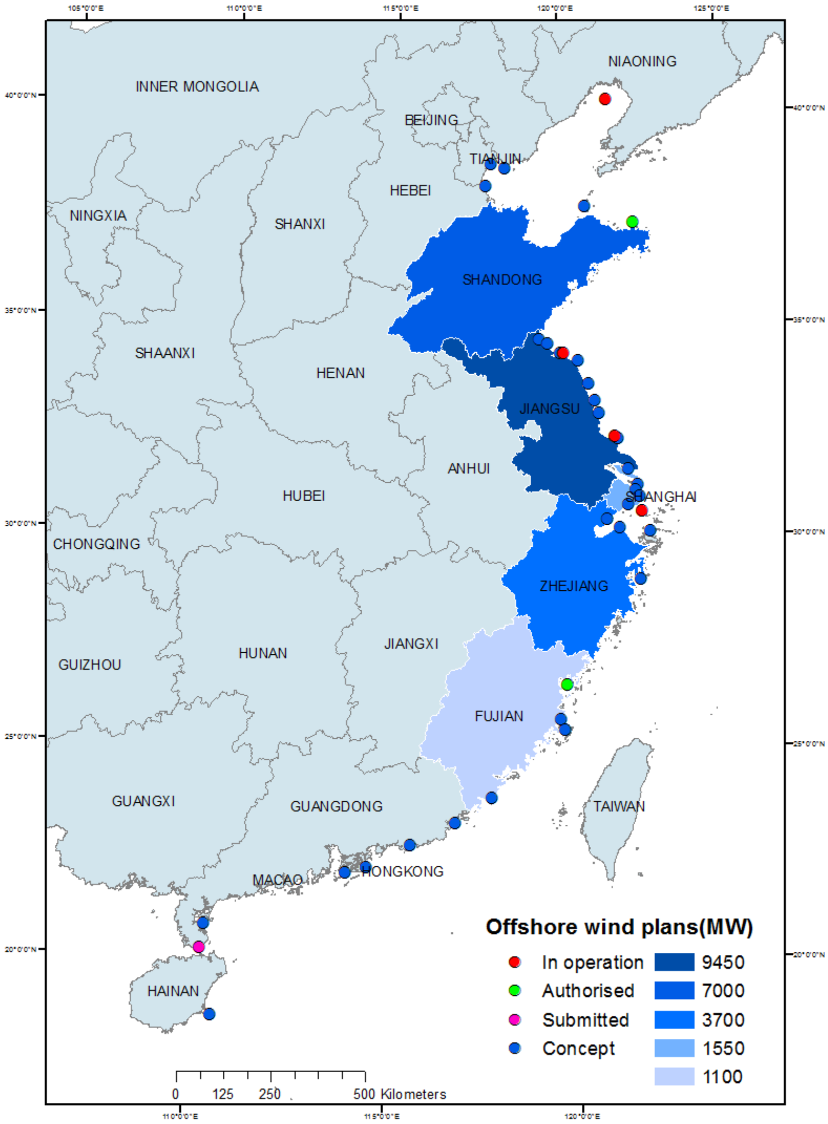

Fig.5 Spatial distribution of offshore wind projects in coastal provinces [34].

4. Spatial cost distribution under risk and constraints

The spatial distribution of tropical cyclone risk included LPC under spatial constraints is shown in Fig.6. The least cost sites for developing offshore wind energy are along the coasts of Niaoning, Tianjing, Hebei, southern Jiangsu and Shanghai, with an average RLPC of 47-80 €/MWh. In 20-50m waters of Jiangsu, 0-20m waters of Bohai Rim, Zhejiang and Fujian, an average RLPC is in the range of 80-100 €/MWh. As the distance being far away from the coasts, the average RLPC of developing offshore wind farms would reach as high as 200 €/MWh. However, spatial constraints have an influential impact on the RLPC, especially for the least cost locations. The reference scenario excludes 40.7%, 24.9%, 12.7%, 7.4% and 4.4% of areas located within the RLPC range of 47-80 €/MWh, 80-120 €/MWh, 120-160 €/MWh, 160-200 €/MWh and above 200 €/MWh respectively. In Fig.7, it compares the marginal levelised production costs of offshore wind energy with and without tropical cyclone risk and spatial constraints. Taken an assumption of a nation-wide average full-loaded hour of 3000 h by 2020, the power generation of 30 GW target would reach approximately 90 TWh. Compared to a condition free of spatial constraints and tropical cyclone risk, spatial constraints would increase the marginal production costs of reaching the 30 GW target by approximately 7 €/MWh, while the increase caused by tropical cyclone events under a 20-year recurrence probability is expected to be as high as 34 €/MWh.

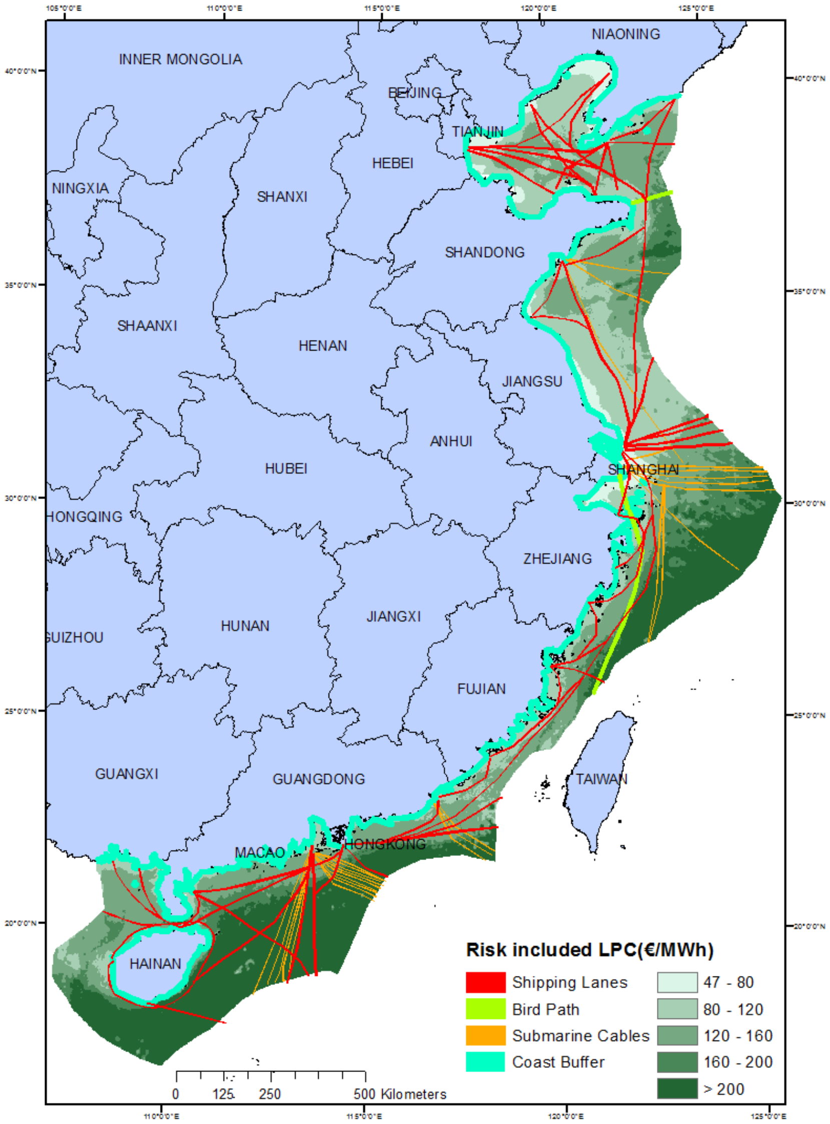

Fig.6 Spatial distribution of LPC under tropical cyclone risk and spatial constraints.

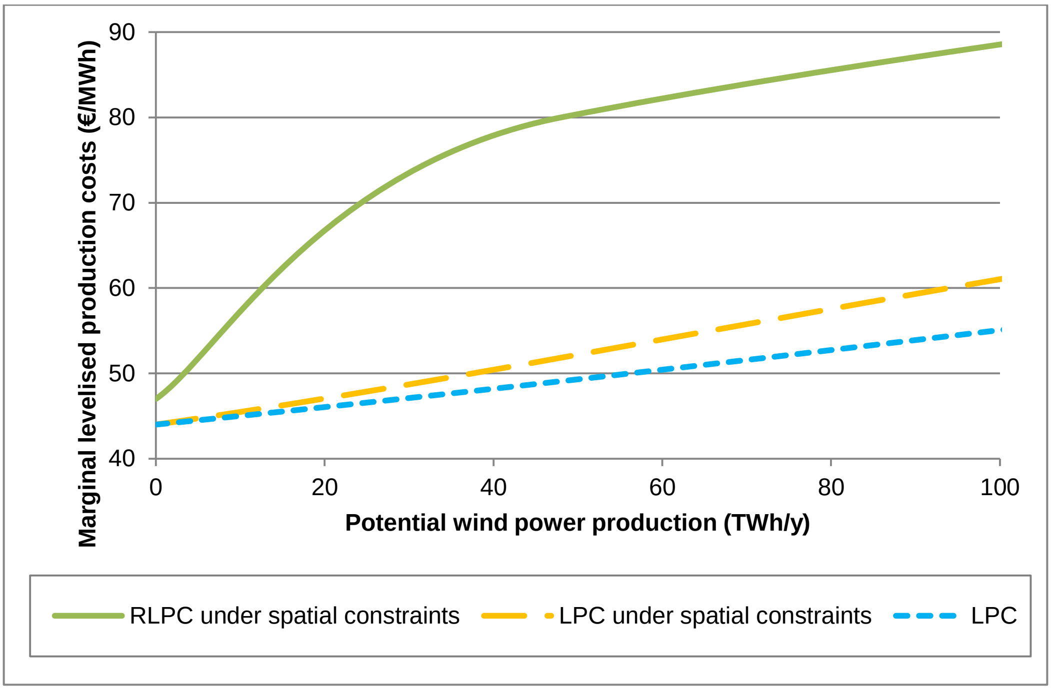

Fig.7 Comparison of marginal production costs with and without tropical cyclone risk and spatial constraints.

Assessment of offshore wind potential, its associated costs and economic risk of tropical cyclone under existing technological level in each coastal province are summarized in Table 5. Technical potential of offshore wind energy are estimated to be 174 TWh, 169 TWh, 70 TWh, 313 TWh, 153 TWh and 405 TWh in Shandong, Jiangsu, Shanghai, Zhejiang, Fujian and Guangdong respectively. Their aggregate potential accounts for 73.3% of the total offshore wind potential within the EEZ area of China. However, spatial constraints would exclude 12.0%, 11.2%, 13.4%, 10.2%, 15.6% and 14.5% of offshore wind potential in Shandong, Jiangsu, Shanghai, Zhejiang, Fujian and Guangdong. The cost-supply curves under spatial constraints and tropical cyclone risk for each coastal province are displayed in Fig.8. It shows that Shanghai is capable of generation 8 TWh electricity under the most economically competitive cost in the country. Yet its marginal levelised production cost for offshore wind energy would increase sharply afterwards. Besides, average marginal levelised production costs in Jiangsu is the lowest for developing offshore wind farms under spatial constraints and tropical cyclone risk compared to other provinces. Based on the full-loaded hour in each province, the power generation is expected to be 19.6 TWh, 28.35 TWh, 4.96 TWh, 12.95 TWh and 4.4 TWh in Shandong, Jiangsu, Shanghai, Zhejiang and Fujian under their respective target by 2020. In Fig.8, it shows that marginal levelised production costs for reaching their respective target are approximately 95 €/MWh, 88 €/MWh, 67 €/MWh, 90 €/MWh and 80 €/MWh in Shandong, Jiangsu, Shanghai, Zhejiang and Fujian.

Table 5 Assessment of wind potential, cost and risk in coastal provinces.

Items	**Shandong**	**Jiangsu**	**Shanghai**	**Zhejiang**	**Fujian**	**Guangdong**
Wind Density(W/m^2)	200-300	200-400	400-500	400-700	600-1300	400-700
Full-loaded hours (h)	2456	2604	3149	3301	3751	3303
Technical potential (TWh)	174	169	70	313	153	405
Spatial exclusion (%)	12.0	11.2	13.4	10.2	15.6	14.5
Risk/Investment (%)	0	1	1-3	3-15	10-15	10-23
RLPC (€/MWh)	47-200	47-160	47-200	80-200	80-160	120-200

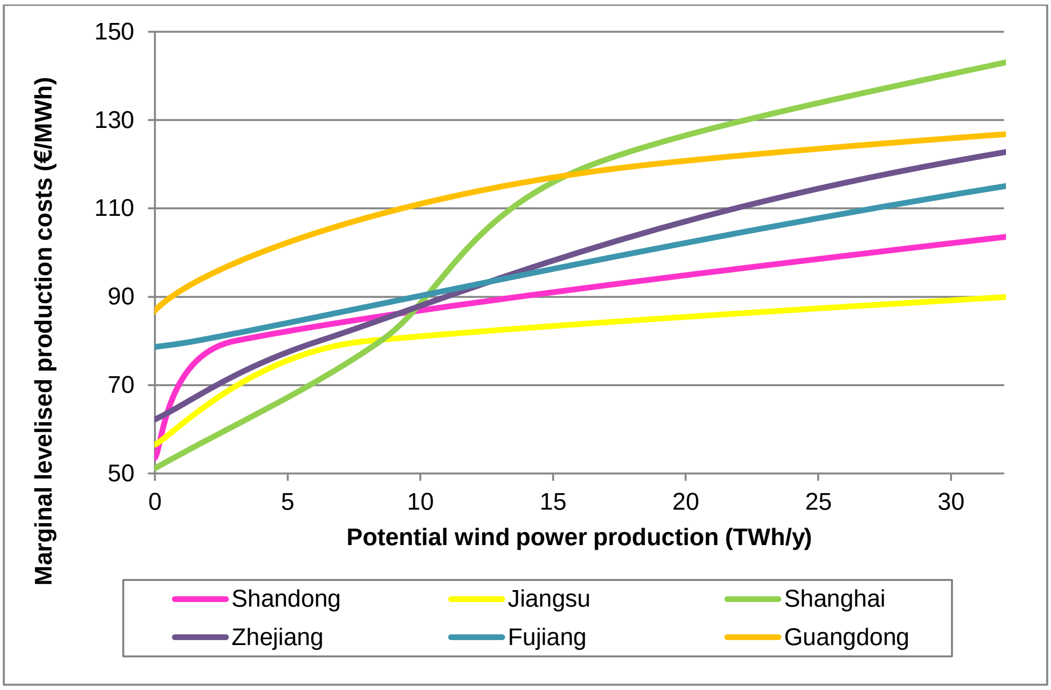

Fig.8 Marginal levelised production costs in coastal provinces.

5. The implication of technological progress on the target

As aforementioned, tropical cyclone is a fair problem for offshore wind development in China, which impose severe limitations on wind potential and marginal levelised production costs. Hence, the development of economically competitive offshore wind turbines with better quality of withstanding tropical cyclones would be extremely important. As demonstrated in [35], the reliability of large wind turbines and their components are apparently improving with time. Currently, Minyang Wind Power of China developed a tropical cyclone-resistant wind turbine with a single capacity of 1.5 MW. Thirty-three of this type of turbines have been installed in Yangqian wind farm and succeed in withstanding the attacks of 15 tropical cyclones, including one with the extreme wind speed of 50m/s. Clause et al. [36] proposed a design of wind turbines in tropical cyclone prone areas and estimated a 20-30% increase of turbine cost in an area with an estimated reference wind speed of 60m/s compared to a site with that of 50 m/s. Even though the progress of tropical cyclone-resistant offshore wind turbines lags behind, a sensitivity analysis based on different levels of tropical cyclone-resistant technologies has been conducted. In the tech_1 scenario, offshore wind turbines start to get damaged when the gust wind speed of tropical cyclones exceed their cut-out wind speed of 25 m/s under currently widely used turbine technology as modeled in [23]. In the tech_2 scenario, the threshold of getting damaged is increased to 34 m/s [37], and the damage level decrease by 50% under the same gust wind speed compared to that in tech_1 scenario. In the tech_3 scenario, turbines begin to suffer damage when the gust wind speed of tropical cyclones exceed 45 m/s [38], and the damage level decrease by 80% under the same gust wind speed compared to that in tech_1 scenario. In Fig.9, it shows that tropical cyclones decrease the wind potential by approximately 300 TWh and increase the marginal levelised production costs by 70 €/MWh under current technology level compared to risk free scenario in the long term. Scenarios of tech_2 and tech_3 help increase the wind potential by 100 TWh and 200 TWh respectively while simultaneously decrease the marginal levelised production costs by 35 €/MWh and 50 €/MWh compared to the condition in scenario tech_1. The different effects of technological scenarios on the short-term target are reflected in Fig. 10. The marginal levelised production costs for the 30 GW target increase by 27 €/MWh, 23 €/MWh and 17 €/MWh under scenario tech_1, tech_2 and tech_3 respectively compared to the condition in risk free scenario. It shows that the technological progress assumed in this study is insufficient to greatly decrease the marginal levelised production costs for reaching the 30 GW target by 2020. The reason is that the occurrence of tropical cyclones is most frequent and severe in Fujian and Zhejiang, the least cost location for developing offshore wind farms in the risk free scenario.

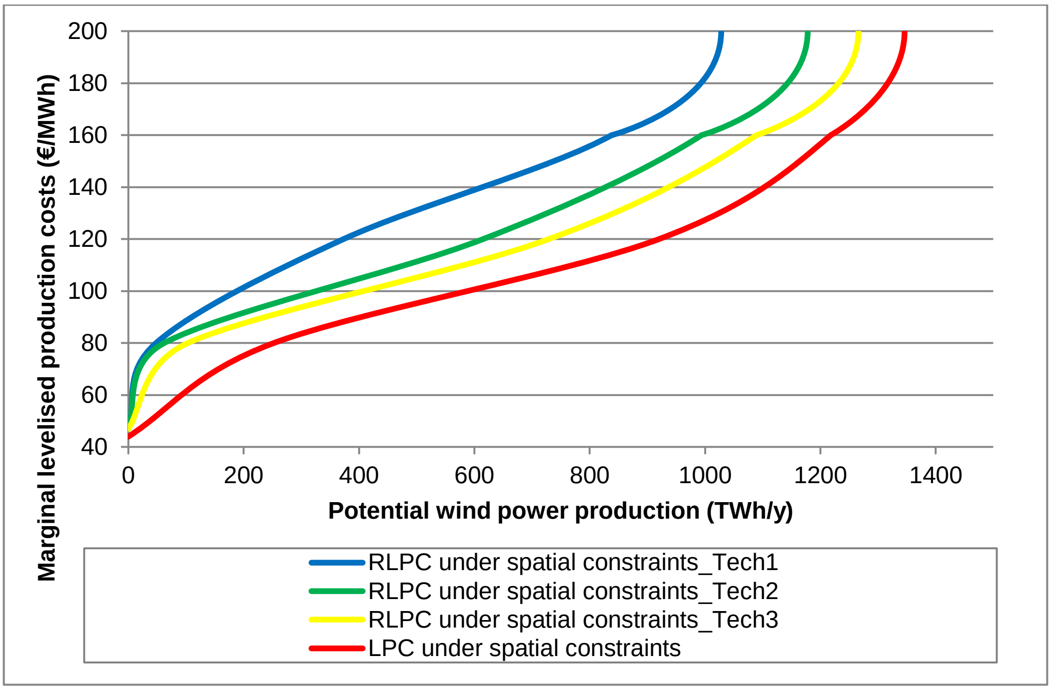

Fig.9 Comparison of marginal production costs under different tropical cyclone-resistant technologies in the long term.

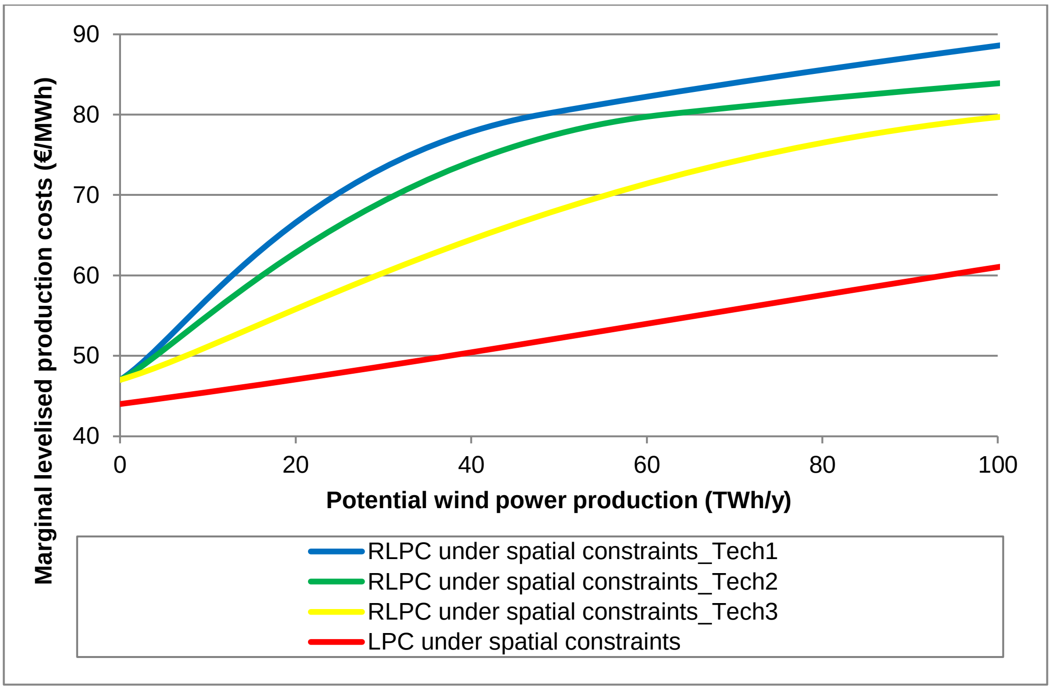

Fig.10 Comparison of marginal production costs under different tropical cyclone-resistant technologies in the short term.

6. The implication of pricing mechanism on the target

In promoting wind power, the feed-in system has been used with some variations in Denmark, Germany and Spain and has proved superior to other methods that have been tried in the EU for promoting green electricity when evaluated in terms of installed RES-E capacity [39]. Non-hydro renewable is generally stimulated by various policies including feed-in-tariffs and a renewable energy portfolio standard for grid and power companies in China [40]. However, the pricing mechanism of offshore wind energy is by public tender for national concession projects in order to reduce the high cost of offshore wind generation. Offshore wind energy developers, mainly power companies combined with a wind turbine manufacturer and a construction and installation enterprise, are invited to bid for the development of a location. Low electricity price and high equipment localization rate are two main factors to decide the winning bidder. Advantages of this concession model include the combination of functions of government and power companies, the selection of suitable developers and lower wind power prices [41]. Disadvantages include that the procedure excludes private and international companies and tends to produce extreme low bids. Most bidders for the offshore concession projects are large state-owned power companies, whose motivation for low bids come from the government's order to raise the proportion of renewable energy generation in their generation mix. Under the country's long-term renewable energy development strategy, which was launched by the National Development and Reform Commission (NDRC) in 2007, power companies that have more than 5 GW power generating capacity should have at least 3% of total installed capacity from non-hydroelectric renewable sources by 2010 and 8% by 2020. In order to win the concession project, some bidders intentionally underestimate operating costs to get a lower price compared to other bidders. Once the bid is selected, it proves economically impossible to construct and operate the offshore wind farm.

The experience from Shanghai Donghai Bridge suggests a price of 0.978 Yuan/kWh (106 €/MWh) in 2009. According to the UNFCCC report, the internal return rate (IRR) of the project without certified emission reduction (CER) revenue is below the benchmark 8% even under the on-grid tariff (including VAT) of 1.1406 Yuan/kWh (124 €/MWh) [42]. In the first round of 1 GW offshore concession projects, the bid winning prices are 0.6235 Yuan/kWh (66.9 €/MWh) for 200 MW Dongtai intertidal wind farm, 0.6396 Yuan/kWh (68.6 €/MWh) for 200 MW Dafeng intertidal wind farm, 0.737 Yuan/kWh (79.1 €/MWh) for 300 MW Binhai offshore wind farm and 0.7047 Yuan/kWh (75.6 €/MWh) for 300 MW Sheyang offshore wind farm respectively. These prices are much lower than offshore wind tariffs in other countries (Table 6), and even approaching the benchmark prices for inland wind farms[7]. And the result of insufficient financial resources is the long-term delay of offshore wind farm constructions. In Fig.10, it shows that the marginal levelised production costs for the 30 GW target is expected to be in the range of 77-87 €/MWh under tropical cyclone risk and spatial constraints considering technological improvement and learning curves by 2020. Compared to the above-mentioned low bid prices, it implies that only 40-70 % of the national target can be achieved even under aggressive progresses of turbine technologies by 2020.

[7] The NDRC issued Notice on improving the Price Policy for Wind Power in July 2009. This establishes the principles for formulating the benchmark price for land-based wind power based on different resource areas, dividing the country into four categories of wind energy resource area. The resulting four benchmark grid tariffs are correspondingly 0.51 yuan/kWh, 0.54 yuan/kWh, 0.58 yuan/kWh and 0.61 yuan/kWh.

Table 6 Summary of worldwide offshore wind tariffs [43].

Jurisdiction	Years	€/MWh
Germany with Sprinter Bonus	20	190
Spain (Maximum)	20	177
Germany	20	150
Ireland	15	140
France	15	130
Greece	20	97
Denmark (Maximum)	20	83

7. Conclusions

Offshore wind energy is gaining momentum in China due to its rich resources and close proximity to electricity demand centers. It is also deemed as a means of increasing local employment and securing energy supply by local governments. The country has already set an ambitious target of developing 30 GW offshore wind energy by 2020, while provincial plans in coastal regions are at varying stages. Shandong, Jiangsu, Shanghai, Zhejiang and Fujian are identified as the main regions to develop offshore wind energy in the near future. The aggregate expected offshore wind generation in these provinces by 2020 is estimated to be 63.3% of their total imported electricity in 2009, contributing to 56.05 Mt of CO_2 emission reductions. However, insufficient planning framework, incremental investment costs and high tropical cyclone risk cast doubts on the large-scale development of offshore wind energy in China. In this paper, a tropical cyclone risk included SCREAM-offshore wind model is built using GIS, in order to investigate the implications of technology, economic cost, spatial constraints, and tropical cyclone risk on the feasibility of the 30 GW offshore wind target by 2020 from both national and provincial level and thus provide macroscopic information for policy-makers and investors.

Spatial constraints and tropical cyclone have an influential impact on economically available offshore wind potential in China. It shows that the increases of marginal levelised production costs for the 30 GW target caused by spatial constraints and tropical cyclone risk under a 20-year recurrence probability are 7 €/MWh and 34 €/MWh respectively. The marginal levelised production costs for reaching provincial targets are further investigated, which are approximately 95 €/MWh, 88 €/MWh, 67 €/MWh, 90 €/MWh and 80 €/MWh in Shandong, Jiangsu, Shanghai, Zhejiang and Fujian respectively. What's more, the implications of technological progress suggests that the marginal levelised production cost for achieving the national target will be in the range of 77-87 €/MWh as better tropical cyclone-resistant turbines are developed. However, the current public tender procedure for offshore wind concession projects tends to produce extreme low bids by large state-owned power companies. It implies that only 40-70 % of the national target can be achieved even under aggressive progresses of turbine technologies by 2020 in terms of economic consideration. A more stable FIT is needed to promote the healthy development of offshore wind energy in the near future and provincial based FIT can be set based on its respective marginal levelised production cost. Also long-term policies contribute to technological learning of offshore wind industry are very important as already been identified in Danish and British cases [44].

Admittedly, the GIS model is based on multiple of input layers such as spatial and tropical cyclone risk parameters, the result of which might be influenced by the completeness and accuracy of all inputs. However, the sensitivity analyses on the influence of different spatial constraint scenarios and tropical cyclone probabilities on offshore wind potential and its associated marginal production costs have already been conducted in [21] and [23]. This paper chose the scenario with the lowest standard which means the lower spatial constraints and tropical cyclone risk on offshore wind development compared to other scenarios. Hence, the conclusion remains correct if we incorporate more spatial constraints such as military training zones, stricter standards for spatial constraints or higher risks of tropical cyclones. Nevertheless, the GIS model is a useful tool for conducting resource and economic analysis in both national and regional scale and it can be continuously improved by incorporating the latest geographic input layers.

References

[1] Li J, Shi P, Gao H. China wind power outlook 2010. Chinese Renewable Energy Association. Global Wind Energy Council. Greenpeace. October,2010. See also: http://www.greenpeace.org/eastasia/publications/reports/climate-energy/2010/wind-power-report-english-2010/;2010.

[2] China Electricity Council. National electric power industry statistics bulletin 2010. Available at: http://tj.cec.org.cn/tongji/niandushuju/2011-02-23/44236.html;2011.

[3] GREENPEACE. China wind power outlook 2011 summary. Available at: http://www.greenpeace.org/eastasia/Global/eastasia/publications/reports/climate-energy/2011/china-wind-power-2011-summary.pdf;2011.

[4] Xinhua. China's offshore wind installed capacity to hit 30GW by 2020.See also: http://news.xinhuanet.com/english2010/china/2011-06/22/c_13944105.htm.

[5] Danish Energy Agency. Future offshore wind power sites - 2025. 2007. See also: http://193.88.185.141/Graphics/Publikationer/Havvindmoeller/Fremtidens_%20havvindm_UKsummery_aug07.pdf.

[6] European Wind Energy Association. Pure power: wind energy scenarios up to 2030. 2008. See also: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/purepower.pdf.

[7] European Wind Energy Association. Pure power: wind energy targets for 2020 and 2030. 2009. See also: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_Full_Report.pdf.

[8] Blanco MI. The economics of wind energy. Renewable and Sustainable Energy Reviews 2009;13(6-7):1372-1382.

[9] European Wind Energy Association. Pure power: wind energy targets for 2020 and 2030. 2011. See also: http://www.ewea.org/fileadmin/ewea_documents/documents/publications/reports/Pure_Power_III.pdf.

[10] Mott MacDonald. UK electricity generation costs update. 2010.See also: http://www.decc.gov.uk/assets/decc/statistics/projections/71-uk-electricity-generation-costs-update-.pdf.

[11] Xinhua. Offshore wind energy with huge potential but high costs. See also: http://news.xinhuanet.com/fortune/2010-08/18/c_12460264.htm.

[12] Yu J, Zheng J. Offshore wind development in China and its future with the existing renewable policy. Energy Policy. In press.

[13] Xiao FJ, Xiao ZN. Characteristics of tropical cyclones in China and their impacts analysis. Natural Hazards 2010;54(3):827-837.

[14] KPMG. Offshore wind in Europe 2010 market report, November 2010.See also: http://www.kpmg.com/Global/en/IssuesAndInsights/ArticlesPublications/Pages/Offshore-Wind-in-Europe.aspx.

[15] Global Wind Energy Council. See also: http://www.gwec.net/.

[16] Möller B, Nielsen PS. Analysing transport costs of Danish forest wood chip resources by means of continuous cost surfaces. Biomass and Bioenergy 2007;31(5):291-298.

[17] Cockerill TT, Kühn M, van Bussel GJW, Bierbooms W, Harrison R. Combined technical and economic evaluation of the Northern European offshore wind resource. J.Wind Eng.Ind.Aerodyn. 2001;89(7-8):689-711.

[18] Kline D, Heimiller D, Cowlin S. A GIS method for developing wind supply curves, 2008.

[19] Möller B. Continuous spatial modelling to analyse planning and economic consequences of offshore wind energy. Energy Policy 2011;39(2):511-517.

[20] Möller B, Hong L, Lonsing R, Hvelplund F. Evaluation of offshore wind resources by scale of development. Energy. Forthcoming.

[21] Hong L, Möller B. Offshore wind energy potential in China: under technical, spatial and economic constraints. Energy 2011;36(7):4482-4491.

[22] Tande JO, R Hunte, E Kilbride. Estimation of cost of energy from wind energy conversion system. International Energy Agency, 1994.

[23] Hong L, Möller B. An economic assessment of tropical cyclone risk on offshore wind farms. Renewable Energy. Forthcoming.

[24] Nielsen P. EMD. Offshore wind energy projects feasibility study guidelines. 2003. See also: http://www.emd.dk/Projects/Projekter/Seawind/OTHER%20RELEVANT%20DOCUMENTS/Feasibility%20Study%20Guidelines.pdf.

[25] Christiansen MB, Hasager CB. Wake effects of large offshore wind farms identified from satellite SAR. Remote Sensing of Environment 2005;98(2-3):251-268.

[26] SeaWinds/QuikSCAT Science Team. National Aeronautics and Space Administration. SeaWinds on QuikSCAT Level 2B Ocean Wind Vectors in 12.5 km Swath Grid. See also: http://podaac.jpl.nasa.gov/DATA_CATALOG/quikscat.html.

[27] Shanghai Typhoon Institute. China Meteorological Administration. CMA-STI Best Track Dataset for Tropical Cyclones in the Western North Pacific. 2010. See also: http://www.typhoon.gov.cn.

[28] National Bureau of Statistics PRC. China Statistical Yearbook 2010. Beijing: China Statistics Press, 2010.

[29] Department of Energy Statistics. National Bureau of Statistics PRC. China Energy Statistical Yearbook 2010. Beijing: China Statistics Press, 2010.

[30] China daily. China battles power shortage for summer's peak. See also: http://www.chinadaily.com.cn/bizchina/2011-05/27/content_12594070.htm.

[31] East China Bureau of State Electricity Regulatory Commission. Annual report of east China electricity regulation 2009. 2010. See also: http://www.ecerb.gov.cn

[32] South China Bureau of State Electricity Regulatory Commission. Annual report of south China electricity regulation 2009. 2010. See also: http://nfj.serc.gov.cn

[33] Shanghai investigation, design & research institute. Offshore wind planning of Shanghai. 2011. See also: http://wenku.baidu.com/view/a2477e21aaea998fcc220e9b.html?from=related.

[34] Global offshore wind farms database. 4C Offshore Limited. See also: http://www.4coffshore.com/offshorewind/.

[35] Tavner PJ, Xiang J, Spinato F. Reliability analysis of wind turbines. Wind Energy 2007;10(1):1-18.

[36] Clausen NE, Ott S, Tarp-Johansen NJ. Design of Wind Turbines in an Area with Tropical Cyclones. Proc. of European Wind Energy Conference. See also: http://130.226.56.153/rispubl/art/2007_99_paper.pdf.

[37] Alstom. ECO 100, ECO 110 & ECO 122 wind turbines. See also: http://www.alstom.com/assetmanagement/DownloadAsset.aspx?ID=da1947ac-0ae8-4792-ace2-74da46d55444&version=799921be67dc4bebba03873b5918f52d17.pdf&lang=2057.

[38] Jha A. Offshore wind turbines: extreme wind/wave risk and regulatory needs. 2008. See also: http://www.boemre.gov/tarprojects/618/MMIEngineeringOffshoreWindTurbine.pdf.

[39] Meyer NI. European schemes for promoting renewables in liberalised markets. Energy Policy 2003;31(7):665-676.

[40] Buijs B. Why China matters. Energy, sustainability and the environment: technology, incentives, behavior. Burlington, USA: Elsevier Inc. 2011, p. 445-476.

[41] Han J, Mol APJ, Lu Y, Zhang L. Onshore wind power development in China: challenges behind a successful story. Energy Policy 2009;37(8):2914-2951.

[42] UNFCCC. Shanghai Donghai bridge offshore wind farm project. 2008. See also: http://cdm.unfccc.int/filestorage/B/R/W/BRWX9I3FUVH5MQEYLJP6GD4O20NKZS/PDD.pdf?t=dTV8bHRpdzlqfDCSSKfAq2_eXo9Y_TriJWf_.

[43] Gipe P. Snapshot of Feed-in Tariffs around the world in 2011. See also: http://www.wind-works.org/FeedLaws/SnapshotofFeed-inTariffsaroundtheWorldin2011.html.

[44] Smit T, Junginger M, Smits R. Technological learning in offshore wind energy: different roles of the government. Energy Policy 2007;35(12):6431-6444.